NURBS-Python Documentation

Release 5.3.1

Onur Rauf Bingol

Jul 06, 2021

Introduction

Welcome to the **NURBS-Python (geomdl) v5.x** documentation!

NURBS-Python (geomdl) is a cross-platform (pure Python), object-oriented B-Spline and NURBS library. It is compatible with Python versions 2.7.x, 3.4.x and later. It supports rational and non-rational curves, surfaces and volumes.

NURBS-Python (geomdl) provides easy-to-use data structures for storing geometry descriptions in addition to the fundamental and advanced evaluation algorithms.

This documentation is organized into a couple sections:

- *Introduction*
- *Using the Library*
- *Modules*

CHAPTER 1

Motivation

NURBS-Python (geomdl) is a self-contained, object-oriented pure Python B-Spline and NURBS library with implementations of curve, surface and volume generation and evaluation algorithms. It also provides convenient and easy-to-use data structures for storing curve, surface and volume descriptions.

Some significant features of NURBS-Python (geomdl):

- Self-contained, object-oriented, extensible and highly customizable API
- Convenient data structures for storing curve, surface and volume descriptions
- Surface and curve fitting with interpolation and least squares approximation
- Knot vector and surface grid generators
- Support for common geometric algorithms: tessellation, voxelization, ray intersection, etc.
- Construct surfaces and volumes, extract isosurfaces via `construct` module
- Customizable visualization and animation options with Matplotlib, Plotly and VTK modules
- Import geometry data from common CAD formats, such as 3DM and SAT.
- Export geometry data into common CAD formats, such as 3DM, STL, OBJ and VTK
- Support importing/exporting in JSON, YAML and libconfig formats
- Jinja2 support for file imports
- Pure Python, no external C/C++ or FORTRAN library dependencies
- Python compatibility: 2.7.x, 3.4.x and later
- For higher performance, optional *Compile with Cython* options are also available
- Easy to install via pip or conda
- Docker images are available
- `geomdl-shapes` module for generating common spline and analytic geometries
- `geomdl-cli` module for using the library from the command line

NURBS-Python (geomdl) contains the following fundamental geometric algorithms:

- Point evaluation
- Derivative evaluation
- Knot insertion
- Knot removal
- Knot vector refinement
- Degree elevation
- Degree reduction

1.1 References

- Leslie Piegl and Wayne Tiller. The NURBS Book. Springer Science & Business Media, 2012.
- David F. Rogers. An Introduction to NURBS: With Historical Perspective. Academic Press, 2001.
- Elaine Cohen et al. Geometric Modeling with Splines: An Introduction. CRC Press, 2001.
- Mark de Berg et al. Computational Geometry: Algorithms and Applications. Springer-Verlag TELOS, 2008.
- John F. Hughes et al. Computer Graphics: Principles and Practice. Pearson Education, 2014.
- Fletcher Dunn and Ian Parberry. 3D Math Primer for Graphics and Game Development. CRC Press, 2015.
- Erwin Kreyszig. Advanced Engineering Mathematics. John Wiley & Sons, 2010.
- Erich Gamma et al. Design Patterns: Elements of Reusable Object-Oriented Software. Addison-Wesley, 1994.

1.2 Author

- Onur R. Bingol (@orbingol)

CHAPTER 2

Citing NURBS-Python

2.1 Article

We have published an article outlining the design and features of NURBS-Python (geomdl) on an open-access Elsevier journal SoftwareX in the January-June 2019 issue.

Please refer to the following DOI link to access the article: https://doi.org/10.1016/j.softx.2018.12.005

2.2 BibTex

You can use the following BibTeX entry to cite the NURBS-Python paper:

```
@article{bingol2019geomdl,
  title={{NURBS-Python}: An open-source object-oriented {NURBS} modeling framework in
↪{Python}},
  author={Bingol, Onur Rauf and Krishnamurthy, Adarsh},
  journal={{SoftwareX}},
  volume={9},
  pages={85--94},
  year={2019},
  publisher={Elsevier}
}
```

2.3 Licenses

- Source code is released under the terms of the MIT License
- Examples are released under the terms of the MIT License

CHAPTER 3

Questions and Answers

3.1 What is NURBS?

NURBS is an acronym for *Non-Uniform Rational Basis Spline* and it represents a mathematical model for generation of geometric shapes in a flexible way. It is a well-accepted industry standard and used as a basis for nearly all of the 3-dimensional modeling and CAD/CAM software packages as well as modeling and visualization frameworks.

Although the mathematical theory of behind the splines dates back to early 1900s, the spline theory in the way we know is coined by Isaac (Iso) Schoenberg and developed further by various researchers around the world.

The following books are recommended for individuals who prefer to investigate the technical details of NURBS:

- A Practical Guide to Splines
- The NURBS Book
- Geometric Modeling with Splines: An Introduction

3.2 Why NURBS-Python?

NURBS-Python started as a final project for *M E 625 Surface Modeling* course offered in 2016 Spring semester at Iowa State University. The main purpose of the project was development of a free and open-source, object-oriented, pure Python NURBS library and releasing it on the public domain. As an added challenge to the project, everything was developed using Python Standard Library but no other external modules.

In years, NURBS-Python has grown up to a self-contained and extensible general-purpose pure Python spline library with support for various computational geometry and linear algebra algorithms. Apart from the computational side, user experience was also improved by introduction of visualization and CAD exchange modules.

NURBS-Python is a user-friendly library, regardless of the mathematical complexity of the splines. To give a head start, it comes with 40+ examples for various use cases. It also provides several extension modules for

- Using the library directly from the command-line
- Generating common spline shapes

- Rhino .3dm file import/export support
- ACIS .sat file import support

Moreover, NURBS-Python and its extensions are free and open-source projects distributed under the MIT license.

NURBS-Python is **not** *an another NURBS library* but it is mostly considered as one of its kind. Please see the *Motivation* page for more details.

3.3 Why two packages on PyPI?

Prior to NURBS-Python v4.0.0, the PyPI project name was NURBS-Python. The latest version of this package is v3.9.0 which is an alias for the geomdl package. To get the latest features and bug fixes, please use geomdl package and update whenever a new version is released. The simplest way to check if you are using the latest version is

```
$ pip list --outdated
```

3.4 Minimum Requirements

NURBS-Python (geomdl) is tested with Python versions 2.7.x, 3.4.x and higher.

3.5 Help and Support

Please join the email list on Google Groups. It is open for NURBS-Python users to ask questions, request new features and submit any other comments you may have.

Alternatively, you may send an email to `nurbs-python@googlegroups.com`.

3.6 How can I add a new feature?

The library is designed to be extensible in mind. It provides a set of *abstract classes* for creating new geometry types. All classes use *evaluators* which contain the evaluation algorithms. Evaluator classes can be extended for new type of algorithms. Please refer to `BSpline` and `NURBS` modules for implementation examples. It would be also a good idea to refer to the constructors of the abstract classes for more details.

3.7 Why doesn't NURBS-Python have XYZ feature?

NURBS-Python tries to keep the geometric operations on the parametric space without any conversion to other representations. This approach makes some operations and queries hard to implement. Keeping NURBS-Python independent of libraries that require compilation caused including implementations some well-known geometric queries and computations, as well as a simple linear algebra module. However, **the main purpose is providing a base for NURBS data and fundamental operations while keeping the external dependencies at minimum**. It is users' choice to extend the library and add new more advanced features (e.g. intersection computations) or capabilities (e.g. a new file format import/export support).

All advanced features should be packaged separately. If you are developing a feature to replace an existing feature, it might be a good idea to package it separately.

NURBS-Python may seem to keep very high standards by means of accepting contributions. For instance, if you implement a feature applicable to curves but not surfaces and volumes, such a pull request won't be accepted till you add that feature to surfaces and volumes. Similarly, if you change a single module and/or the function you use most frequently, but that change is affecting the library as a whole, your pull request will be put on hold.

If you are not interested in such level of contributions, it is suggested to create a separate module and add `geomdl` as its dependency. If you create a module which uses `geomdl`, please let the developers know via emailing `nurbs-python@googlegroups.com` and you may be credited as a contributor.

3.8 Documentation references to the text books

NURBS-Python contains implementations of several algorithms and equations from the references stated in the *Introduction* section. Please be aware that there is always a difference between an algorithm and an implementation. Depending on the function/method documentation you are looking, it might be an implementation of an algorithm, an equation, a set of equations or the concept/the idea discussed in the given page range.

3.9 Why doesn't NURBS-Python follow the algorithms?

Actually, NURBS-Python does follow the algorithms pretty much all the time. However, as stated above, the implementation that you are looking at might not belong to an algorithm, but an equation or a concept.

3.10 NURBS-Python API changes

Please refer to CHANGELOG file for details.

CHAPTER 4

Contributing

4.1 Bugs reports

You are encouraged to use the **Bug Reporting Template** on the issue tracker for reporting bugs. Please fill all required fields and be clear as much as possible. You may attach scripts and sample data to the ticket.

All bug reports must be reproducable. Tickets with missing or unclear information may be ignored.

Please email the author if you have any questions about bug reporting.

4.2 Pull requests

Before working on a pull request, please contact the author or open a ticket on the issue tracker to discuss the details. Otherwise, your pull requests may be ignored.

4.3 Feature requests

Please email the author for feature requests with the details of your feature request.

4.4 Questions and comments

Using `nurbs-python@googlegroups.com` is strongly encouraged for questions and comments.

CHAPTER 5

Installation and Testing

Installation via pip or conda is the recommended method for all users. Manual method is only recommended for advanced users. Please note that if you have used any of these methods to install NURBS-Python, please use the same method to upgrade to the latest version.

Note: On some Linux and MacOS systems, you may encounter 2 different versions of Python installed. In that case Python 2.x package would use `python2` and `pip2`, whereas Python 3.x package would use `python3` and `pip3`. The default `python` and `pip` commands could be linked to one of those. Please check your installed Python version via `python -V` to make sure that you are using the correct Python package.

5.1 Install via Pip

The easiest method to install/upgrade NURBS-Python is using pip. The following commands will download and install NURBS-Python from Python Package Index.

```
$ pip install --user geomdl
```

Upgrading to the latest version:

```
$ pip install geomdl --upgrade
```

Installing a specific version:

```
$ pip install --user geomdl==5.0.0
```

5.2 Install via Conda

NURBS-Python can also be installed/upgraded via conda package manager from the Anaconda Cloud repository.

Installing:

```
$ conda install -c orbingol geomdl
```

Upgrading to the latest version:

```
$ conda upgrade -c orbingol geomdl
```

If you are experiencing problems with this method, you can try to upgrade `conda` package itself before installing the NURBS-Python library.

5.3 Manual Install

The initial step of the manual install is cloning the repository via `git` or downloading the ZIP archive from the repository page on GitHub. The package includes a *setup.py* script which will take care of the installation and automatically copy/link the required files to your Python distribution's *site-packages* directory.

The most convenient method to install NURBS-Python manually is using `pip`:

```
$ pip install --user .
```

To upgrade, please pull the latest commits from the repository via `git pull --rebase` and then execute the above command.

5.4 Development Mode

The following command enables development mode by creating a link from the directory where you cloned NURBS-Python repository to your Python distribution's *site-packages* directory:

```
$ pip install --user -e .
```

Since this command only generates a link to the library directory, pulling the latest commits from the repository would be enough to update the library to the latest version.

5.5 Checking Installation

If you would like to check if you have installed the package correctly, you may try to print `geomdl.__version__` variable after import. The following example illustrates installation check on a Windows PowerShell instance:

```
Windows PowerShell
Copyright (C) Microsoft Corporation. All rights reserved.

PS C:\> python
Python 3.6.2 (v3.6.2:5fd33b5, Jul  8 2017, 04:57:36) [MSC v.1900 64 bit (AMD64)] on␣
↪win32
Type "help", "copyright", "credits" or "license" for more information.
>>> import geomdl
>>> geomdl.__version__
'4.0.2'
>>>
```

5.6 Testing

The package includes `tests/` directory which contains all the automated testing scripts. These scripts require pytest installed on your Python distribution. Then, you can execute the following from your favorite IDE or from the command line:

```
$ pytest
```

pytest will automatically find the tests under `tests/` directory, execute them and show the results.

5.7 Compile with Cython

To improve performance, the *Core Library* of NURBS-Python can be compiled and installed using the following command along with the pure Python version.

```
$ pip install --user . --install-option="--use-cython"
```

This command will generate .c files (i.e. cythonization) and compile the .c files into binary Python modules.

The following command can be used to directly compile and install from the existing .c files, skipping the cythonization step:

```
$ pip install --user . --install-option="--use-source"
```

To update the compiled module with the latest changes, you need to re-cythonize the code.

To enable Cython-compiled module in development mode;

```
$ python setup.py build_ext --use-cython --inplace
```

After the successful execution of the command, the you can import and use the compiled library as follows:

```
# Importing NURBS module
from geomdl.core import NURBS
# Importing visualization module
from geomdl.visualization import VisMPL as vis

# Creating a curve instance
crv = NURBS.Curve()

# Make a quadratic curve
crv.degree = 2

#######################################################
# Skipping control points and knot vector assignments #
#######################################################

# Set the visualization component and render the curve
crv.vis = vis.VisCurve3D()
crv.render()
```

Before Cython compilation, please make sure that you have Cython module and a valid compiler installed for your operating system.

5.8 Docker Containers

A collection of Docker containers is provided on Docker Hub containing NURBS-Python, Cython-compiled core and the command-line application. To get started, first install Docker and then run the following on the Docker command prompt to pull the image prepared with Python v3.5:

```
$ docker pull idealabisu/nurbs-python:py35
```

On the Docker Repository page, you can find containers tagged for Python versions and Debian (no suffix) and Alpine Linux (`-alpine` suffix) operating systems. Please change the tag of the pull command above for downloading your preferred image.

After pulling your preferred image, run the following command:

```
$ docker run --rm -it --name geomdl -p 8000:8000 idealabisu/nurbs-python:py35
```

In all images, Matplotlib is set to use `webagg` backend by default. Please follow the instructions on the command line to view your figures.

Please refer to the Docker documentation for details on using Docker.

CHAPTER 6

Basics

In order to generate a spline shape with NURBS-Python, you need 3 components:

- degree
- knot vector
- control points

The number of components depend on the parametric dimensionality of the shape regardless of the spatial dimensionality.

- **curve** is parametrically 1-dimensional (or 1-manifold)
- **surface** is parametrically 2-dimensional (or 2-manifold)
- **volume** is parametrically 3-dimensional (or 3-manifold)

Parametric dimensions are defined by `u`, `v`, `w` and spatial dimensions are defined by `x`, `y`, `z`.

6.1 Working with the curves

In this section, we will cover the basics of spline curve generation using NURBS-Python. The following code snippet is an example to a 3-dimensional curve.

```
from geomdl import BSpline

# Create the curve instance
crv = BSpline.Curve()

# Set degree
crv.degree = 2

# Set control points
crv.ctrlpts = [[1, 0, 0], [1, 1, 0], [0, 1, 0]]

```

(continues on next page)

(continued from previous page)

```
# Set knot vector
crv.knotvector = [0, 0, 0, 1, 1, 1]
```

As described in the introduction text, we set the 3 required components to generate a 3-dimensional spline curve.

6.1.1 Evaluating the curve points

The code snippet is updated to retrieve evaluated curve points.

```
from geomdl import BSpline

# Create the curve instance
crv = BSpline.Curve()

# Set degree
crv.degree = 2

# Set control points
crv.ctrlpts = [[1, 0, 0], [1, 1, 0], [0, 1, 0]]

# Set knot vector
crv.knotvector = [0, 0, 0, 1, 1, 1]

# Get curve points
points = crv.evalpts

# Do something with the evaluated points
for pt in points:
    print(pt)
```

`evalpts` property will automatically call `evaluate()` function.

6.1.2 Getting the curve point at a specific parameter

`evaluate_single` method will return the point evaluated as the specified parameter.

```
from geomdl import BSpline

# Create the curve instance
crv = BSpline.Curve()

# Set degree
crv.degree = 2

# Set control points
crv.ctrlpts = [[1, 0, 0], [1, 1, 0], [0, 1, 0]]

# Set knot vector
crv.knotvector = [0, 0, 0, 1, 1, 1]

# Get curve point at u = 0.5
point = crv.evaluate_single(0.5)
```

6.1.3 Setting the evaluation delta

Evaluation delta is used to change the number of evaluated points. Increasing the number of points will result in a bigger evaluated points array, as described with `evalpts` property and decreasing will reduce the size of the `evalpts` array. Therefore, evaluation delta can also be used to change smoothness of the plots generated using the visualization modules.

`delta` property will set the evaluation delta. It is also possible to use `sample_size` property to set the number of evaluated points.

```python
from geomdl import BSpline

# Create the curve instance
crv = BSpline.Curve()

# Set degree
crv.degree = 2

# Set control points
crv.ctrlpts = [[1, 0, 0], [1, 1, 0], [0, 1, 0]]

# Set knot vector
crv.knotvector = [0, 0, 0, 1, 1, 1]

# Set evaluation delta
crv.delta = 0.005

# Get evaluated points
points_a = crv.evalpts

# Update delta
crv.delta = 0.1

# The curve will be automatically re-evaluated
points_b = crv.evalpts
```

6.1.4 Inserting a knot

`insert_knot` method is recommended for this purpose.

```python
from geomdl import BSpline

# Create the curve instance
crv = BSpline.Curve()

# Set degree
crv.degree = 2

# Set control points
crv.ctrlpts = [[1, 0, 0], [1, 1, 0], [0, 1, 0]]

# Set knot vector
crv.knotvector = [0, 0, 0, 1, 1, 1]

# Insert knot
crv.insert_knot(0.5)
```

6.1.5 Plotting

To plot the curve, a visualization module should be imported and curve should be updated to use the visualization module.

```
from geomdl import BSpline

# Create the curve instance
crv = BSpline.Curve()

# Set degree
crv.degree = 2

# Set control points
crv.ctrlpts = [[1, 0, 0], [1, 1, 0], [0, 1, 0]]

# Set knot vector
crv.knotvector = [0, 0, 0, 1, 1, 1]

# Import Matplotlib visualization module
from geomdl.visualization import VisMPL

# Set the visualization component of the curve
crv.vis = VisMPL.VisCurve3D()

# Plot the curve
crv.render()
```

6.1.6 Convert non-rational to rational curve

The following code snippet generates a B-Spline (non-rational) curve and converts it into a NURBS (rational) curve.

```
from geomdl import BSpline

# Create the curve instance
crv = BSpline.Curve()

# Set degree
crv.degree = 2

# Set control points
crv.ctrlpts = [[1, 0, 0], [1, 1, 0], [0, 1, 0]]

# Set knot vector
crv.knotvector = [0, 0, 0, 1, 1, 1]

# Import convert module
from geomdl import convert

# BSpline to NURBS
crv_rat = convert.bspline_to_nurbs(crv)
```

6.1.7 Using knot vector generator

Knot vector generator is located in the *knotvector* module.

```python
from geomdl import BSpline
from geomdl import knotvector

# Create the curve instance
crv = BSpline.Curve()

# Set degree
crv.degree = 2

# Set control points
crv.ctrlpts = [[1, 0, 0], [1, 1, 0], [0, 1, 0]]

# Generate a uniform knot vector
crv.knotvector = knotvector.generate(crv.degree, crv.ctrlpts_size)
```

6.1.8 Plotting multiple curves

multi module can be used to plot multiple curves on the same figure.

```python
from geomdl import BSpline
from geomdl import multi
from geomdl import knotvector

# Create the curve instance #1
crv1 = BSpline.Curve()

# Set degree
crv1.degree = 2

# Set control points
crv1.ctrlpts = [[1, 0, 0], [1, 1, 0], [0, 1, 0]]

# Generate a uniform knot vector
crv1.knotvector = knotvector.generate(crv1.degree, crv1.ctrlpts_size)

# Create the curve instance #2
crv2 = BSpline.Curve()

# Set degree
crv2.degree = 3

# Set control points
crv2.ctrlpts = [[1, 0, 0], [1, 1, 0], [2, 1, 0], [1, 1, 0]]

# Generate a uniform knot vector
crv2.knotvector = knotvector.generate(crv2.degree, crv2.ctrlpts_size)

# Create a curve container
mcrv = multi.CurveContainer(crv1, crv2)

# Import Matplotlib visualization module
from geomdl.visualization import VisMPL

# Set the visualization component of the curve container
mcrv.vis = VisMPL.VisCurve3D()

```

(continues on next page)

(continued from previous page)

```
# Plot the curves in the curve container
mcrv.render()
```

Please refer to the *Examples Repository* for more curve examples.

6.2 Working with the surfaces

The majority of the surface API is very similar to the curve API. Since a surface is defined on a 2-dimensional parametric space, the getters/setters have a suffix of `_u` and `_v`; such as `knotvector_u` and `knotvector_v`.

For setting up the control points, please refer to the *control points manager* documentation.

Please refer to the *Examples Repository* for surface examples.

6.3 Working with the volumes

Volumes are defined on a 3-dimensional parametric space. Working with the volumes are very similar to working with the surfaces. The only difference is the 3rd parametric dimension, `w`. For instance, to access the knot vectors, the properties you will use are `knotvector_u`, `knotvector_v` and `knotvector_w`.

For setting up the control points, please refer to the *control points manager* documentation.

Please refer to the *Examples Repository* for volume examples.

CHAPTER 7

Examples Repository

Although using NURBS-Python is straight-forward, it is always confusing to do the initial start with a new library. To give you a headstart on working with NURBS-Python, an Examples repository over 50 example scripts which describe usage scenarios of the library and its modules is provided. You can run the scripts from the command line, inside from favorite IDE or copy them to a Jupyter notebook.

The Examples repository contains examples on

- Bézier curves and surfaces
- B-Spline & NURBS curves, surfaces and volumes
- Spline algorithms, e.g. knot insertion and removal, degree elevation and reduction
- Curve & surface splitting and Bézier decomposition (*info*)
- Surface and curve fitting using interpolation and least squares approximation (*docs*)
- Geometrical operations, e.g. tangent, normal, binormal (*docs*)
- Importing & exporting spline geometries into supported formats (*docs*)
- Compatibility module for control points conversion (*docs*)
- Surface grid generators (*info* and *docs*)
- Geometry containers (*docs*)
- Automatic uniform knot vector generation via `knotvector.generate()`
- Visualization components (*info*, *Matplotlib*, *Plotly* and *VTK*)
- Ray operations (*docs*)
- Voxelization (*docs*)

Matplotlib and Plotly visualization modules are compatible with Jupyter notebooks but VTK visualization module is not. Please refer to the NURBS-Python wiki for more details on using NURBS-Python Matplotlib and Plotly visualization modules with Jupyter notebooks.

CHAPTER 8

Loading and Saving Data

NURBS-Python provides the following API calls for exporting and importing spline geometry data:

- *exchange.import_json()*
- *exchange.export_json()*

JSON import/export works with all spline geometry and container objects. Please refer to *File Formats* for more details.

The following code snippet illustrates a B-spline curve generation and its JSON export:

```
from geomdl import BSpline
from geomdl import utilities
from geomdl import exchange

# Create a B-Spline curve instance
curve = BSpline.Curve()

# Set the degree
curve.degree = 3

# Load control points from a text file
curve.ctrlpts = exchange.import_txt("control_points.txt")

# Auto-generate the knot vector
curve.knotvector = utilities.generate_knot_vector(curve.degree, len(curve.ctrlpts))

# Export the curve as a JSON file
exchange.export_json(curve, "curve.json")
```

The following code snippet illustrates importing from a JSON file and adding the result to a container object:

```
from geomdl import multi
from geomdl import exchange

# Import curve from a JSON file
```

(continues on next page)

(continued from previous page)

```
curve_list = exchange.import_json("curve.json")

# Add curve list to the container
curve_container = multi.CurveContainer(curve_list)
```

CHAPTER 9

Supported File Formats

NURBS-Python supports several input and output formats for importing and exporting B-Spline/NURBS curves and surfaces. Please note that NURBS-Python uses right-handed notation on input and output files.

9.1 Text Files

NURBS-Python provides a simple way to import and export the control points and the evaluated control points as ASCII text files. The details of the file format for curves and surfaces is described below:

9.1.1 NURBS-Python Custom Format

NURBS-Python provides `import_txt()` function for reading control points of curves and surfaces from a text file. For saving the control points `export_txt()` function may be used.

The format of the text file depends on the type of the geometric element, i.e. curve or surface. The following sections explain this custom format.

2D Curves

To generate a 2D B-Spline Curve, you need a list of *(x, y)* coordinates representing the control points (P), where

- *x*: value representing the x-coordinate
- *y*: value representing the y-coordinate

The format of the control points file for generating 2D B-Spline curves is as follows:

x	y
x_1	y_1
x_2	y_2
x_3	y_3

The control points file format of the NURBS curves are very similar to B-Spline ones with the difference of weights. To generate a **2D NURBS curve**, you need a list of *(x*w, y*w, w)* coordinates representing the weighted control points (P_w) where,

- *x*: value representing the x-coordinate
- *y*: value representing the y-coordinate
- *w*: value representing the weight

The format of the control points file for generating **2D NURBS curves** is as follows:

x*w	y*w	w
x_1*w_1	y_1*w_1	w_1
x_2*w_2	y_2*w_2	w_2
x_3*w_3	y_3*w_3	w_3

Note: *compatibility* module provides several functions to manipulate & convert control point arrays into NURBS-Python compatible ones and more.

3D Curves

To generate a **3D B-Spline curve**, you need a list of *(x, y, z)* coordinates representing the control points (P), where

- *x*: value representing the x-coordinate
- *y*: value representing the y-coordinate
- *z*: value representing the z-coordinate

The format of the control points file for generating 3D B-Spline curves is as follows:

x	y	z
x_1	y_1	z_1
x_2	y_2	z_2
x_3	y_3	z_3

To generate a **3D NURBS curve**, you need a list of *(x*w, y*w, z*w, w)* coordinates representing the weighted control points (P_w) where,

- *x*: value representing the x-coordinate
- *y*: value representing the y-coordinate
- *z*: value representing the z-coordinate
- *w*: value representing the weight

The format of the control points file for generating 3D NURBS curves is as follows:

x*w	y*w	z*w	w
x_1*w_1	y_1*w_1	z_1*w_1	w_1
x_2*w_2	y_2*w_2	z_2*w_2	w_2
x_3*w_3	y_3*w_3	z_3*w_3	w_3

Note: *compatibility* module provides several functions to manipulate & convert control point arrays into NURBS-Python compatible ones and more.

Surfaces

Control points file for generating B-Spline and NURBS has 2 options:

First option is very similar to the curve control points files with one noticeable difference to process *u* and *v* indices. In this list, the *v* index varies first. That is, a row of *v* control points for the first *u* value is found first. Then, the row of *v* control points for the next *u* value.

The second option sets the rows as *v* and columns as *u*. To generate a **B-Spline surface** using this option, you need a list of *(x, y, z)* coordinates representing the control points (P) where,

- *x*: value representing the x-coordinate
- *y*: value representing the y-coordinate
- *z*: value representing the z-coordinate

The format of the control points file for generating B-Spline surfaces is as follows:

	v0	v1	v2	v3	v4
u0	(x, y, z)	(x, y, z)	(x, y, z)	(x, y, z)	(x, y, z)
u1	(x, y, z)	(x, y, z)	(x, y, z)	(x, y, z)	(x, y, z)
u2	(x, y, z)	(x, y, z)	(x, y, z)	(x, y, z)	(x, y, z)

To generate a **NURBS surface** using the 2nd option, you need a list of *(x*w, y*w, z*w, w)* coordinates representing the weighted control points (P_w) where,

- *x*: value representing the x-coordinate
- *y*: value representing the y-coordinate
- *z*: value representing the z-coordinate
- *w*: value representing the weight

The format of the control points file for generating NURBS surfaces is as follows:

	v0	v1	v2	v3
u0	(x*w, y*w, z*w, w)	(x*w, y*w, z*w, w)	(x*w, y*w, z*w, w)	(x*w, y*w, z*w, w)
u1	(x*w, y*w, z*w, w)	(x*w, y*w, z*w, w)	(x*w, y*w, z*w, w)	(x*w, y*w, z*w, w)
u2	(x*w, y*w, z*w, w)	(x*w, y*w, z*w, w)	(x*w, y*w, z*w, w)	(x*w, y*w, z*w, w)

Note: *compatibility* module provides several functions to manipulate & convert control point arrays into NURBS-Python compatible ones and more.

Volumes

Parametric volumes can be considered as a stacked surfaces, which means that w-parametric axis comes the first and then other parametric axes come.

9.2 Comma-Separated (CSV)

You may use *export_csv()* and *import_csv()* functions to save/load control points and/or evaluated points as a CSV file. This function works with both curves and surfaces.

9.3 OBJ Format

You may use *export_obj()* function to export a NURBS surface as a Wavefront .obj file.

9.3.1 Example 1

The following example demonstrates saving surfaces as .obj files:

```
# ex_bezier_surface.py
from geomdl import BSpline
from geomdl import utilities
from geomdl import exchange

# Create a BSpline surface instance
surf = BSpline.Surface()

# Set evaluation delta
surf.delta = 0.01

# Set up the surface
surf.degree_u = 3
surf.degree_v = 2
control_points = [[0, 0, 0], [0, 1, 0], [0, 2, -3],
                  [1, 0, 6], [1, 1, 0], [1, 2, 0],
                  [2, 0, 0], [2, 1, 0], [2, 2, 3],
                  [3, 0, 0], [3, 1, -3], [3, 2, 0]]
surf.set_ctrlpts(control_points, 4, 3)
surf.knotvector_u = utilities.generate_knot_vector(surf.degree_u, 4)
surf.knotvector_v = utilities.generate_knot_vector(surf.degree_v, 3)

# Evaluate surface
surf.evaluate()

# Save surface as a .obj file
exchange.export_obj(surf, "bezier_surf.obj")
```

9.3.2 Example 2

The following example combines `shapes` module together with `exchange` module:

```
from geomdl.shapes import surface
from geomdl import exchange

# Generate cylindirical surface
surf = surface.cylinder(radius=5, height=12.5)

# Set evaluation delta
```

(continues on next page)

(continued from previous page)

```
surf.delta = 0.01

# Evaluate the surface
surf.evaluate()

# Save surface as a .obj file
exchange.export_obj(surf, "cylindirical_surf.obj")
```

9.4 STL Format

Exporting to STL files works in the same way explained in OBJ Files section. To export a NURBS surface as a .stl file, you may use `export_stl()` function. This function saves in binary format by default but there is an option to change the save file format to plain text. Please see the *documentation* for details.

9.5 Object File Format (OFF)

Very similar to exporting as OBJ and STL formats, you may use `export_off()` function to export a NURBS surface as a .off file.

9.6 Custom Formats (libconfig, YAML, JSON)

NURBS-Python provides several custom formats, such as libconfig, YAML and JSON, for importing and exporting complete NURBS shapes (i.e. degrees, knot vectors and control points of single and multi curves/surfaces).

9.6.1 libconfig

libconfig is a lightweight library for processing configuration files and it is often used on C/C++ projects. The library doesn't define a format but it defines a syntax for the files it can process. NURBS-Python uses `export_cfg()` and `import_cfg()` functions to exporting and importing shape data which can be processed by libconfig-compatible libraries. Although exporting does not require any external libraries, importing functionality depends on libconf module, which is a pure Python library for parsing libconfig-formatted files.

9.6.2 YAML

YAML is a data serialization format and it is supported by the major programming languages. NURBS-Python uses ruamel.yaml package as an external dependency for its YAML support since the package is well-maintained and compatible with the latest YAML standards. NURBS-Python supports exporting and importing NURBS data to YAML format with the functions `export_yaml()` and `import_yaml()`, respectively.

9.6.3 JSON

JSON is also a serialization and data interchange format and it is **natively supported** by Python via `json` module. NURBS-Python supports exporting and importing NURBS data to JSON format with the functions `export_json()` and `import_json()`, respectively.

9.6.4 Format Definition

Curve

The following example illustrates a 2-dimensional NURBS curve. 3-dimensional NURBS curves are also supported and they can be generated by updating the control points.

```
shape:
  type: curve  # type of the geometry
  count: 1  # number of curves in "data" list (optional)
  data:
    - rational: True  # rational or non-rational (optional)
      dimension: 2  # spatial dimension of the curve (optional)
      degree: 2
      knotvector: [0, 0, 0, 0.25, 0.25, 0.5, 0.5, 0.75, 0.75, 1, 1, 1]
      control_points:
        points:  # cartesian coordinates of the control points
          - [0.0, -1.0]  # each control point is defined as a list
          - [-1.0, -1.0]
          - [-1.0, 0.0]
          - [-1.0, 1.0]
          - [0.0, 1.0]
          - [1.0, 1.0]
          - [1.0, 0.0]
          - [1.0, -1.0]
          - [0.0, -1.0]
        weights:  # weights vector (required if rational)
          - 1.0
          - 0.707
          - 1.0
          - 0.707
          - 1.0
          - 0.707
          - 1.0
          - 0.707
          - 1.0
      delta: 0.01  # evaluation delta
```

- **Shape section:** This section contains the single or multi NURBS data. `type` and `data` sections are mandatory.
- **Type section:** This section defines the type of the NURBS shape. For NURBS curves, it should be set to *curve*.
- **Data section:** This section defines the NURBS data, i.e. degrees, knot vectors and control_points. `weights` and `delta` sections are optional.

Surface

The following example illustrates a NURBS surface:

```
shape:
  type: surface  # type of the geometry
  count: 1  # number of surfaces in "data" list (optional)
  data:
    - rational: True  # rational or non-rational (optional)
      dimension: 3  # spatial dimension of the surface (optional)
      degree_u: 1  # degree of the u-direction
      degree_v: 2  # degree of the v-direction
```

(continues on next page)

(continued from previous page)

```
    knotvector_u: [0.0, 0.0, 1.0, 1.0]
    knotvector_v: [0.0, 0.0, 0.0, 0.25, 0.25, 0.5, 0.5, 0.75, 0.75, 1.0, 1.0, 1.0]
    size_u: 2  # number of control points on the u-direction
    size_v: 9  # number of control points on the v-direction
    control_points:
      points:  # cartesian coordinates (x, y, z) of the control points
        - [1.0, 0.0, 0.0]  # each control point is defined as a list
        - [1.0, 1.0, 0.0]
        - [0.0, 1.0, 0.0]
        - [-1.0, 1.0, 0.0]
        - [-1.0, 0.0, 0.0]
        - [-1.0, -1.0, 0.0]
        - [0.0, -1.0, 0.0]
        - [1.0, -1.0, 0.0]
        - [1.0, 0.0, 0.0]
        - [1.0, 0.0, 1.0]
        - [1.0, 1.0, 1.0]
        - [0.0, 1.0, 1.0]
        - [-1.0, 1.0, 1.0]
        - [-1.0, 0.0, 1.0]
        - [-1.0, -1.0, 1.0]
        - [0.0, -1.0, 1.0]
        - [1.0, -1.0, 1.0]
        - [1.0, 0.0, 1.0]
      weights:  # weights vector (required if rational)
        - 1.0
        - 0.7071
        - 1.0
        - 0.7071
        - 1.0
        - 0.7071
        - 1.0
        - 0.7071
        - 1.0
        - 1.0
        - 0.7071
        - 1.0
        - 0.7071
        - 1.0
        - 0.7071
        - 1.0
        - 0.7071
        - 1.0
    delta:
      - 0.05  # evaluation delta of the u-direction
      - 0.05  # evaluation delta of the v-direction
    trims:  # define trim curves (optional)
      count: 3  # number of trims in the "data" list (optional)
      data:
        - type: spline  # type of the trim curve
          rational: False  # rational or non-rational (optional)
          dimension: 2  # spatial dimension of the trim curve (optional)
          degree: 2  # degree of the 1st trim
          knotvector: [ ... ]  # knot vector of the 1st trim curve
          control_points:
            points:  # parametric coordinates of the 1st trim curve
              - [u1, v1]  # expected to be 2-dimensional, corresponding to (u,v)
```

(continues on next page)

(continued from previous page)

```
                - [u2, v2]
                - ...
            reversed: 0  # 0: trim inside, 1: trim outside (optional, default is 0)
          - type: spline  # type of the 2nd trim curve
            rational: True  # rational or non-rational (optional)
            dimension: 2  # spatial dimension of the trim curve (optional)
            degree: 1  # degree of the 2nd trim
            knotvector: [ ... ]  # knot vector of the 2nd trim curve
            control_points:
              points:  # parametric coordinates of the 2nd trim curve
                - [u1, v1]  # expected to be 2-dimensional, corresponding to (u,v)
                - [u2, v2]
                - ...
              weights:  # weights vector of the 2nd trim curve (required if rational)
                - 1.0
                - 1.0
                - ...
            delta: 0.01  # evaluation delta (optional)
            reversed: 1  # 0: trim inside, 1: trim outside (optional, default is 0)
          - type: freeform  # type of the 3rd trim curve
            dimension: 2  # spatial dimension of the trim curve (optional)
            points:  # parametric coordinates of the 3rd trim curve
              - [u1, v1]  # expected to be 2-dimensional, corresponding to (u,v)
              - [u2, v2]
              - ...
            name: "my freeform curve"  # optional
            reversed: 1  # 0: trim inside, 1: trim outside (optional, default is 0)
          - type: container  # type of the 4th trim curve
            dimension: 2  # spatial dimension of the trim curve (optional)
            data:  # a list of freeform and/or spline geometries
              - ...
              - ...
            name: "my trim curves"  # optional
            reversed: 1  # 0: trim inside, 1: trim outside (optional, default is 0)
```

- **Shape section:** This section contains the single or multi NURBS data. `type` and `data` sections are mandatory.
- **Type section:** This section defines the type of the NURBS shape. For NURBS curves, it should be set to *surface*.
- **Data section:** This section defines the NURBS data, i.e. degrees, knot vectors and control_points. `weights` and `delta` sections are optional.

Surfaces can also contain trim curves. These curves can be stored in 2 geometry types inside the surface:

- `spline` corresponds to a spline geometry, which is defined by a set of degrees, knot vectors and control points
- `container` corresponds to a geometry container
- `freeform` corresponds to a freeform geometry; defined by a set of points

Volume

The following example illustrates a B-spline volume:

```
shape:
  type: volume  # type of the geometry
```

(continues on next page)

(continued from previous page)

```
  count: 1  # number of volumes in "data" list (optional)
  data:
    - rational: False  # rational or non-rational (optional)
      degree_u: 1  # degree of the u-direction
      degree_v: 2  # degree of the v-direction
      degree_w: 1  # degree of the w-direction
      knotvector_u: [0.0, 0.0, 1.0, 1.0]
      knotvector_v: [0.0, 0.0, 0.0, 0.25, 0.25, 0.5, 0.5, 0.75, 0.75, 1.0, 1.0, 1.0]
      knotvector_w: [0.0, 0.0, 1.0, 1.0]
      size_u: 2  # number of control points on the u-direction
      size_v: 9  # number of control points on the v-direction
      size_w: 2  # number of control points on the w-direction
      control_points:
        points:  # cartesian coordinates (x, y, z) of the control points
          - [x1, y1, x1]  # each control point is defined as a list
          - [x2, y2, z2]
          - ...
      delta:
        - 0.25  # evaluation delta of the u-direction
        - 0.25  # evaluation delta of the v-direction
        - 0.10  # evaluation delta of the w-direction
```

The file organization is very similar to the surface example. The main difference is the parametric 3rd dimension, w.

9.6.5 Example: Reading .cfg Files with libconf

The following example illustrates reading the exported .cfg file with libconf module as a reference for libconfig-based systems in different programming languages.

```
# Assuming that you have already installed 'libconf'
import libconf

# Skipping export steps and assuming that we have already exported the data as 'my_
↪nurbs.cfg'
with open("my_nurbs.cfg", "r") as fp:
    # Open the file and parse using libconf module
    ns = libconf.load(fp)

# 'count' shows the number of shapes loaded from the file
print(ns['shape']['count']

# Traverse through the loaded shapes
for n in ns['shape']['data']:
    # As an example, we get the control points
    ctrlpts = n['control_points']['points']
```

NURBS-Python exports data in the way that allows processing any number of curves or surfaces with a simple for loop. This approach simplifies implementation of file reading routines for different systems and programming languages.

9.7 Using Templates

NURBS-Python v5.x supports Jinja2 templates with the following functions:

- *import_txt()*

- *import_cfg()*
- *import_json()*
- *import_yaml()*

To import files formatted as Jinja2 templates, an additional `jinja2=True` keyword argument should be passed to the functions. For instance:

```
from geomdl import exchange

# Importing a .yaml file formatted as a Jinja2 template
data = exchange.import_yaml("surface.yaml", jinja2=True)
```

NURBS-Python also provides some custom Jinja2 template functions for user convenience. These are:

- `knot_vector(d, np)`: generates a uniform knot vector. *d*: degree, *np*: number of control points
- `sqrt(x)`: square root of *x*
- `cubert(x)`: cube root of *x*
- `pow(x, y)`: *x* to the power of *y*

Please see `ex_cylinder_tmpl.py` and `ex_cylinder_tmpl.cptw` files in the *Examples repository* for details on using Jinja2 templates with control point text files.

CHAPTER 10

Compatibility

Most of the time, users experience problems in converting data between different software packages. To aid this problem a little bit, NURBS-Python provides a *compatibility* module for converting control points sets into NURBS-Python compatible ones.

The following example illustrates the usage of *compatibility* module:

```
from geomdl import NURBS
from geomdl import utilities as utils
from geomdl import compatibility as compat
from geomdl.visualization import VisMPL

#
# Surface exported from your CAD software
#

# Dimensions of the control points grid
p_size_u = 4
p_size_v = 3

# Control points in u-row order
p_ctrlpts = [[0, 0, 0], [1, 0, 6], [2, 0, 0], [3, 0, 0],
             [0, 1, 0], [1, 1, 0], [2, 1, 0], [3, 1, -3],
             [0, 2, -3], [1, 2, 0], [2, 2, 3], [3, 2, 0]]

# Weights vector
p_weights = [1, 1, 1, 1, 1, 1, 1, 1, 1, 1, 1, 1]

# Degrees
p_degree_u = 3
p_degree_v = 2


#
# Prepare data for import
```

(continues on next page)

(continued from previous page)

```
#

# Combine weights vector with the control points list
t_ctrlptsw = compat.combine_ctrlpts_weights(p_ctrlpts, p_weights)

# Since NURBS-Python uses v-row order, we need to convert the exported ones
n_ctrlptsw = compat.flip_ctrlpts_u(t_ctrlptsw, p_size_u, p_size_v)

# Since we have no information on knot vectors, let's auto-generate them
n_knotvector_u = utils.generate_knot_vector(p_degree_u, p_size_u)
n_knotvector_v = utils.generate_knot_vector(p_degree_v, p_size_v)


#
# Import surface to NURBS-Python
#

# Create a NURBS surface instance
surf = NURBS.Surface()

# Fill the surface object
surf.degree_u = p_degree_u
surf.degree_v = p_degree_v
surf_set_ctrlpts(n_ctrlptsw, p_size_u, p_size_v)
surf.knotvector_u = n_knotvector_u
surf.knotvector_v = n_knotvector_v

# Set evaluation delta
surf.delta = 0.05

# Set visualization component
vis_comp = VisMPL.VisSurface()
surf.vis = vis_comp

# Render the surface
surf.render()
```

Please see *Compatibility Module Documentation* for more details on manipulating and exporting control points.

NURBS-Python has some other options for exporting and importing data. Please see *File Formats* page for details.

CHAPTER 11

Surface Generator

NURBS-Python comes with a simple surface generator which is designed to generate a control points grid to be used as a randomized input to *BSpline.Surface* and *NURBS.Surface*. It is capable of generating customized surfaces with arbitrary divisions and generating hills (or bumps) on the surface. It is also possible to export the surface as a text file in the format described under *File Formats* documentation.

The classes *CPGen.Grid* and *CPGen.GridWeighted* are responsible for generating the surfaces.

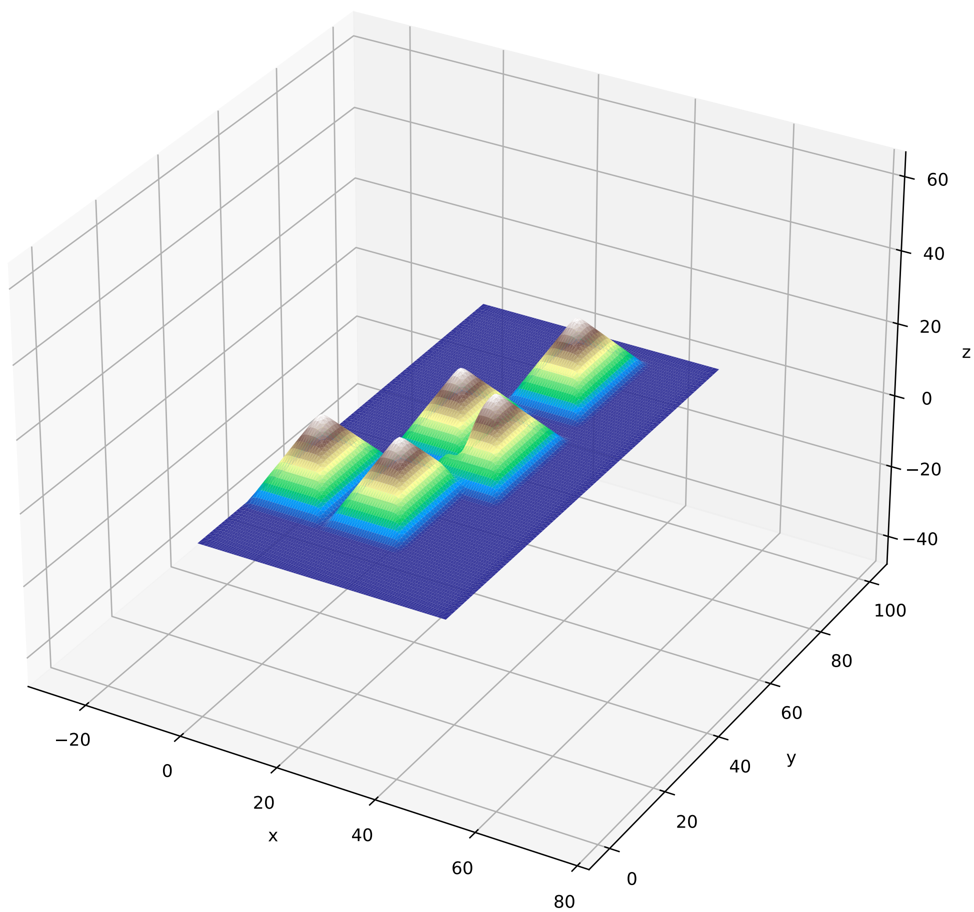
The following example illustrates a sample usage of the B-Spline surface generator:

```
from geomdl import CPGen
from geomdl import BSpline
from geomdl import utilities
from geomdl.visualization import VisMPL
from matplotlib import cm

# Generate a plane with the dimensions 50x100
surfgrid = CPGen.Grid(50, 100)

# Generate a grid of 25x30
surfgrid.generate(50, 60)

# Generate bumps on the grid
surfgrid.bumps(num_bumps=5, bump_height=20, base_extent=8)

# Create a BSpline surface instance
surf = BSpline.Surface()

# Set degrees
surf.degree_u = 3
surf.degree_v = 3

# Get the control points from the generated grid
surf.ctrlpts2d = surfgrid.grid

# Set knot vectors
```

(continues on next page)

(continued from previous page)

```
surf.knotvector_u = utilities.generate_knot_vector(surf.degree_u, surf.ctrlpts_size_u)
surf.knotvector_v = utilities.generate_knot_vector(surf.degree_v, surf.ctrlpts_size_v)

# Set sample size
surf.sample_size = 100

# Set visualization component
surf.vis = VisMPL.VisSurface(ctrlpts=False, legend=False)

# Plot the surface
surf.render(colormap=cm.terrain)
```



CPGen.Grid.bumps() method takes the following keyword arguments:

- `num_bumps`: Number of hills to be generated
- `bump_height`: Defines the peak height of the generated hills
- `base_extent`: Due to the structure of the grid, the hill base can be defined as a square with the edge length of *a*. `base_extent` is defined by the value of *a/2*.
- `base_adjust`: Defines the padding of the area where the hills are generated. It accepts positive and negative values. A negative value means a padding to the inside of the grid and a positive value means padding to the

outside of the grid.

CHAPTER 12

Knot Refinement

New in version 5.1.

Knot refinement is simply the operation of *inserting multiple knots at the same time*. NURBS-Python (geomdl) supports knot refinement operation for the curves, surfaces and volumes via `operations.refine_knotvector()` function.

One of the interesting features of the `operations.refine_knotvector()` function is the controlling of **knot refinement density**. It can increase the number of knots to be inserted in a knot vector. Therefore, it increases the number of control points.

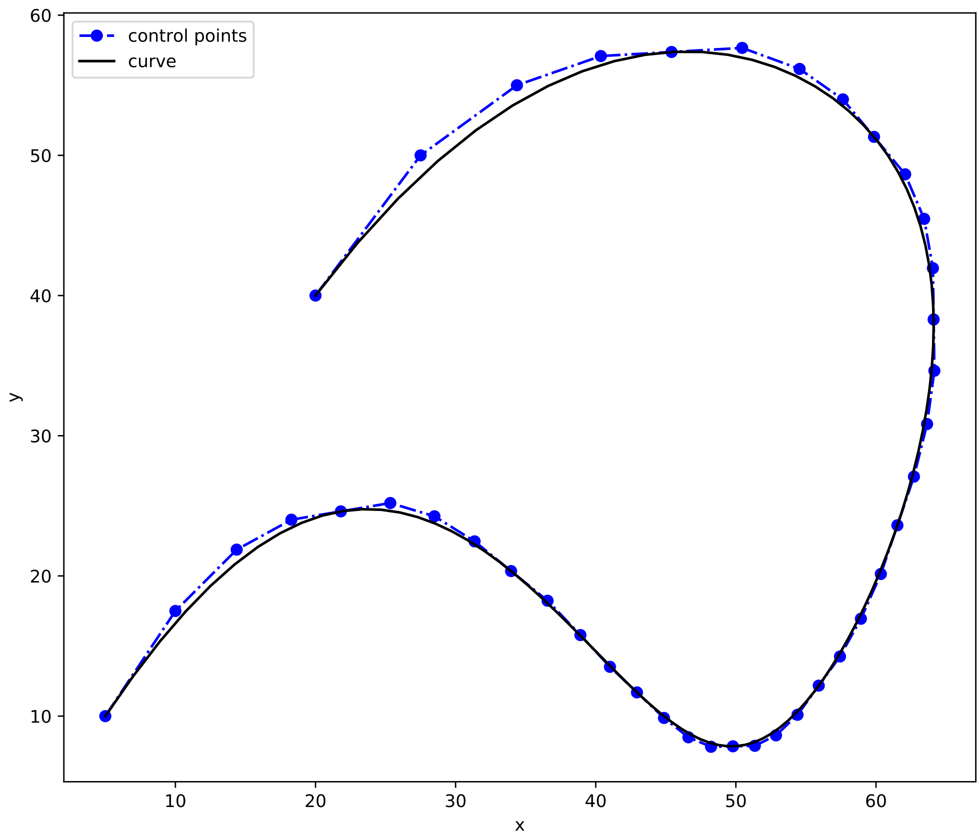
The following code snippet and the figure illustrate a 2-dimensional spline curve with knot refinement:

```
from geomdl import BSpline
from geomdl import utilities
from geomdl import exchange
from geomdl.visualization import VisMPL

# Create a curve instance
curve = BSpline.Curve()

# Set degree
curve.degree = 4

# Set control points
curve.ctrlpts = [
    [5.0, 10.0], [15.0, 25.0], [30.0, 30.0], [45.0, 5.0], [55.0, 5.0],
    [70.0, 40.0], [60.0, 60.0], [35.0, 60.0], [20.0, 40.0]
]

# Set knot vector
curve.knotvector = [0.0, 0.0, 0.0, 0.0, 0.0, 0.2, 0.4, 0.6, 0.8, 1.0, 1.0, 1.0, 1.0,␣
↪1.0]

# Set visualization component
curve.vis = VisMPL.VisCurve2D()
```

(continues on next page)

(continued from previous page)

```

# Refine knot vector
operations.refine_knotvector(curve, [1])

# Visualize
curve.render()
```



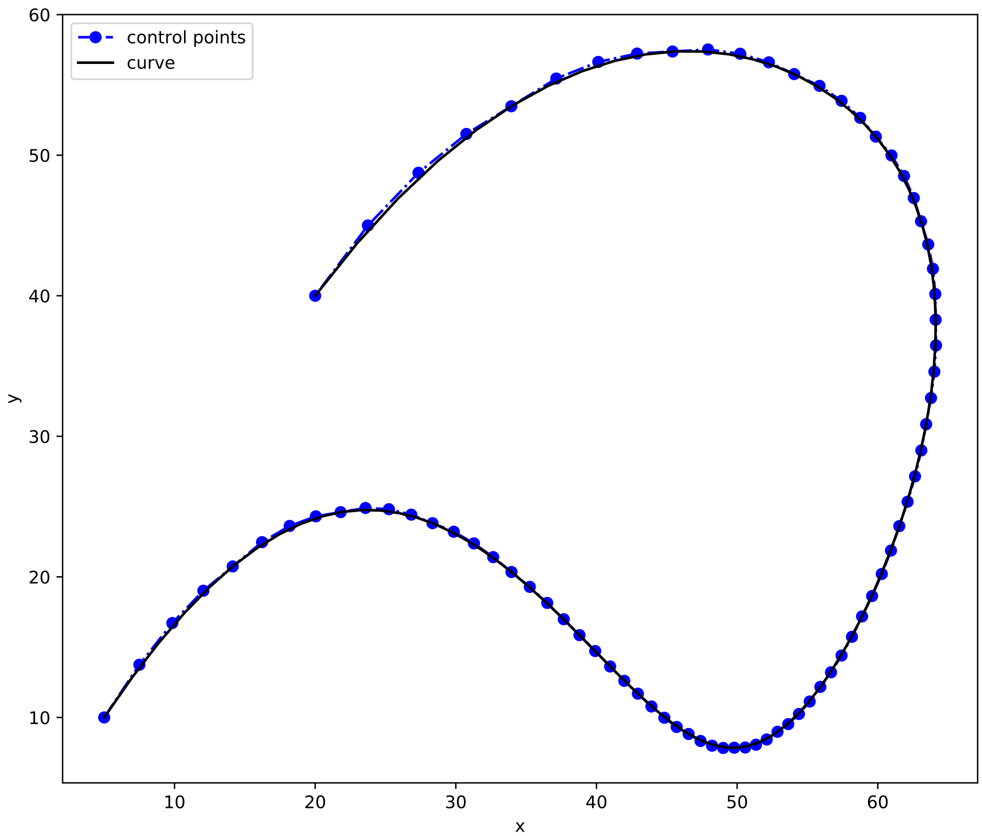
The default `density` value is **1** for the knot refinement operation. The following code snippet and the figure illustrate the result of the knot refinement operation if `density` is set to **2**.

```
from geomdl import BSpline
from geomdl import utilities
from geomdl import exchange
from geomdl.visualization import VisMPL

# Create a curve instance
curve = BSpline.Curve()

# Set degree
curve.degree = 4

```

(continues on next page)

(continued from previous page)

```
# Set control points
curve.ctrlpts = [
    [5.0, 10.0], [15.0, 25.0], [30.0, 30.0], [45.0, 5.0], [55.0, 5.0],
    [70.0, 40.0], [60.0, 60.0], [35.0, 60.0], [20.0, 40.0]
]

# Set knot vector
curve.knotvector = [0.0, 0.0, 0.0, 0.0, 0.0, 0.2, 0.4, 0.6, 0.8, 1.0, 1.0, 1.0, 1.0,␣
↪1.0]

# Set visualization component
curve.vis = VisMPL.VisCurve2D()

# Refine knot vector
operations.refine_knotvector(curve, [2])

# Visualize
curve.render()
```



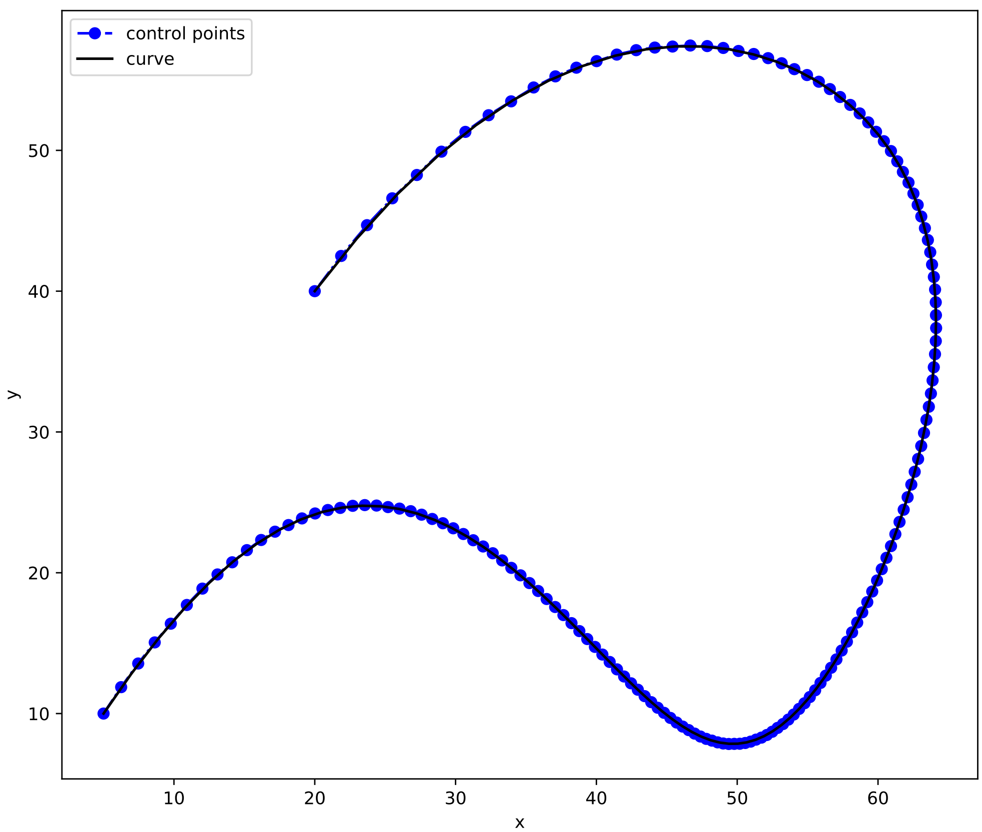
The following code snippet and the figure illustrate the result of the knot refinement operation if `density` is set to **3**.

```python
from geomdl import BSpline
from geomdl import utilities
from geomdl import exchange
from geomdl.visualization import VisMPL

# Create a curve instance
curve = BSpline.Curve()

# Set degree
curve.degree = 4

# Set control points
curve.ctrlpts = [
    [5.0, 10.0], [15.0, 25.0], [30.0, 30.0], [45.0, 5.0], [55.0, 5.0],
    [70.0, 40.0], [60.0, 60.0], [35.0, 60.0], [20.0, 40.0]
]

# Set knot vector
curve.knotvector = [0.0, 0.0, 0.0, 0.0, 0.0, 0.2, 0.4, 0.6, 0.8, 1.0, 1.0, 1.0, 1.0, 1.0]

# Set visualization component
curve.vis = VisMPL.VisCurve2D()

# Refine knot vector
operations.refine_knotvector(curve, [3])

# Visualize
curve.render()
```

The following code snippet and the figure illustrate the knot refinement operation applied to a surface with `density` value of **3** for the u-direction. No refinement was applied for the v-direction.

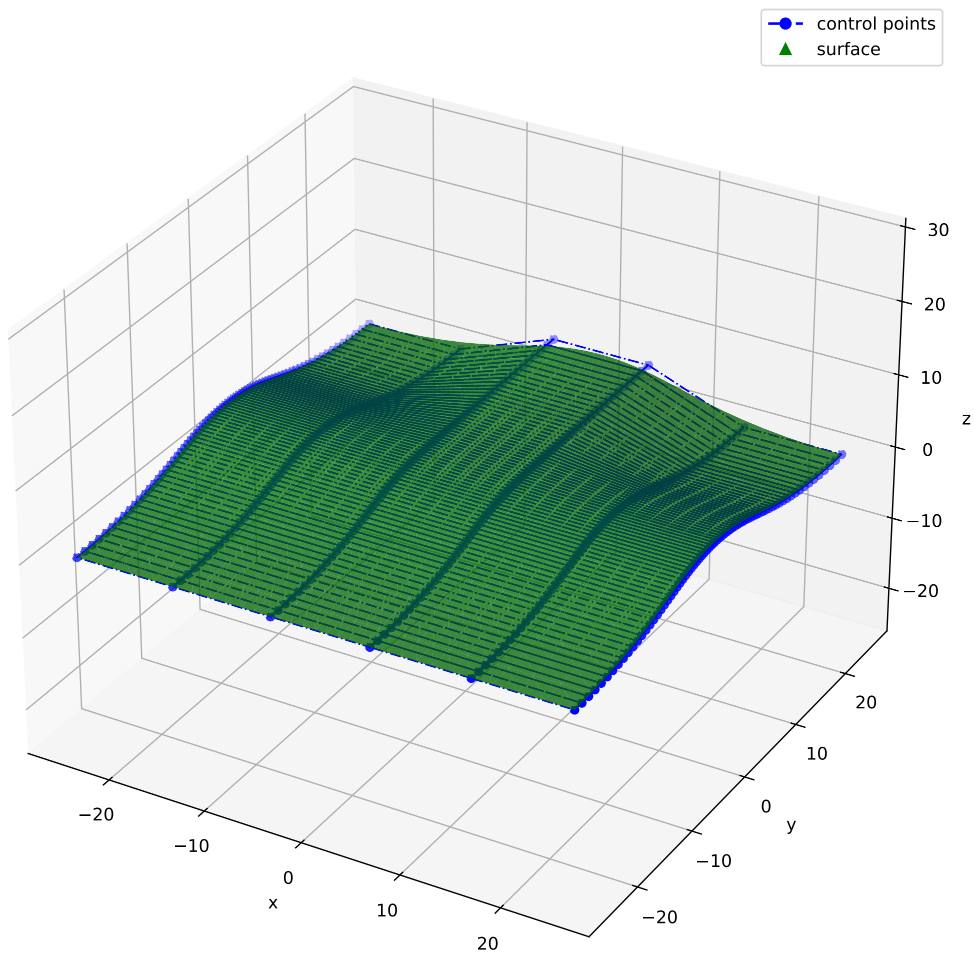
```python
from geomdl import NURBS
from geomdl import operations
from geomdl.visualization import VisMPL


# Control points
ctrlpts = [[[25.0, -25.0, 0.0, 1.0], [15.0, -25.0, 0.0, 1.0], [5.0, -25.0, 0.0, 1.0],
            [-5.0, -25.0, 0.0, 1.0], [-15.0, -25.0, 0.0, 1.0], [-25.0, -25.0, 0.0, 1.0]],
           [[25.0, -15.0, 0.0, 1.0], [15.0, -15.0, 0.0, 1.0], [5.0, -15.0, 0.0, 1.0],
            [-5.0, -15.0, 0.0, 1.0], [-15.0, -15.0, 0.0, 1.0], [-25.0, -15.0, 0.0, 1.0]],
           [[25.0, -5.0, 5.0, 1.0], [15.0, -5.0, 5.0, 1.0], [5.0, -5.0, 5.0, 1.0],
            [-5.0, -5.0, 5.0, 1.0], [-15.0, -5.0, 5.0, 1.0], [-25.0, -5.0, 5.0, 1.0]],
           [[25.0, 5.0, 5.0, 1.0], [15.0, 5.0, 5.0, 1.0], [5.0, 5.0, 5.0, 1.0],
            [-5.0, 5.0, 5.0, 1.0], [-15.0, 5.0, 5.0, 1.0], [-25.0, 5.0, 5.0, 1.0]],
           [[25.0, 15.0, 0.0, 1.0], [15.0, 15.0, 0.0, 1.0], [5.0, 15.0, 5.0, 1.0],
            [-5.0, 15.0, 5.0, 1.0], [-15.0, 15.0, 0.0, 1.0], [-25.0, 15.0, 0.0, 1.0]],
           [[25.0, 25.0, 0.0, 1.0], [15.0, 25.0, 0.0, 1.0], [5.0, 25.0, 5.0, 1.0],
            [-5.0, 25.0, 5.0, 1.0], [-15.0, 25.0, 0.0, 1.0], [-25.0, 25.0, 0.0, 1.0]]]

# Generate surface
surf = NURBS.Surface()
surf.degree_u = 3
```

(continues on next page)


control points
curve
50
40
30
20
10
y
10
20
30
40
50
60
x

(continued from previous page)

```
surf.degree_v = 3
surf.ctrlpts2d = ctrlpts
surf.knotvector_u = [0.0, 0.0, 0.0, 0.0, 1.0, 2.0, 3.0, 3.0, 3.0, 3.0]
surf.knotvector_v = [0.0, 0.0, 0.0, 0.0, 1.0, 2.0, 3.0, 3.0, 3.0, 3.0]
surf.sample_size = 30

# Set visualization component
surf.vis = VisMPL.VisSurface(VisMPL.VisConfig(alpha=0.75))

# Refine knot vectors
operations.refine_knotvector(surf, [3, 0])

# Visualize
surf.render()
```



CHAPTER 13

Curve & Surface Fitting

geomdl includes 2 fitting methods for curves and surfaces: approximation and interpolation. Please refer to the *Curve and Surface Fitting* page for more details on the curve and surface fitting API.

The following sections explain 2-dimensional curve fitting using the included fitting methods. geomdl also supports 3-dimensional curve and surface fitting (not shown here). Please refer to the *Examples Repository* for more examples on curve and surface fitting.

13.1 Interpolation

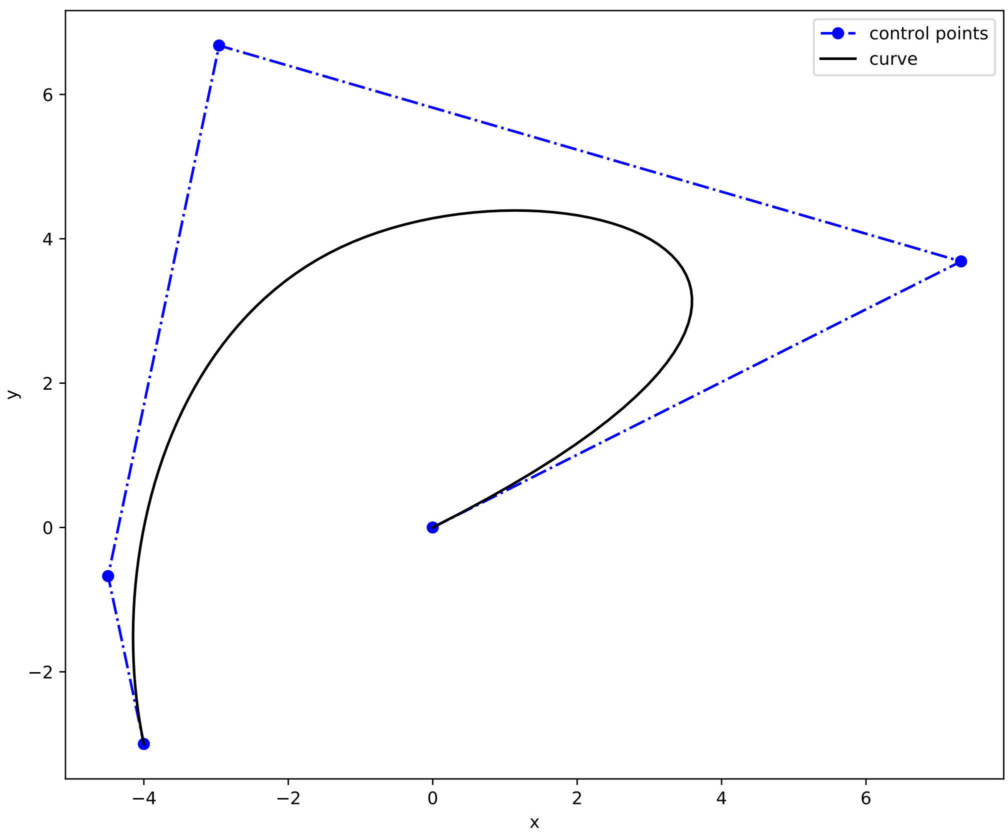
The following code snippet and the figure illustrate interpolation for a 2-dimensional curve:

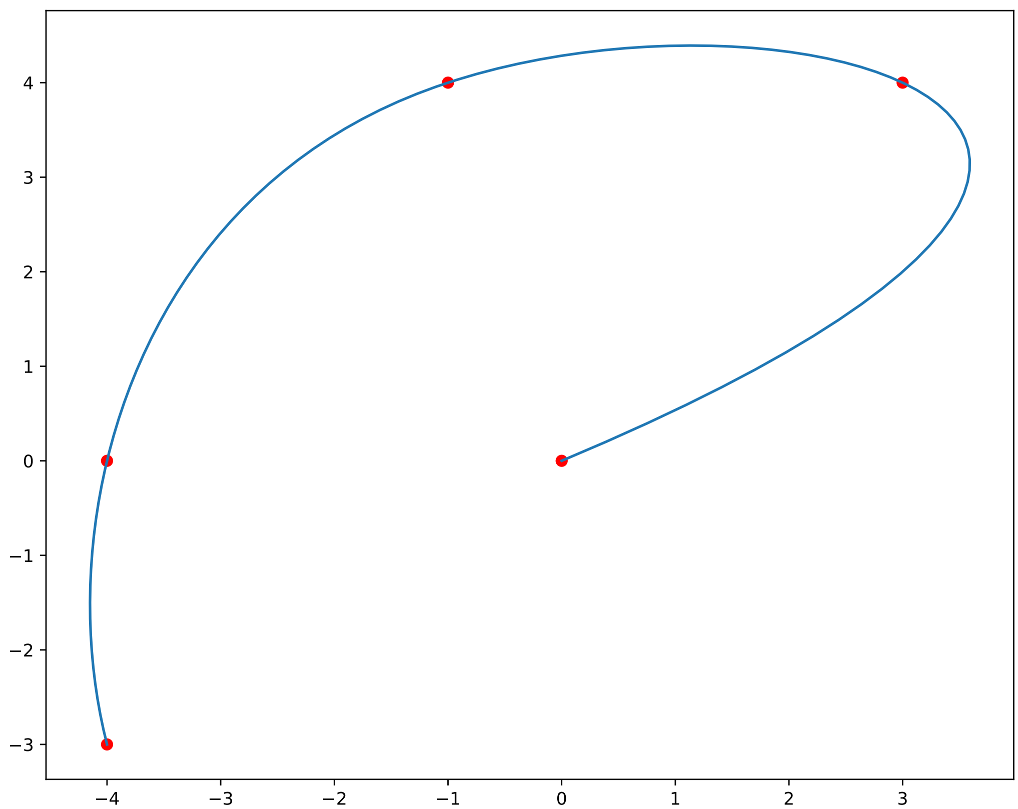
```
from geomdl import fitting
from geomdl.visualization import VisMPL as vis

# The NURBS Book Ex9.1
points = ((0, 0), (3, 4), (-1, 4), (-4, 0), (-4, -3))
degree = 3  # cubic curve

# Do global curve interpolation
curve = fitting.interpolate_curve(points, degree)

# Plot the interpolated curve
curve.delta = 0.01
curve.vis = vis.VisCurve2D()
curve.render()
```

The following figure displays the input data (sample) points in red and the evaluated curve after interpolation in blue:

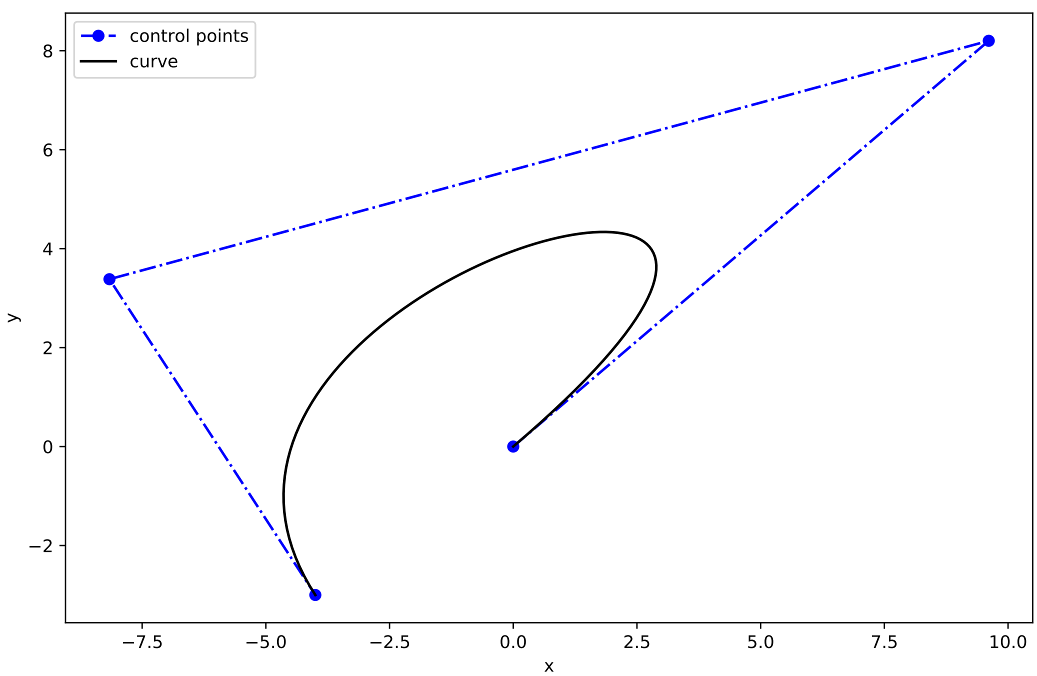
13.2 Approximation

The following code snippet and the figure illustrate approximation method for a 2-dimensional curve:


control points
curve
y
x
6
4
2
0
−2
−4
−2
0
2
4
6

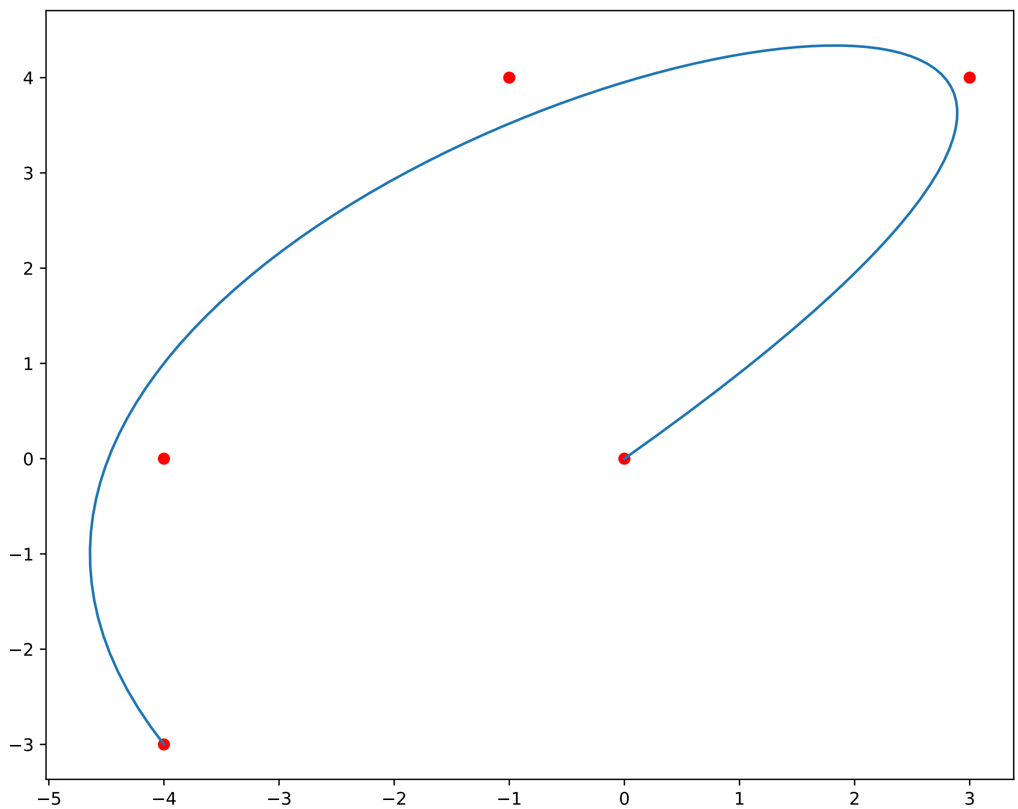

4
3
2
1
0
−1
−2
−3
−4
−3
−2
−1
0
1
2
3

```
from geomdl import fitting
from geomdl.visualization import VisMPL as vis

# The NURBS Book Ex9.1
points = ((0, 0), (3, 4), (-1, 4), (-4, 0), (-4, -3))
degree = 3  # cubic curve

# Do global curve approximation
curve = fitting.approximate_curve(points, degree)

# Plot the interpolated curve
curve.delta = 0.01
curve.vis = vis.VisCurve2D()
curve.render()
```



The following figure displays the input data (sample) points in red and the evaluated curve after approximation in blue:

Please note that a spline geometry with a constant set of evaluated points may be represented with an infinite set of control points. The number and positions of the control points depend on the application and the method used to generate the control points.


4
3
2
1
0
−1
−2
−3
−5
−4
−3
−2
−1
0
1
2
3

CHAPTER 14

Visualization

NURBS-Python comes with the following visualization modules for direct plotting evaluated curves and surfaces:

- *VisMPL* module for Matplotlib
- *VisPlotly* module for Plotly
- *VisVTK* module for VTK

Examples repository contains over 40 examples on how to use the visualization components in various ways. Please see *Visualization Modules Documentation* for more details.

14.1 Examples

The following figures illustrate some example NURBS and B-spline shapes that can be generated and directly visualized via NURBS-Python.

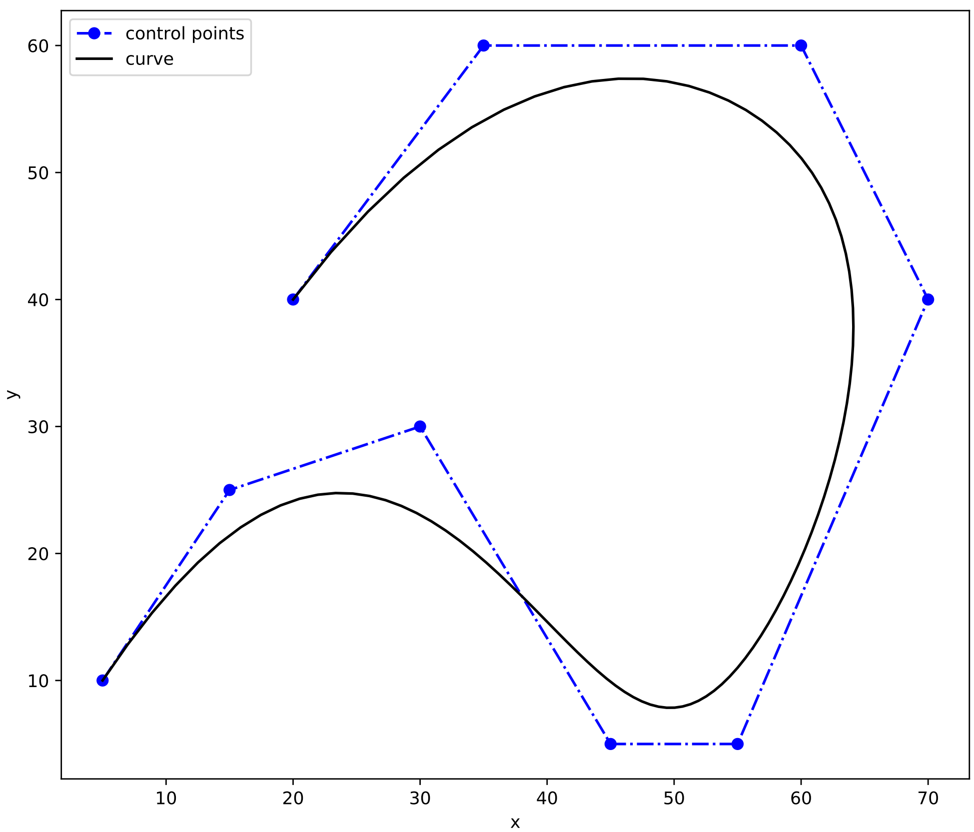
14.1.1 Curves

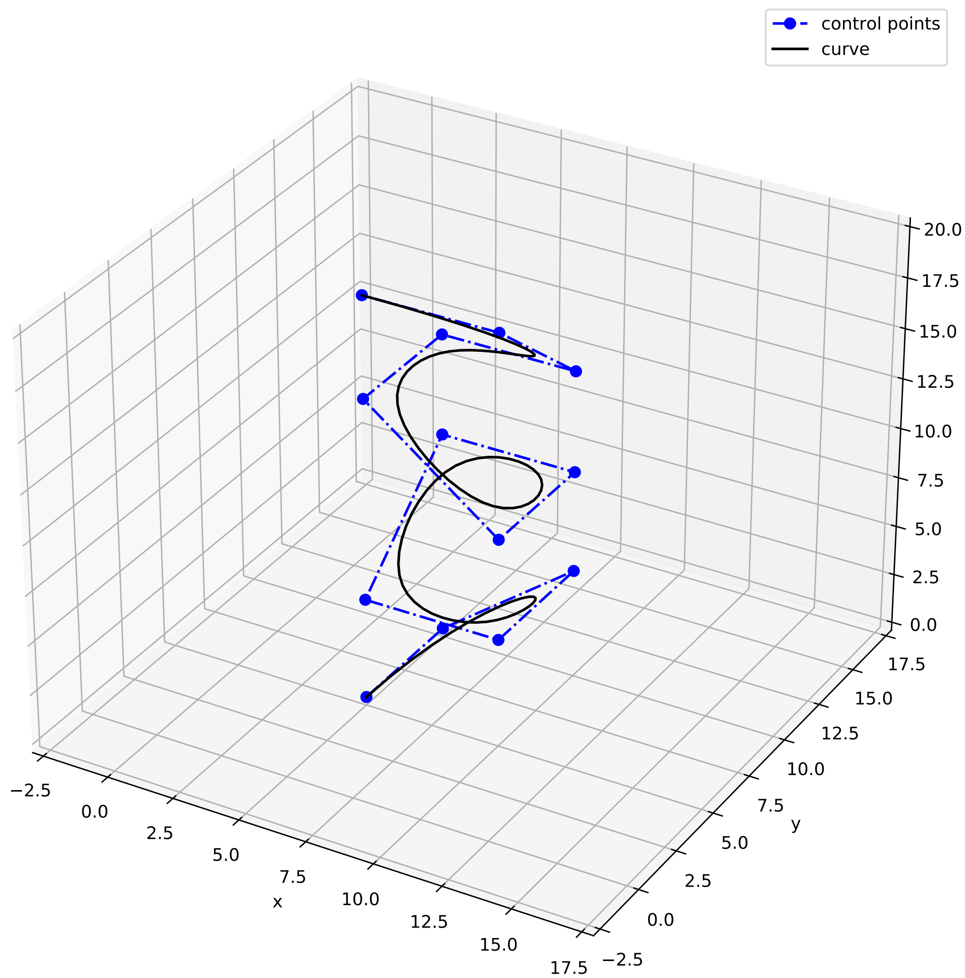
14.1.2 Surfaces

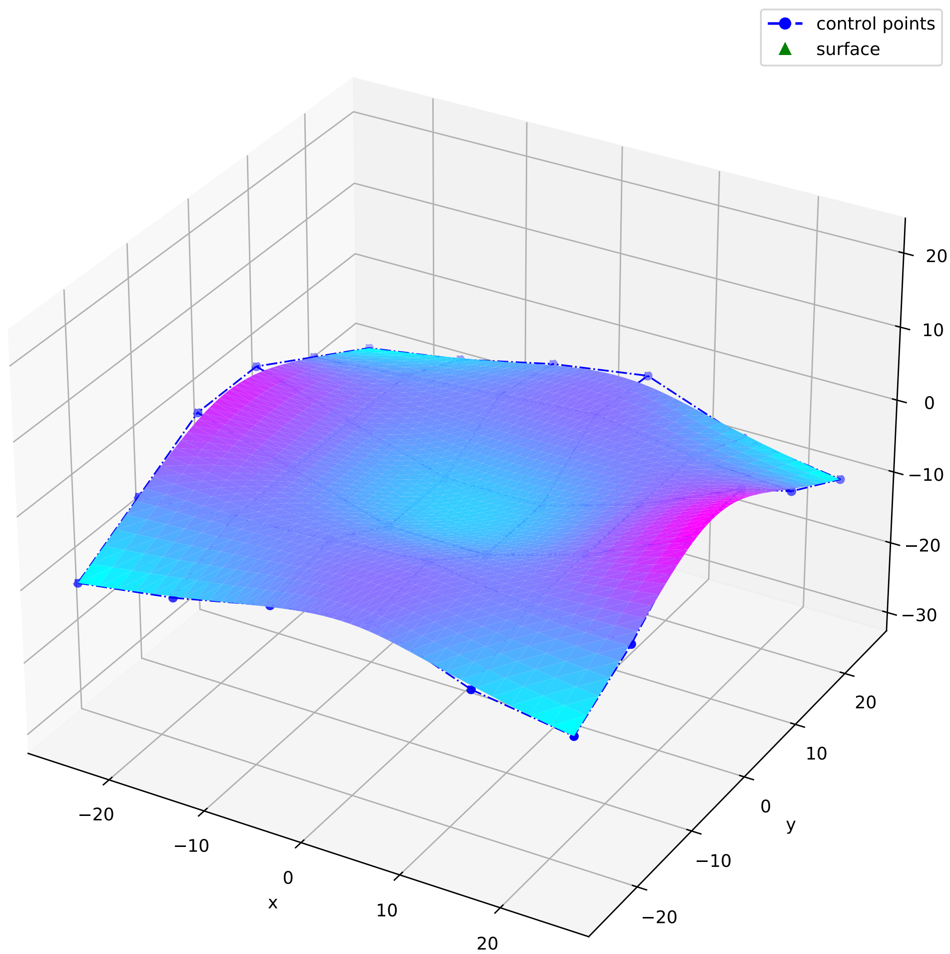
14.1.3 Volumes

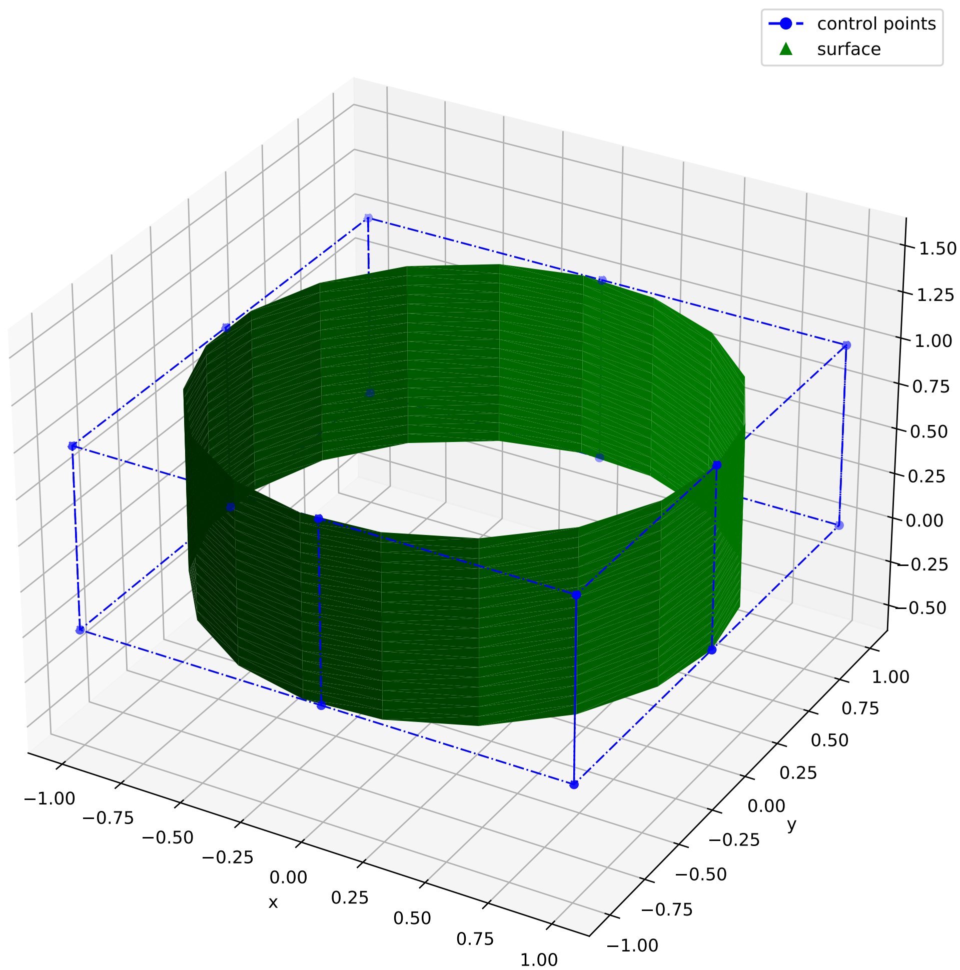
14.1.4 Advanced Visualization Examples

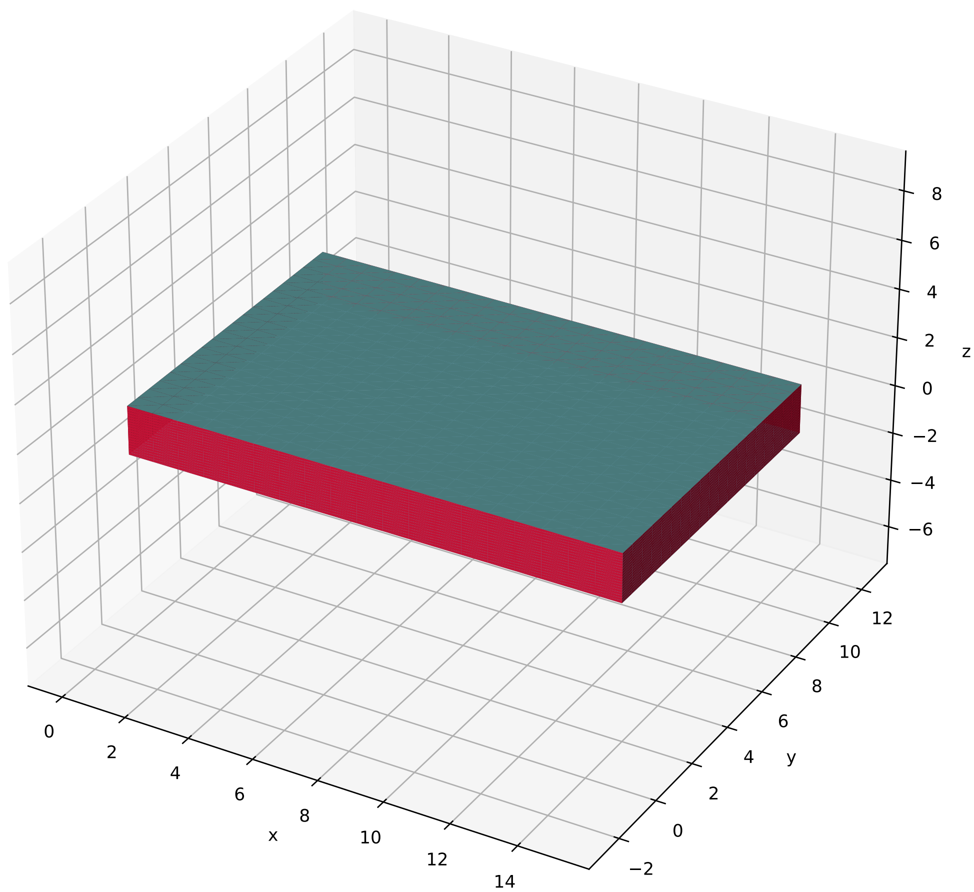
The following example scripts can be found in Examples repository under the `visualization` directory.


control points
curve
60
50
40
30
20
10
y
10
20
30
40
50
60
70
x


control points
curve
x
y
z
−2.5
0.0
2.5
5.0
7.5
10.0
12.5
15.0
17.5
20.0


control points
surface
20
10
0
z
−10
−20
−30
20
10
0
y
−10
−20
−20
−10
0
x
10
20

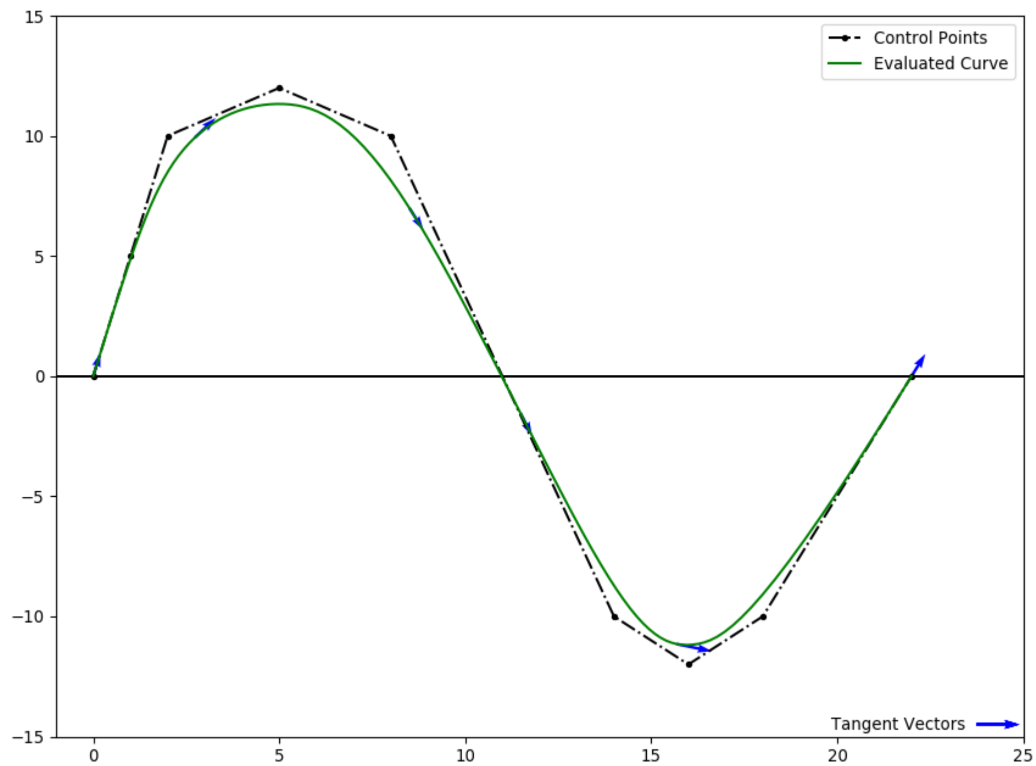

control points
surface
1.50
1.25
1.00
0.75
0.50
0.25
0.00
−0.25
−0.50
z
−1.00
−0.75
−0.50
−0.25
0.00
0.25
0.50
0.75
1.00
x
1.00
0.75
0.50
0.25
0.00
−0.25
−0.50
−0.75
−1.00
y



x
y
z
0
2
4
6
8
10
12
14
−2
0
2
4
6
8
10
12
−6
−4
−2
0
2
4
6
8

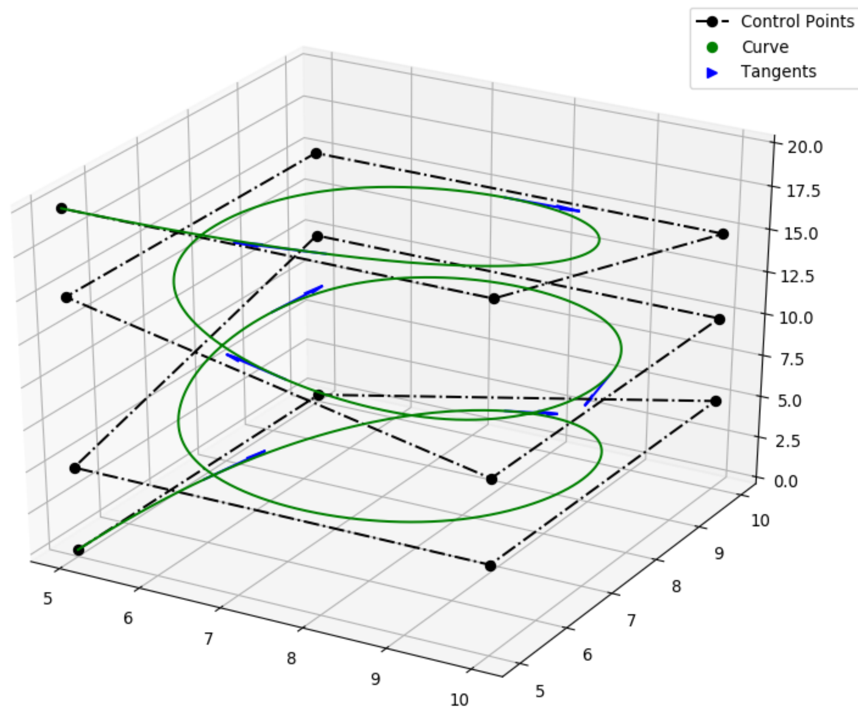
mpl_curve2d_tangents.py

This example illustrates a more advanced visualization option for plotting the 2D curve tangents alongside with the control points grid and the evaluated curve.



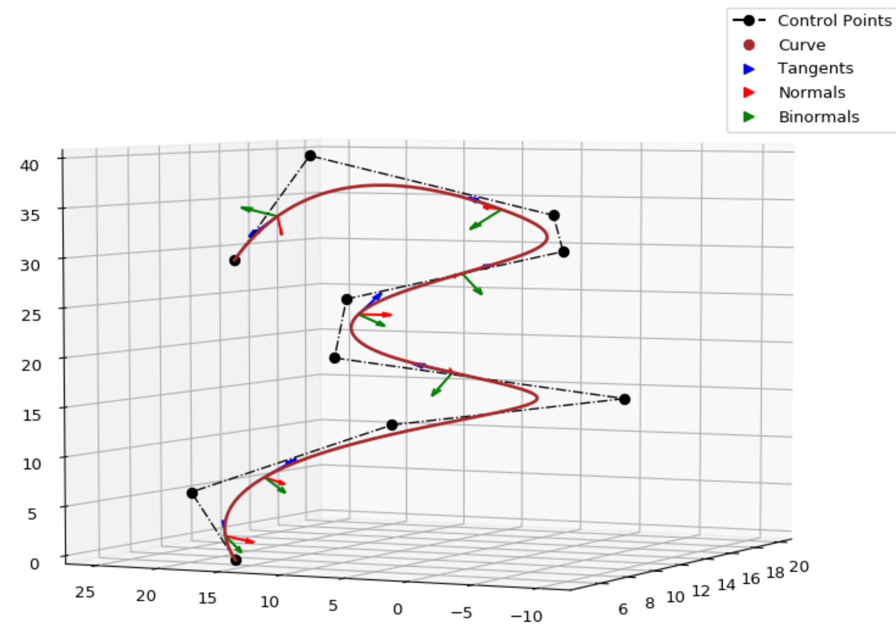
mpl_curve3d_tangents.py

This example illustrates a more advanced visualization option for plotting the 3D curve tangents alongside with the control points grid and the evaluated curve.



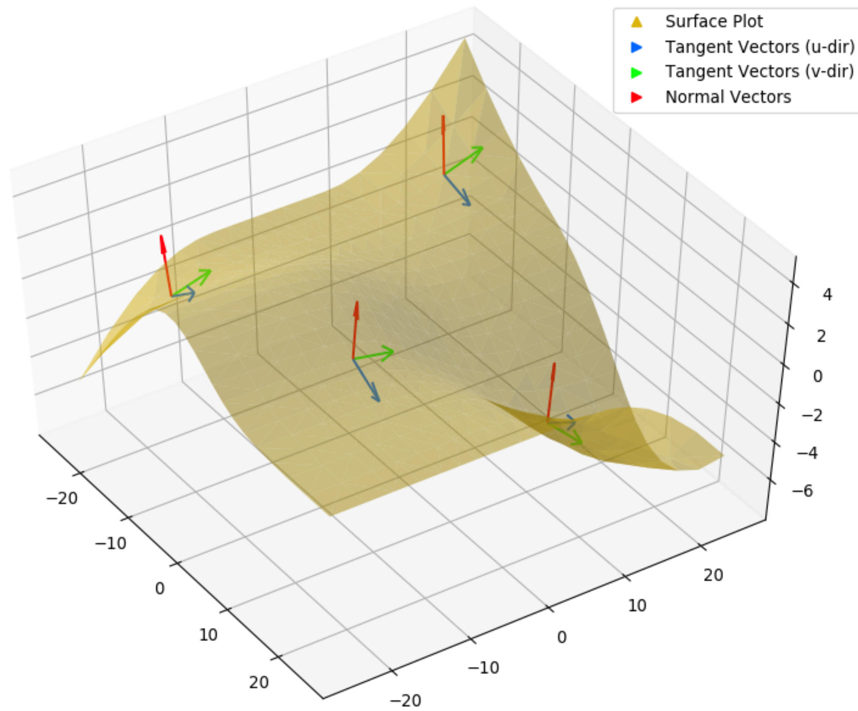
mpl_curve3d_vectors.py

This example illustrates a visualization option for plotting the 3D curve tangent, normal and binormal vectors alongside with the control points grid and the evaluated curve.



mpl_trisurf_vectors.py

The following figure illustrates tangent and normal vectors on `ex_surface02.py` example.


Surface Plot
Tangent Vectors (u-dir)
Tangent Vectors (v-dir)
Normal Vectors
−20
−10
0
10
20
−20
−10
0
10
20
4
2
0
−2
−4
−6

CHAPTER 15

Splitting and Decomposition

NURBS-Python is also capable of splitting the curves and the surfaces, as well as applying Bézier decomposition.

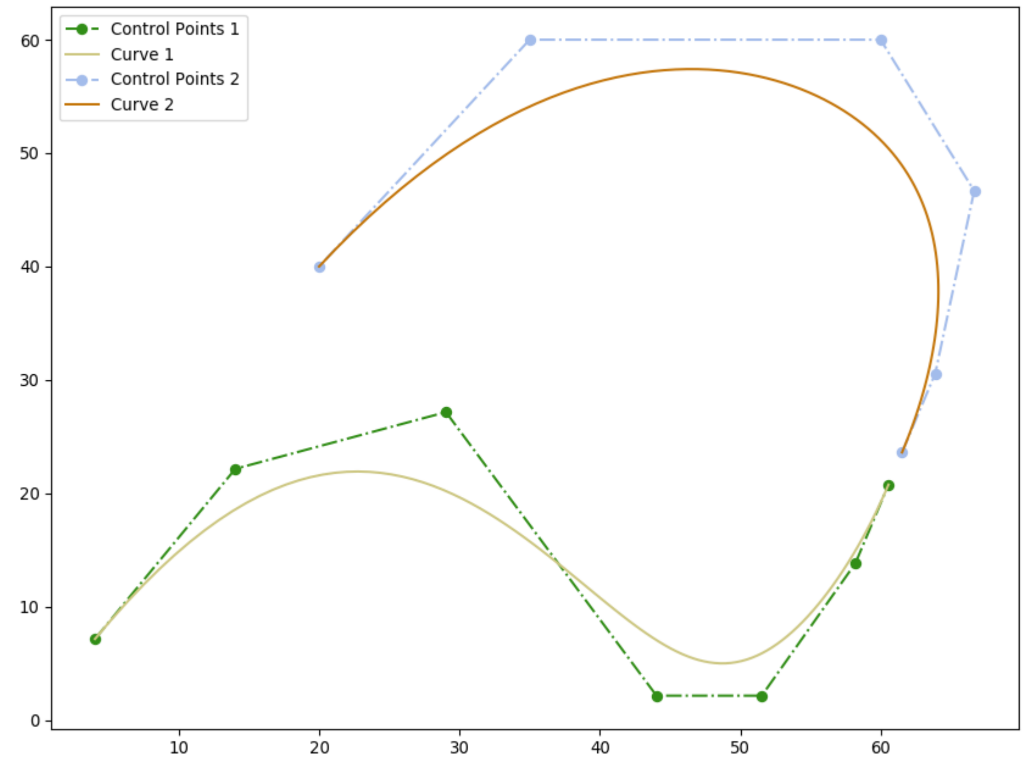
Splitting of curves can be achieved via `operations.split_curve()` method. For the surfaces, there are 2 different splitting methods, `operations.split_surface_u()` for splitting the surface on the u-direction and `operations.split_surface_v()` for splitting on the v-direction.

Bézier decomposition can be applied via `operations.decompose_curve()` and `operations.decompose_surface()` methods for curves and surfaces, respectively.

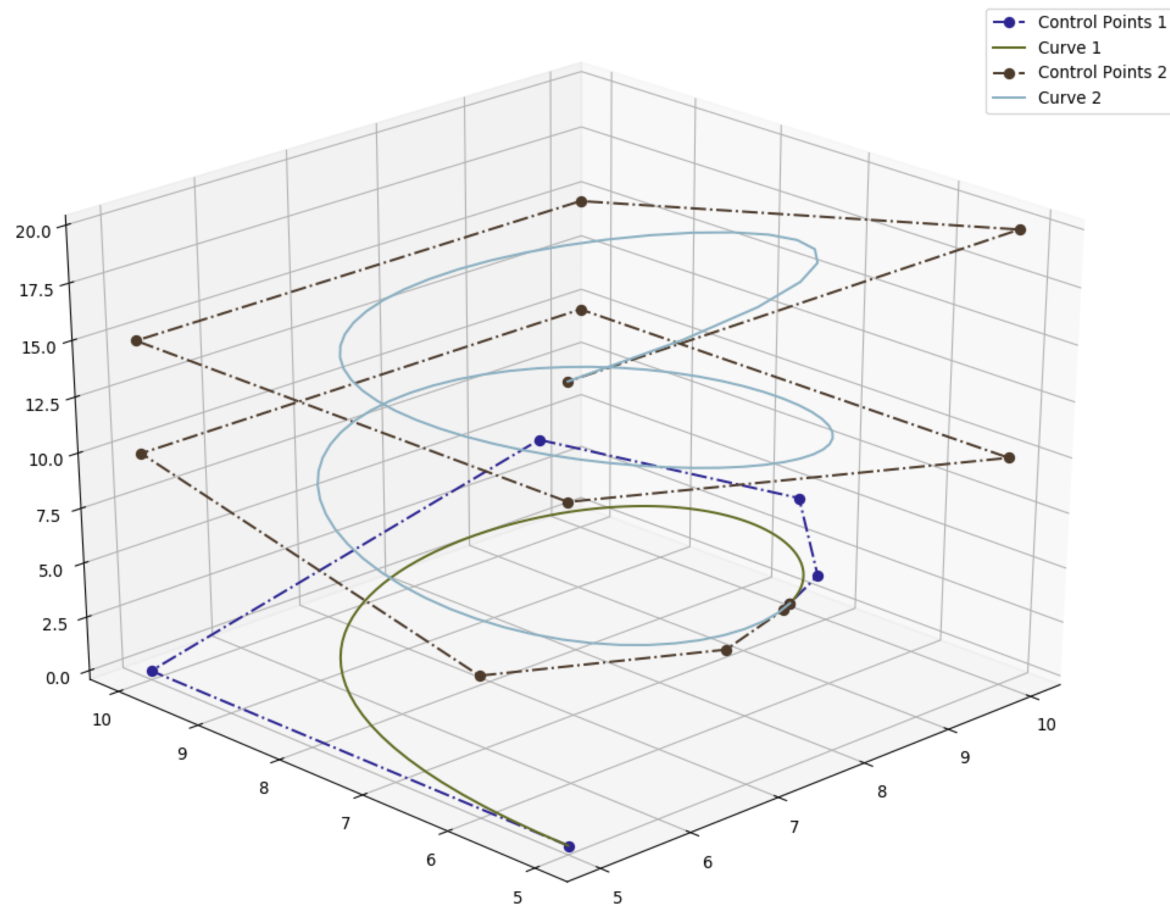
The following figures are generated from the examples provided in the Examples repository.

15.1 Splitting

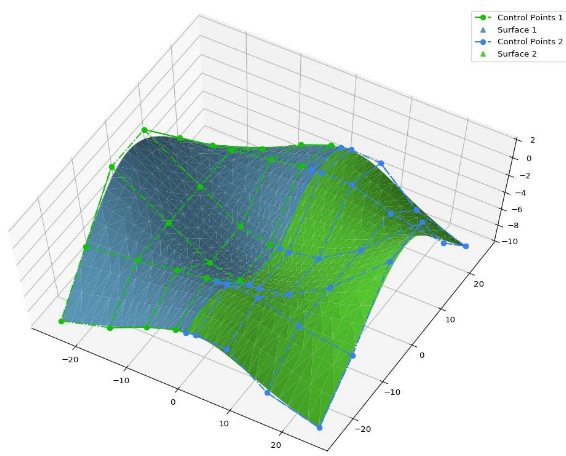
The following 2D curve is split at `u = 0.6` and applied translation by the tangent vector using `operations.translate()` method.

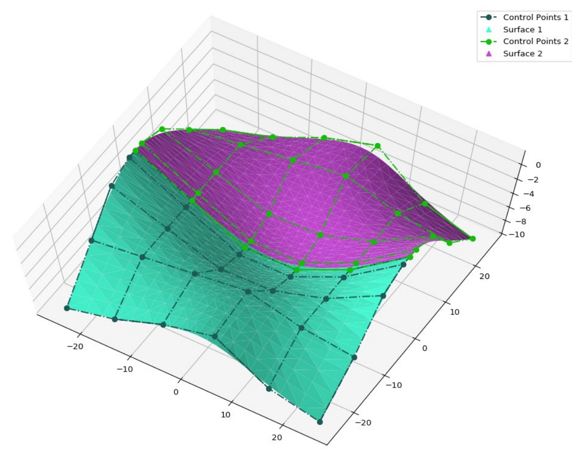


Splitting can also be applied to 3D curves (split at `u = 0.3`) without any translation.

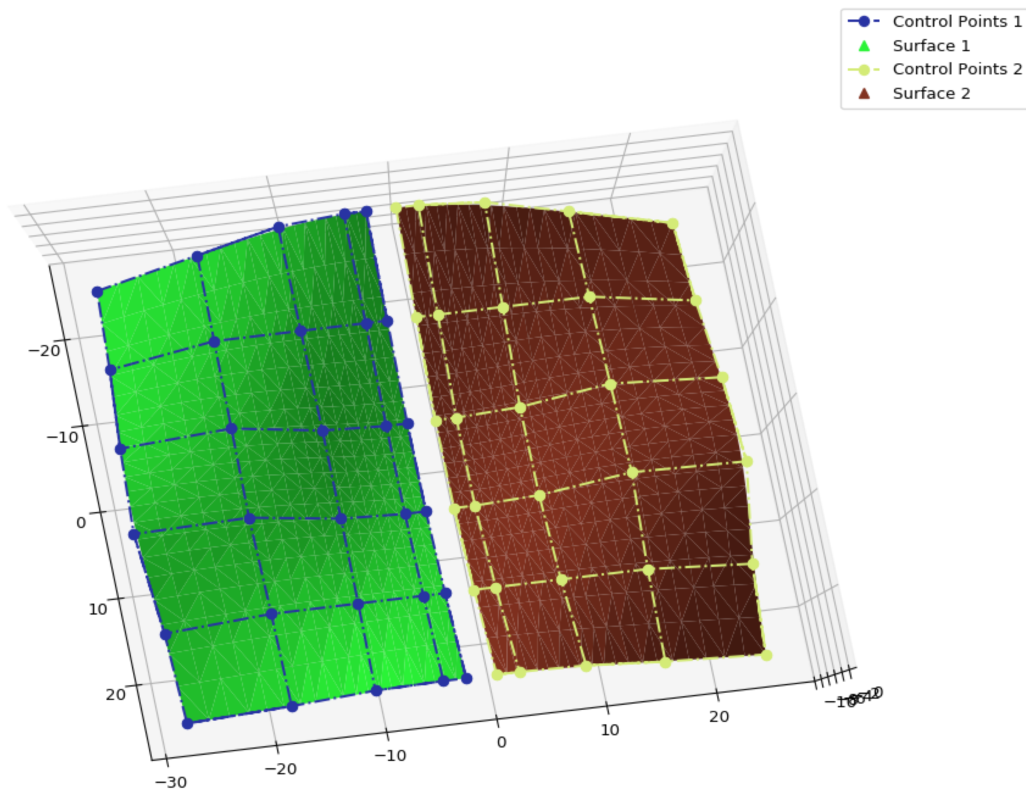


Surface splitting is also possible. The following figure compares splitting at `u = 0.5` and `v = 0.5`.

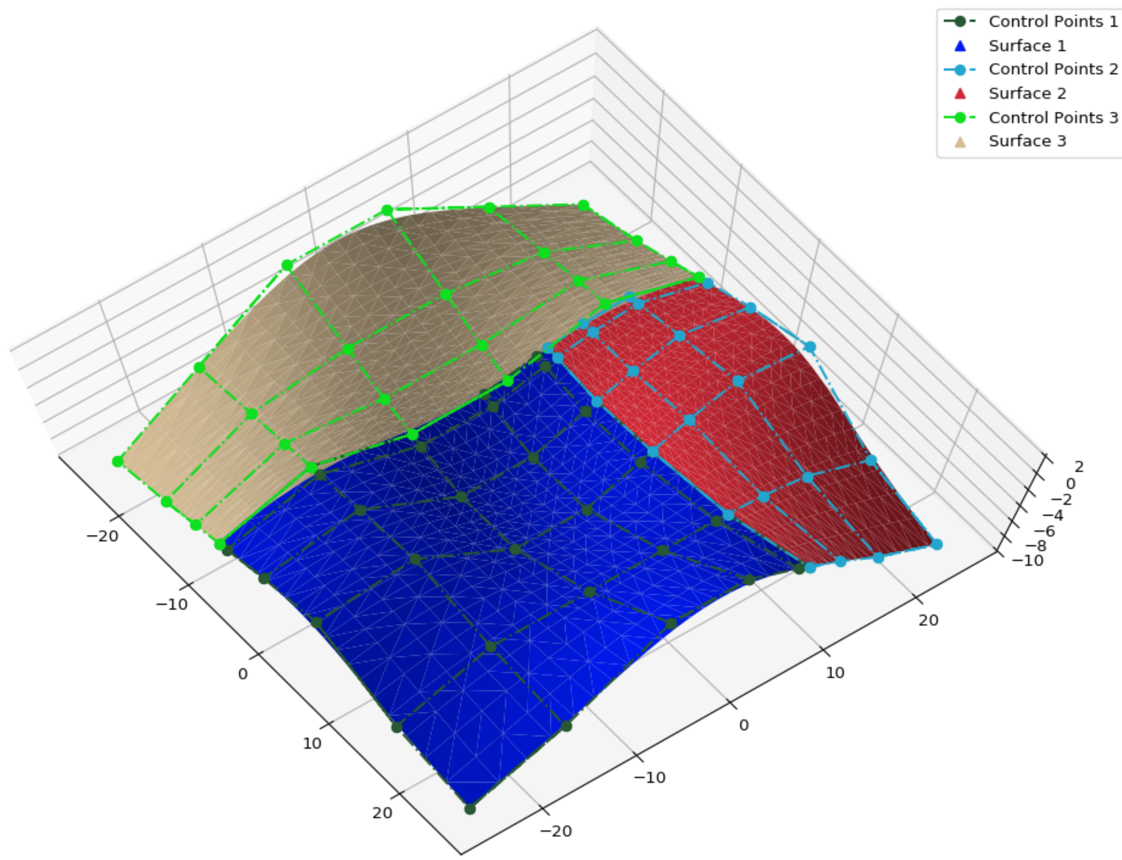




Surfaces can also be translated too before or after splitting operation. The following figure illustrates translation after splitting the surface at `u = 0.5`.

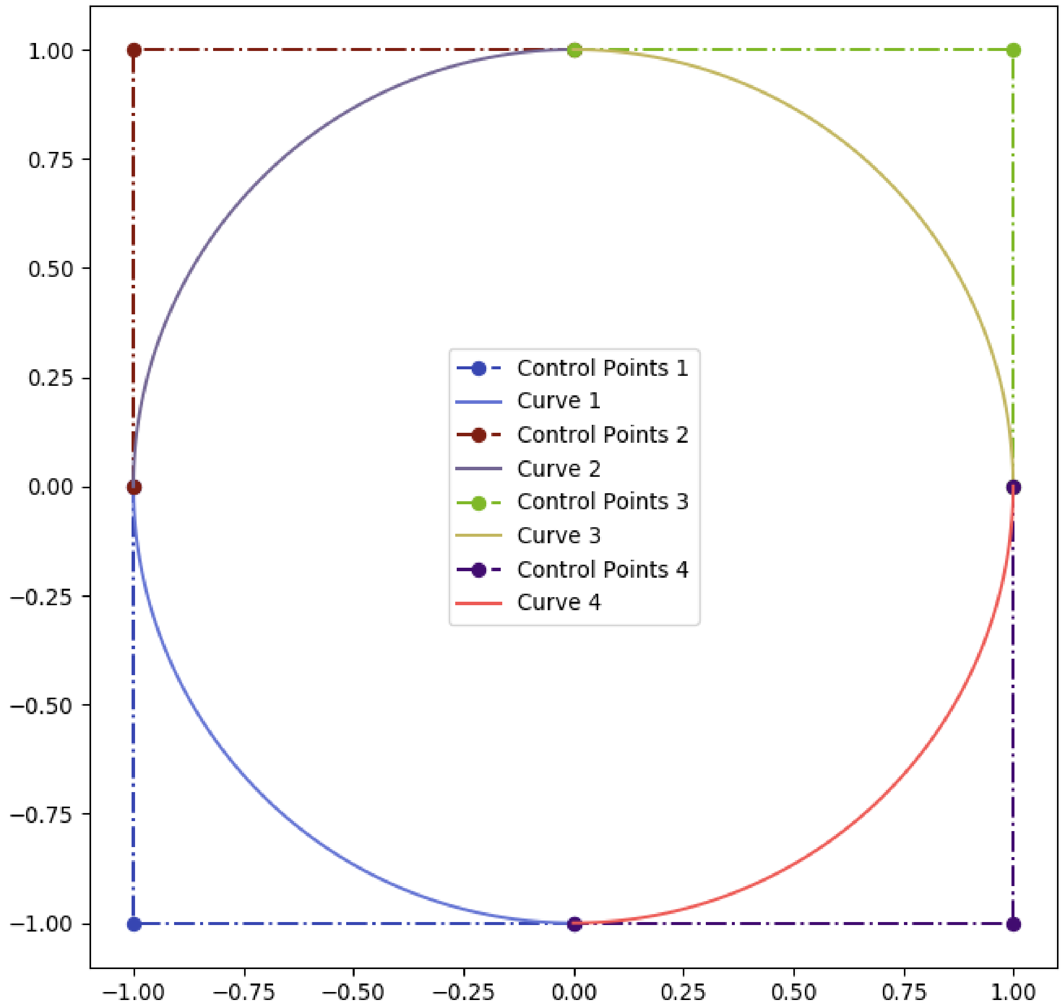


Multiple splitting is also possible for all curves and surfaces. The following figure describes multi splitting in surfaces. The initial surface is split at `u = 0.25` and then, one of the resultant surfaces is split at `v = 0.75`, finally resulting 3 surfaces.

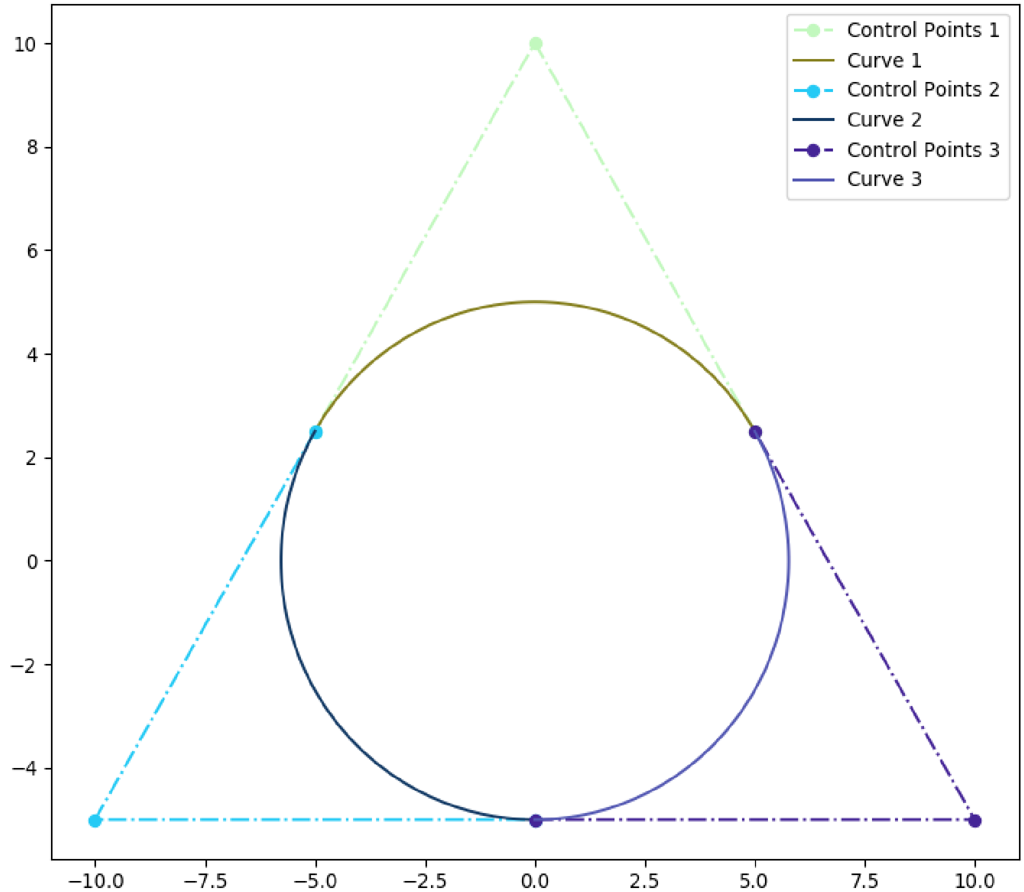


15.2 Bézier Decomposition

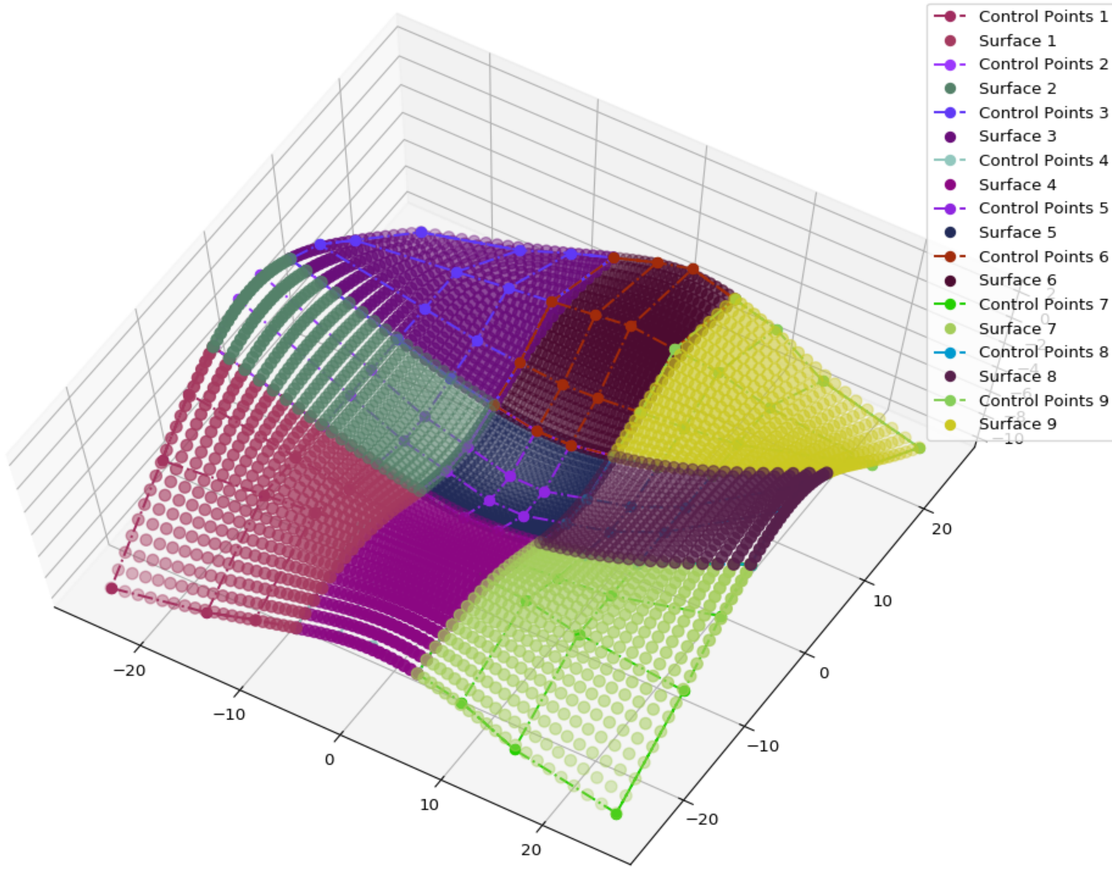
The following figures illustrate Bézier decomposition capabilities of NURBS-Python. Let's start with the most obvious one, a full circle with 9 control points. It also is possible to directly generate this shape via `geomdl.shapes` module.



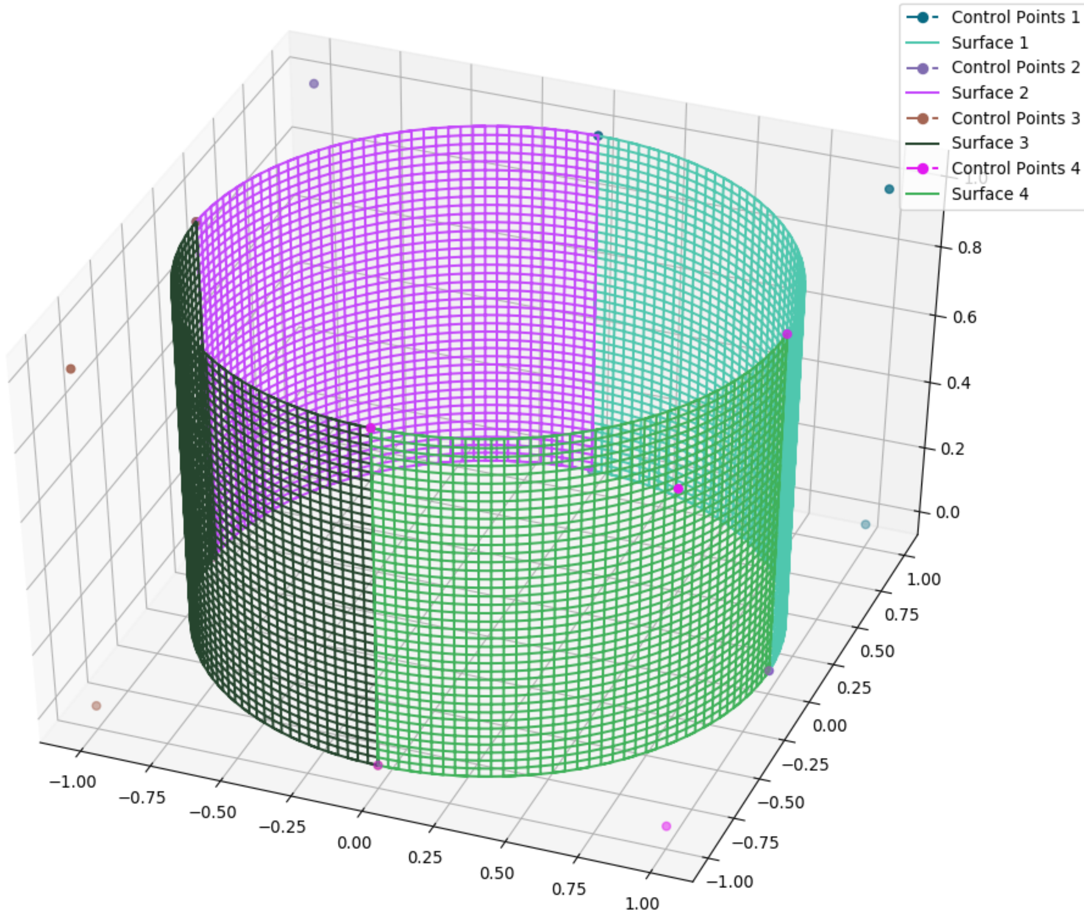
The following is a circular curve generated with 7 control points as illustrated on page 301 of *The NURBS Book* (2nd Edition) by Piegl and Tiller. There is also an option to generate this shape via `geomdl.shapes` module.



The following figures illustrate the possibility of Bézier decomposition in B-Spline and NURBS surfaces.



Control Points 1
Surface 1
Control Points 2
Surface 2
Control Points 3
Surface 3
Control Points 4
Surface 4
Control Points 5
Surface 5
Control Points 6
Surface 6
Control Points 7
Surface 7
Control Points 8
Surface 8
Control Points 9
Surface 9
−20
−10
0
10
20
−20
−10
0
10
20



The colors are randomly generated via `utilities.color_generator()` function.

CHAPTER 16

Exporting Plots as Image Files

The `render()` method allows users to directly plot the curves and surfaces using predefined visualization classes. This method takes some keyword arguments to control plot properties at runtime. Please see the class documentation on description of these keywords. The `render()` method also allows users to save the plots directly as a file and to control the plot window visibility. The keyword arguments that control these features are `filename` and `plot`, respectively.

The following example script illustrates creating a 3-dimensional Bézier curve and saving the plot as `bezier-curve3d.pdf` without popping up the Matplotlib plot window. `filename` argument is a string value defining the name of the file to be saved and `plot` flag controls the visibility of the plot window.

```python
from geomdl import BSpline
from geomdl import utilities
from geomdl.visualization import VisMPL

# Create a 3D B-Spline curve instance (Bezier Curve)
curve = BSpline.Curve()

# Set up the Bezier curve
curve.degree = 3
curve.ctrlpts = [[10, 5, 10], [10, 20, -30], [40, 10, 25], [-10, 5, 0]]

# Auto-generate knot vector
curve.knotvector = utilities.generate_knot_vector(curve.degree, len(curve.ctrlpts))

# Set sample size
curve.sample_size = 40

# Evaluate curve
curve.evaluate()

# Plot the control point polygon and the evaluated curve
vis_comp = VisMPL.VisCurve3D()
curve.vis = vis_comp

```

(continues on next page)

(continued from previous page)

```
# Don't pop up the plot window, instead save it as a PDF file
curve.render(filename="bezier-curve3d.pdf", plot=False)
```

This functionality strongly depends on the plotting library used. Please see the documentation of the plotting library that you are using for more details on its figure exporting capabilities.

CHAPTER 17

Core Modules

The following are the lists of modules included in NURBS-Python (geomdl) Core Library. They are split into separate groups to make the documentation more understandable.

17.1 User API

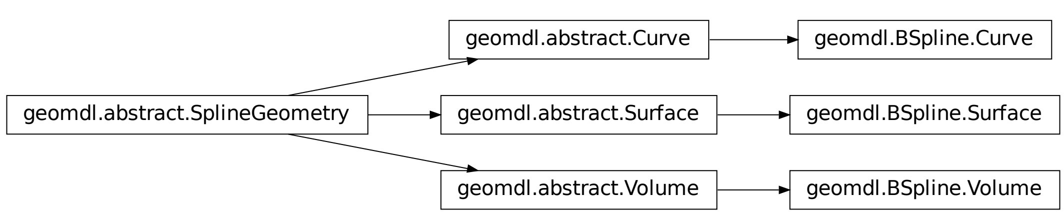
The User API is the main entrance point to the library. It provides geometry classes and containers, as well as the geometric operators and support modules.

The following is the list of the geometry classes included in the library:

17.1.1 B-Spline Geometry

`BSpline` module provides data storage and evaluation functions for non-rational spline geometries.

Inheritance Diagram



B-Spline Curve

class geomdl.BSpline.**Curve**(***kwargs*)

Bases: *geomdl.abstract.Curve*

Data storage and evaluation class for n-variate B-spline (non-rational) curves.

This class provides the following properties:

- *type* = spline
- *id*
- *order*
- *degree*
- *knotvector*
- *ctrlpts*
- *delta*
- *sample_size*
- *bbox*
- *vis*
- *name*
- *dimension*
- *evaluator*
- *rational*

The following code segment illustrates the usage of Curve class:

```
from geomdl import BSpline

# Create a 3-dimensional B-spline Curve
curve = BSpline.Curve()

# Set degree
curve.degree = 3

# Set control points
curve.ctrlpts = [[10, 5, 10], [10, 20, -30], [40, 10, 25], [-10, 5, 0]]

# Set knot vector
curve.knotvector = [0, 0, 0, 0, 1, 1, 1, 1]

# Set evaluation delta (controls the number of curve points)
curve.delta = 0.05

# Get curve points (the curve will be automatically evaluated)
curve_points = curve.evalpts
```

Keyword Arguments:

- `precision`: number of decimal places to round to. *Default: 18*
- `normalize_kv`: activates knot vector normalization. *Default: True*

- `find_span_func`: sets knot span search implementation. *Default:* `helpers.find_span_linear()`
- `insert_knot_func`: sets knot insertion implementation. *Default:* `operations.insert_knot()`
- `remove_knot_func`: sets knot removal implementation. *Default:* `operations.remove_knot()`

Please refer to the `abstract.Curve()` documentation for more details.

bbox
Bounding box.

Evaluates the bounding box and returns the minimum and maximum coordinates.

Please refer to the wiki for details on using this class member.

Getter Gets the bounding box

Type tuple

binormal (*parpos*, ***kwargs*)
Evaluates the binormal vector of the curve at the given parametric position(s).

Parameters **parpos** (*float, list or tuple*) – parametric position(s) where the evaluation will be executed

Returns binormal vector as a tuple of the origin point and the vector components

Return type tuple

cpsize
Number of control points in all parametric directions.

Note: This is an expert property for getting and setting control point size(s) of the geometry.

Please refer to the wiki for details on using this class member.

Getter Gets the number of control points

Setter Sets the number of control points

Type list

ctrlpts
Control points.

Please refer to the wiki for details on using this class member.

Getter Gets the control points

Setter Sets the control points

Type list

ctrlpts_size
Total number of control points.

Getter Gets the total number of control points

Type int

data
Returns a dict which contains the geometry data.

Please refer to the wiki for details on using this class member.

degree
Degree.

Please refer to the wiki for details on using this class member.

Getter Gets the degree

Setter Sets the degree

Type int

delta
Evaluation delta.

Evaluation delta corresponds to the *step size* while `evaluate` function iterates on the knot vector to generate curve points. Decreasing step size results in generation of more curve points. Therefore; smaller the delta value, smoother the curve.

The following figure illustrates the working principles of the delta property:

$$[u_{start}, u_{start} + \delta, (u_{start} + \delta) + \delta, \dots, u_{end}]$$

Please refer to the wiki for details on using this class member.

Getter Gets the delta value

Setter Sets the delta value

Type float

derivatives (*u*, *order=0*, ***kwargs*)
Evaluates n-th order curve derivatives at the given parameter value.

The output of this method is list of n-th order derivatives. If `order` is `0`, then it will only output the evaluated point. Similarly, if `order` is `2`, then it will output the evaluated point, 1st derivative and the 2nd derivative. For instance;

```
# Assuming a curve (crv) is defined on a parametric domain [0.0, 1.0]
# Let's take the curve derivative at the parametric position u = 0.35
ders = crv.derivatives(u=0.35, order=2)
ders[0]  # evaluated point, equal to crv.evaluate_single(0.35)
ders[1]  # 1st derivative at u = 0.35
ders[2]  @ 2nd derivative at u = 0.35
```

Parameters

- **u** (*float*) – parameter value
- **order** (*int*) – derivative order

Returns a list containing up to {order}-th derivative of the curve

Return type list

dimension
Spatial dimension.

Spatial dimension will be automatically estimated from the first element of the control points array.

Please refer to the wiki for details on using this class member.

Getter Gets the spatial dimension, e.g. 2D, 3D, etc.

Type int

domain
Domain.

Domain is determined using the knot vector(s).

Getter Gets the domain

evalpts
Evaluated points.

Please refer to the wiki for details on using this class member.

Getter Gets the coordinates of the evaluated points

Type list

evaluate(***kwargs*)
Evaluates the curve.

The evaluated points are stored in `evalpts` property.

Keyword arguments:

- `start`: start parameter
- `stop`: stop parameter

The `start` and `stop` parameters allow evaluation of a curve segment in the range *[start, stop]*, i.e. the curve will also be evaluated at the `stop` parameter value.

The following examples illustrate the usage of the keyword arguments.

```
# Start evaluating from u=0.2 to u=1.0
curve.evaluate(start=0.2)

# Start evaluating from u=0.0 to u=0.7
curve.evaluate(stop=0.7)

# Start evaluating from u=0.1 to u=0.5
curve.evaluate(start=0.1, stop=0.5)

# Get the evaluated points
curve_points = curve.evalpts
```

evaluate_list(*param_list*)
Evaluates the curve for an input range of parameters.

Parameters **param_list** (*list, tuple*) – list of parameters

Returns evaluated surface points at the input parameters

Return type list

evaluate_single(*param*)
Evaluates the curve at the input parameter.

Parameters **param** (*float*) – parameter

Returns evaluated surface point at the given parameter

Return type list

evaluator
Evaluator instance.

Evaluators allow users to use different algorithms for B-Spline and NURBS evaluations. Please see the documentation on `Evaluator` classes.

Please refer to the wiki for details on using this class member.

Getter Gets the current Evaluator instance

Setter Sets the Evaluator instance

Type *evaluators.AbstractEvaluator*

id

Object ID (as an integer).

Please refer to the wiki for details on using this class member.

Getter Gets the object ID

Setter Sets the object ID

Type int

insert_knot (*param*, ***kwargs*)

Inserts the knot and updates the control points array and the knot vector.

Keyword Arguments:

- `num`: Number of knot insertions. *Default: 1*

Parameters **param** (*float*) – knot to be inserted

knotvector

Knot vector.

The knot vector will be normalized to [0, 1] domain if the class is initialized with `normalize_kv=True` argument.

Please refer to the wiki for details on using this class member.

Getter Gets the knot vector

Setter Sets the knot vector

Type list

load (*file_name*)

Loads the curve from a pickled file.

Deprecated since version 5.2.4: Use *exchange.import_json()* instead.

Parameters **file_name** (*str*) – name of the file to be loaded

name

Object name (as a string)

Please refer to the wiki for details on using this class member.

Getter Gets the object name

Setter Sets the object name

Type str

normal (*parpos*, ***kwargs*)

Evaluates the normal to the tangent vector of the curve at the given parametric position(s).

Parameters **parpos** (*float, list or tuple*) – parametric position(s) where the evaluation will be executed

Returns normal vector as a tuple of the origin point and the vector components

Return type tuple

opt

Dictionary for storing custom data in the current geometry object.

`opt` is a wrapper to a dict in *key* => *value* format, where *key* is string, *value* is any Python object. You can use `opt` property to store custom data inside the geometry object. For instance:

```
geom.opt = ["face_id", 4]  # creates "face_id" key and sets its value to an␣
↪integer
geom.opt = ["contents", "data values"]  # creates "face_id" key and sets its␣
↪value to a string
print(geom.opt)  # will print: {'face_id': 4, 'contents': 'data values'}

del geom.opt  # deletes the contents of the hash map
print(geom.opt)  # will print: {}

geom.opt = ["body_id", 1]  # creates "body_id" key  and sets its value to 1
geom.opt = ["body_id", 12]  # changes the value of "body_id" to 12
print(geom.opt)  # will print: {'body_id': 12}

geom.opt = ["body_id", None]  # deletes "body_id"
print(geom.opt)  # will print: {}
```

Please refer to the wiki for details on using this class member.

Getter Gets the dict

Setter Adds key and value pair to the dict

Deleter Deletes the contents of the dict

opt_get (*value*)

Safely query for the value from the `opt` property.

Parameters **value** (*str*) – a key in the `opt` property

Returns the corresponding value, if the key exists. `None`, otherwise.

order

Order.

Defined as `order = degree + 1`

Please refer to the wiki for details on using this class member.

Getter Gets the order

Setter Sets the order

Type int

pdimension

Parametric dimension.

Please refer to the wiki for details on using this class member.

Getter Gets the parametric dimension

Type int

range
Domain range.

Getter Gets the range

rational
Defines the rational and non-rational B-spline shapes.

Rational shapes use homogeneous coordinates which includes a weight alongside with the Cartesian coordinates. Rational B-splines are also named as NURBS (Non-uniform rational basis spline) and non-rational B-splines are sometimes named as NUBS (Non-uniform basis spline) or directly as B-splines.

Please refer to the wiki for details on using this class member.

Getter Returns True is the B-spline object is rational (NURBS)

Type bool

remove_knot (*param*, ***kwargs*)
Removes the knot and updates the control points array and the knot vector.

Keyword Arguments:

- `num`: Number of knot removals. *Default: 1*

Parameters **param** (*float*) – knot to be removed

render (***kwargs*)
Renders the curve using the visualization component

The visualization component must be set using `vis` property before calling this method.

Keyword Arguments:

- `cpcolor`: sets the color of the control points polygon
- `evalcolor`: sets the color of the curve
- `bboxcolor`: sets the color of the bounding box
- `filename`: saves the plot with the input name
- `plot`: controls plot window visibility. *Default: True*
- `animate`: activates animation (if supported). *Default: False*
- `extras`: adds line plots to the figure. *Default: None*

`plot` argument is useful when you would like to work on the command line without any window context. If `plot` flag is False, this method saves the plot as an image file (.png file where possible) and disables plot window popping out. If you don't provide a file name, the name of the image file will be pulled from the configuration class.

`extras` argument can be used to add extra line plots to the figure. This argument expects a list of dicts in the format described below:

```
[
    dict(  # line plot 1
        points=[[1, 2, 3], [4, 5, 6]],  # list of points
        name="My line Plot 1",  # name displayed on the legend
        color="red",  # color of the line plot
        size=6.5  # size of the line plot
    ),
    dict(  # line plot 2
```

(continues on next page)

(continued from previous page)

```
        points=[[7, 8, 9], [10, 11, 12]],  # list of points
        name="My line Plot 2",  # name displayed on the legend
        color="navy",   # color of the line plot
        size=12.5  # size of the line plot
    )
]
```

Returns the figure object

reset (***kwargs*)
Resets control points and/or evaluated points.

Keyword Arguments:

- `evalpts`: if True, then resets evaluated points
- `ctrlpts` if True, then resets control points

reverse ()
Reverses the curve

sample_size
Sample size.

Sample size defines the number of evaluated points to generate. It also sets the `delta` property.

The following figure illustrates the working principles of sample size property:

$$\underbrace{[u_{start}, \ldots, u_{end}]}_{n_{sample}}$$

Please refer to the wiki for details on using this class member.

Getter Gets sample size

Setter Sets sample size

Type int

save (*file_name*)
Saves the curve as a pickled file.

Deprecated since version 5.2.4: Use *exchange.export_json()* instead.

Parameters **file_name** (*str*) – name of the file to be saved

set_ctrlpts (*ctrlpts*, **args*, ***kwargs*)
Sets control points and checks if the data is consistent.

This method is designed to provide a consistent way to set control points whether they are weighted or not. It directly sets the control points member of the class, and therefore it doesn't return any values. The input will be an array of coordinates. If you are working in the 3-dimensional space, then your coordinates will be an array of 3 elements representing *(x, y, z)* coordinates.

Parameters **ctrlpts** (*list*) – input control points as a list of coordinates

tangent (*parpos*, ***kwargs*)
Evaluates the tangent vector of the curve at the given parametric position(s).

Parameters **parpos** (*float, list or tuple*) – parametric position(s) where the evaluation will be executed

Returns tangent vector as a tuple of the origin point and the vector components

Return type tuple

type
Geometry type

Please refer to the wiki for details on using this class member.

Getter Gets the geometry type

Type str

vis
Visualization component.

Please refer to the wiki for details on using this class member.

Getter Gets the visualization component

Setter Sets the visualization component

Type vis.VisAbstract

weights
Weights.

Note: Only available for rational spline geometries. Getter return `None` otherwise.

Please refer to the wiki for details on using this class member.

Getter Gets the weights

Setter Sets the weights

B-Spline Surface

class geomdl.BSpline.**Surface**(***kwargs*)
Bases: *geomdl.abstract.Surface*

Data storage and evaluation class for B-spline (non-rational) surfaces.

This class provides the following properties:

- *type* = spline
- *id*
- *order_u*
- *order_v*
- *degree_u*
- *degree_v*
- *knotvector_u*
- *knotvector_v*
- *ctrlpts*
- *ctrlpts_size_u*
- *ctrlpts_size_v*
- *ctrlpts2d*

- *delta*
- *delta_u*
- *delta_v*
- *sample_size*
- *sample_size_u*
- *sample_size_v*
- *bbox*
- *name*
- *dimension*
- *vis*
- *evaluator*
- *tessellator*
- *rational*
- *trims*

The following code segment illustrates the usage of Surface class:

```
from geomdl import BSpline

# Create a BSpline surface instance (Bezier surface)
surf = BSpline.Surface()

# Set degrees
surf.degree_u = 3
surf.degree_v = 2

# Set control points
control_points = [[0, 0, 0], [0, 4, 0], [0, 8, -3],
                  [2, 0, 6], [2, 4, 0], [2, 8, 0],
                  [4, 0, 0], [4, 4, 0], [4, 8, 3],
                  [6, 0, 0], [6, 4, -3], [6, 8, 0]]
surf.set_ctrlpts(control_points, 4, 3)

# Set knot vectors
surf.knotvector_u = [0, 0, 0, 0, 1, 1, 1, 1]
surf.knotvector_v = [0, 0, 0, 1, 1, 1]

# Set evaluation delta (control the number of surface points)
surf.delta = 0.05

# Get surface points (the surface will be automatically evaluated)
surface_points = surf.evalpts
```

Keyword Arguments:

- `precision`: number of decimal places to round to. *Default: 18*
- `normalize_kv`: activates knot vector normalization. *Default: True*
- `find_span_func`: sets knot span search implementation. *Default:* *helpers.find_span_linear()*

- `insert_knot_func`: sets knot insertion implementation. *Default:* `operations.insert_knot()`
- `remove_knot_func`: sets knot removal implementation. *Default:* `operations.remove_knot()`

Please refer to the `abstract.Surface()` documentation for more details.

add_trim(*trim*)

Adds a trim to the surface.

A trim is a 2-dimensional curve defined on the parametric domain of the surface. Therefore, x-coordinate of the trimming curve corresponds to u parametric direction of the surfaceand y-coordinate of the trimming curve corresponds to v parametric direction of the surface.

`trims` uses this method to add trims to the surface.

Parameters **trim** (`abstract.Geometry`) – surface trimming curve

bbox

Bounding box.

Evaluates the bounding box and returns the minimum and maximum coordinates.

Please refer to the wiki for details on using this class member.

Getter Gets the bounding box

Type tuple

cpsize

Number of control points in all parametric directions.

Note: This is an expert property for getting and setting control point size(s) of the geometry.

Please refer to the wiki for details on using this class member.

Getter Gets the number of control points

Setter Sets the number of control points

Type list

ctrlpts

1-dimensional array of control points.

Note: The v index varies first. That is, a row of v control points for the first u value is found first. Then, the row of v control points for the next u value.

Please refer to the wiki for details on using this class member.

Getter Gets the control points

Setter Sets the control points

Type list

ctrlpts2d

2-dimensional array of control points.

The getter returns a tuple of 2D control points (weighted control points + weights if NURBS) in *[u][v]* format. The rows of the returned tuple correspond to v-direction and the columns correspond to u-direction.

The following example can be used to traverse 2D control points:

```
# Create a BSpline surface
surf_bs = BSpline.Surface()

# Do degree, control points and knot vector assignments here

# Each u includes a row of v values
for u in surf_bs.ctrlpts2d:
    # Each row contains the coordinates of the control points
    for v in u:
        print(str(v))  # will be something like (1.0, 2.0, 3.0)

# Create a NURBS surface
surf_nb = NURBS.Surface()

# Do degree, weighted control points and knot vector assignments here

# Each u includes a row of v values
for u in surf_nb.ctrlpts2d:
    # Each row contains the coordinates of the weighted control points
    for v in u:
        print(str(v))  # will be something like (0.5, 1.0, 1.5, 0.5)
```

When using **NURBS.Surface** class, the output of `ctrlpts2d` property could be confusing since, `ctrlpts` always returns the unweighted control points, i.e. `ctrlpts` property returns 3D control points all divided by the weights and you can use `weights` property to access the weights vector, but `ctrlpts2d` returns the weighted ones plus weights as the last element. This difference is intentionally added for compatibility and interoperability purposes.

To explain this situation in a simple way;

- If you need the weighted control points directly, use `ctrlpts2d`
- If you need the control points and the weights separately, use `ctrlpts` and `weights`

Note: Please note that the setter doesn't check for inconsistencies and using the setter is not recommended. Instead of the setter property, please use `set_ctrlpts()` function.

Please refer to the wiki for details on using this class member.

Getter Gets the control points as a 2-dimensional array in [u][v] format

Setter Sets the control points as a 2-dimensional array in [u][v] format

Type list

ctrlpts_size

Total number of control points.

Getter Gets the total number of control points

Type int

ctrlpts_size_u

Number of control points for the u-direction.

Please refer to the wiki for details on using this class member.

Getter Gets number of control points for the u-direction

Setter Sets number of control points for the u-direction

ctrlpts_size_v

Number of control points for the v-direction.

Please refer to the wiki for details on using this class member.

Getter Gets number of control points on the v-direction

Setter Sets number of control points on the v-direction

data

Returns a dict which contains the geometry data.

Please refer to the wiki for details on using this class member.

degree

Degree for u- and v-directions

Getter Gets the degree

Setter Sets the degree

Type list

degree_u

Degree for the u-direction.

Please refer to the wiki for details on using this class member.

Getter Gets degree for the u-direction

Setter Sets degree for the u-direction

Type int

degree_v

Degree for the v-direction.

Please refer to the wiki for details on using this class member.

Getter Gets degree for the v-direction

Setter Sets degree for the v-direction

Type int

delta

Evaluation delta for both u- and v-directions.

Evaluation delta corresponds to the *step size* while `evaluate()` function iterates on the knot vector to generate surface points. Decreasing step size results in generation of more surface points. Therefore; smaller the delta value, smoother the surface.

Please note that `delta` and `sample_size` properties correspond to the same variable with different descriptions. Therefore, setting `delta` will also set `sample_size`.

The following figure illustrates the working principles of the delta property:

$$[u_0, u_{start} + \delta, (u_{start} + \delta) + \delta, \dots, u_{end}]$$

Please refer to the wiki for details on using this class member.

Getter Gets evaluation delta as a tuple of values corresponding to u- and v-directions

Setter Sets evaluation delta for both u- and v-directions

Type float

delta_u

Evaluation delta for the u-direction.

Evaluation delta corresponds to the *step size* while `evaluate()` function iterates on the knot vector to generate surface points. Decreasing step size results in generation of more surface points. Therefore; smaller the delta value, smoother the surface.

Please note that `delta_u` and `sample_size_u` properties correspond to the same variable with different descriptions. Therefore, setting `delta_u` will also set `sample_size_u`.

Please refer to the wiki for details on using this class member.

Getter Gets evaluation delta for the u-direction

Setter Sets evaluation delta for the u-direction

Type float

delta_v

Evaluation delta for the v-direction.

Evaluation delta corresponds to the *step size* while `evaluate()` function iterates on the knot vector to generate surface points. Decreasing step size results in generation of more surface points. Therefore; smaller the delta value, smoother the surface.

Please note that `delta_v` and `sample_size_v` properties correspond to the same variable with different descriptions. Therefore, setting `delta_v` will also set `sample_size_v`.

Please refer to the wiki for details on using this class member.

Getter Gets evaluation delta for the v-direction

Setter Sets evaluation delta for the v-direction

Type float

derivatives (*u*, *v*, *order=0*, ***kwargs*)

Evaluates n-th order surface derivatives at the given (u, v) parameter pair.

- SKL[0][0] will be the surface point itself
- SKL[0][1] will be the 1st derivative w.r.t. v
- SKL[2][1] will be the 2nd derivative w.r.t. u and 1st derivative w.r.t. v

Parameters

- **u** (*float*) – parameter on the u-direction
- **v** (*float*) – parameter on the v-direction
- **order** (*integer*) – derivative order

Returns A list SKL, where SKL[k][l] is the derivative of the surface S(u,v) w.r.t. u k times and v l times

Return type list

dimension

Spatial dimension.

Spatial dimension will be automatically estimated from the first element of the control points array.

Please refer to the wiki for details on using this class member.

Getter Gets the spatial dimension, e.g. 2D, 3D, etc.

Type int

domain

Domain.

Domain is determined using the knot vector(s).

Getter Gets the domain

evalpts

Evaluated points.

Please refer to the wiki for details on using this class member.

Getter Gets the coordinates of the evaluated points

Type list

evaluate(***kwargs*)

Evaluates the surface.

The evaluated points are stored in `evalpts` property.

Keyword arguments:

- `start_u`: start parameter on the u-direction
- `stop_u`: stop parameter on the u-direction
- `start_v`: start parameter on the v-direction
- `stop_v`: stop parameter on the v-direction

The `start_u`, `start_v` and `stop_u` and `stop_v` parameters allow evaluation of a surface segment in the range *[start_u, stop_u][start_v, stop_v]* i.e. the surface will also be evaluated at the `stop_u` and `stop_v` parameter values.

The following examples illustrate the usage of the keyword arguments.

```
# Start evaluating in range u=[0, 0.7] and v=[0.1, 1]
surf.evaluate(stop_u=0.7, start_v=0.1)

# Start evaluating in range u=[0, 1] and v=[0.1, 0.3]
surf.evaluate(start_v=0.1, stop_v=0.3)

# Get the evaluated points
surface_points = surf.evalpts
```

evaluate_list(*param_list*)

Evaluates the surface for a given list of (u, v) parameters.

Parameters **param_list** (*list, tuple*) – list of parameter pairs (u, v)

Returns evaluated surface point at the input parameter pairs

Return type tuple

evaluate_single(*param*)

Evaluates the surface at the input (u, v) parameter pair.

Parameters **param** (*list, tuple*) – parameter pair (u, v)

Returns evaluated surface point at the given parameter pair

Return type list

evaluator

Evaluator instance.

Evaluators allow users to use different algorithms for B-Spline and NURBS evaluations. Please see the documentation on `Evaluator` classes.

Please refer to the wiki for details on using this class member.

Getter Gets the current Evaluator instance

Setter Sets the Evaluator instance

Type *evaluators.AbstractEvaluator*

faces

Faces (triangles, quads, etc.) generated by the tessellation operation.

If the tessellation component is set to None, the result will be an empty list.

Getter Gets the faces

id

Object ID (as an integer).

Please refer to the wiki for details on using this class member.

Getter Gets the object ID

Setter Sets the object ID

Type int

insert_knot (*u=None*, *v=None*, ***kwargs*)

Inserts knot(s) on the u- or v-directions

Keyword Arguments:

- `num_u`: Number of knot insertions on the u-direction. *Default: 1*
- `num_v`: Number of knot insertions on the v-direction. *Default: 1*

Parameters

- **u** (*float*) – knot to be inserted on the u-direction
- **v** (*float*) – knot to be inserted on the v-direction

knotvector

Knot vector for u- and v-directions

Getter Gets the knot vector

Setter Sets the knot vector

Type list

knotvector_u

Knot vector for the u-direction.

The knot vector will be normalized to [0, 1] domain if the class is initialized with `normalize_kv=True` argument.

Please refer to the wiki for details on using this class member.

Getter Gets knot vector for the u-direction

Setter Sets knot vector for the u-direction

Type list

knotvector_v
Knot vector for the v-direction.

The knot vector will be normalized to [0, 1] domain if the class is initialized with `normalize_kv=True` argument.

Please refer to the wiki for details on using this class member.

Getter Gets knot vector for the v-direction

Setter Sets knot vector for the v-direction

Type list

load (*file_name*)
Loads the surface from a pickled file.

Deprecated since version 5.2.4: Use `exchange.import_json()` instead.

Parameters **file_name** (`str`) – name of the file to be loaded

name
Object name (as a string)

Please refer to the wiki for details on using this class member.

Getter Gets the object name

Setter Sets the object name

Type str

normal (*parpos*, ***kwargs*)
Evaluates the normal vector of the surface at the given parametric position(s).

Parameters **parpos** (`list or tuple`) – parametric position(s) where the evaluation will be executed

Returns an array containing "point" and "vector" pairs

Return type tuple

opt
Dictionary for storing custom data in the current geometry object.

`opt` is a wrapper to a dict in *key* => *value* format, where *key* is string, *value* is any Python object. You can use `opt` property to store custom data inside the geometry object. For instance:

```
geom.opt = ["face_id", 4]  # creates "face_id" key and sets its value to an␣
↪integer
geom.opt = ["contents", "data values"]  # creates "face_id" key and sets its␣
↪value to a string
print(geom.opt)  # will print: {'face_id': 4, 'contents': 'data values'}

del geom.opt  # deletes the contents of the hash map
print(geom.opt)  # will print: {}

geom.opt = ["body_id", 1]  # creates "body_id" key  and sets its value to 1
geom.opt = ["body_id", 12]  # changes the value of "body_id" to 12
print(geom.opt)  # will print: {'body_id': 12}

geom.opt = ["body_id", None]  # deletes "body_id"
print(geom.opt)  # will print: {}
```

Please refer to the wiki for details on using this class member.

Getter Gets the dict

Setter Adds key and value pair to the dict

Deleter Deletes the contents of the dict

`opt_get` (*value*)

Safely query for the value from the `opt` property.

Parameters **`value`** (`str`) – a key in the `opt` property

Returns the corresponding value, if the key exists. `None`, otherwise.

`order_u`

Order for the u-direction.

Defined as `order = degree + 1`

Please refer to the wiki for details on using this class member.

Getter Gets order for the u-direction

Setter Sets order for the u-direction

Type int

`order_v`

Order for the v-direction.

Defined as `order = degree + 1`

Please refer to the wiki for details on using this class member.

Getter Gets surface order for the v-direction

Setter Sets surface order for the v-direction

Type int

`pdimension`

Parametric dimension.

Please refer to the wiki for details on using this class member.

Getter Gets the parametric dimension

Type int

`range`

Domain range.

Getter Gets the range

`rational`

Defines the rational and non-rational B-spline shapes.

Rational shapes use homogeneous coordinates which includes a weight alongside with the Cartesian coordinates. Rational B-splines are also named as NURBS (Non-uniform rational basis spline) and non-rational B-splines are sometimes named as NUBS (Non-uniform basis spline) or directly as B-splines.

Please refer to the wiki for details on using this class member.

Getter Returns True is the B-spline object is rational (NURBS)

Type bool

remove_knot (*u=None*, *v=None*, ***kwargs*)
Inserts knot(s) on the u- or v-directions

Keyword Arguments:

- `num_u`: Number of knot removals on the u-direction. *Default: 1*
- `num_v`: Number of knot removals on the v-direction. *Default: 1*

Parameters

- **u** (*float*) – knot to be removed on the u-direction
- **v** (*float*) – knot to be removed on the v-direction

render (***kwargs*)
Renders the surface using the visualization component.

The visualization component must be set using `vis` property before calling this method.

Keyword Arguments:

- `cpcolor`: sets the color of the control points grid
- `evalcolor`: sets the color of the surface
- `trimcolor`: sets the color of the trim curves
- `filename`: saves the plot with the input name
- `plot`: controls plot window visibility. *Default: True*
- `animate`: activates animation (if supported). *Default: False*
- `extras`: adds line plots to the figure. *Default: None*
- `colormap`: sets the colormap of the surface

The `plot` argument is useful when you would like to work on the command line without any window context. If `plot` flag is False, this method saves the plot as an image file (.png file where possible) and disables plot window popping out. If you don't provide a file name, the name of the image file will be pulled from the configuration class.

`extras` argument can be used to add extra line plots to the figure. This argument expects a list of dicts in the format described below:

```
[
    dict(  # line plot 1
        points=[[1, 2, 3], [4, 5, 6]],  # list of points
        name="My line Plot 1",  # name displayed on the legend
        color="red",   # color of the line plot
        size=6.5  # size of the line plot
    ),
    dict(  # line plot 2
        points=[[7, 8, 9], [10, 11, 12]],  # list of points
        name="My line Plot 2",  # name displayed on the legend
        color="navy",   # color of the line plot
        size=12.5  # size of the line plot
    )
]
```

Please note that `colormap` argument can only work with visualization classes that support colormaps. As an example, please see `VisMPL.VisSurfTriangle()` class documentation. This method expects a single colormap input.

Returns the figure object

reset (***kwargs*)
Resets control points and/or evaluated points.

Keyword Arguments:

- `evalpts`: if True, then resets evaluated points
- `ctrlpts` if True, then resets control points

sample_size
Sample size for both u- and v-directions.

Sample size defines the number of surface points to generate. It also sets the `delta` property.

The following figure illustrates the working principles of sample size property:

$$\underbrace{[u_{start}, \ldots, u_{end}]}_{n_{sample}}$$

Please refer to the wiki for details on using this class member.

Getter Gets sample size as a tuple of values corresponding to u- and v-directions

Setter Sets sample size for both u- and v-directions

Type int

sample_size_u
Sample size for the u-direction.

Sample size defines the number of surface points to generate. It also sets the `delta_u` property.

Please refer to the wiki for details on using this class member.

Getter Gets sample size for the u-direction

Setter Sets sample size for the u-direction

Type int

sample_size_v
Sample size for the v-direction.

Sample size defines the number of surface points to generate. It also sets the `delta_v` property.

Please refer to the wiki for details on using this class member.

Getter Gets sample size for the v-direction

Setter Sets sample size for the v-direction

Type int

save (*file_name*)
Saves the surface as a pickled file.

Deprecated since version 5.2.4: Use *`exchange.export_json()`* instead.

Parameters **`file_name`** (*`str`*) – name of the file to be saved

set_ctrlpts (*ctrlpts*, **args*, ***kwargs*)
Sets the control points and checks if the data is consistent.

This method is designed to provide a consistent way to set control points whether they are weighted or not. It directly sets the control points member of the class, and therefore it doesn't return any values. The input will be an array of coordinates. If you are working in the 3-dimensional space, then your coordinates will be an array of 3 elements representing *(x, y, z)* coordinates.

This method also generates 2D control points in *[u][v]* format which can be accessed via `ctrlpts2d`.

Note: The v index varies first. That is, a row of v control points for the first u value is found first. Then, the row of v control points for the next u value.

Parameters **ctrlpts** (*list*) – input control points as a list of coordinates

tangent (*parpos*, ***kwargs*)
Evaluates the tangent vectors of the surface at the given parametric position(s).

Parameters **parpos** (*list or tuple*) – parametric position(s) where the evaluation will be executed

Returns an array containing "point" and "vector"s on u- and v-directions, respectively

Return type tuple

tessellate (***kwargs*)
Tessellates the surface.

Keyword arguments are directly passed to the tessellation component.

tessellator
Tessellation component.

Please refer to the wiki for details on using this class member.

Getter Gets the tessellation component

Setter Sets the tessellation component

transpose ()
Transposes the surface by swapping u and v parametric directions.

trims
Curves for trimming the surface.

Surface trims are 2-dimensional curves which are introduced on the parametric space of the surfaces. Trim curves can be a spline curve, an analytic curve or a 2-dimensional freeform shape. To visualize the trimmed surfaces, you need to use a tessellator that supports trimming. The following code snippet illustrates changing the default surface tessellator to the trimmed surface tessellator, `tessellate.TrimTessellate`.

```
from geomdl import tessellate

# Assuming that "surf" variable stores the surface instance
surf.tessellator = tessellate.TrimTessellate()
```

In addition, using *trims* initialization argument of the visualization classes, trim curves can be visualized together with their underlying surfaces. Please refer to the visualization configuration class initialization arguments for more details.

Please refer to the wiki for details on using this class member.

Getter Gets the array of trim curves

Setter Sets the array of trim curves

type
Geometry type

Please refer to the wiki for details on using this class member.

Getter Gets the geometry type

Type str

vertices
Vertices generated by the tessellation operation.

If the tessellation component is set to None, the result will be an empty list.

Getter Gets the vertices

vis
Visualization component.

Please refer to the wiki for details on using this class member.

Getter Gets the visualization component

Setter Sets the visualization component

Type vis.VisAbstract

weights
Weights.

Note: Only available for rational spline geometries. Getter return `None` otherwise.

Please refer to the wiki for details on using this class member.

Getter Gets the weights

Setter Sets the weights

B-Spline Volume

New in version 5.0.

class geomdl.BSpline.**Volume**(***kwargs*)
Bases: *geomdl.abstract.Volume*

Data storage and evaluation class for B-spline (non-rational) volumes.

This class provides the following properties:

- *type* = spline
- *id*
- *order_u*
- *order_v*
- *order_w*
- *degree_u*
- *degree_v*
- *degree_w*

- *knotvector_u*
- *knotvector_v*
- *knotvector_w*
- *ctrlpts*
- *ctrlpts_size_u*
- *ctrlpts_size_v*
- *ctrlpts_size_w*
- *delta*
- *delta_u*
- *delta_v*
- *delta_w*
- *sample_size*
- *sample_size_u*
- *sample_size_v*
- *sample_size_w*
- *bbox*
- *name*
- *dimension*
- *vis*
- *evaluator*
- *rational*

Keyword Arguments:

- `precision`: number of decimal places to round to. *Default: 18*
- `normalize_kv`: activates knot vector normalization. *Default: True*
- `find_span_func`: sets knot span search implementation. *Default:* *helpers.find_span_linear()*
- `insert_knot_func`: sets knot insertion implementation. *Default:* *operations.insert_knot()*
- `remove_knot_func`: sets knot removal implementation. *Default:* *operations.remove_knot()*

Please refer to the *abstract.Volume()* documentation for more details.

add_trim(*trim*)

Adds a trim to the volume.

trims uses this method to add trims to the volume.

Parameters **trim** (abstract.Surface) – trimming surface

bbox

Bounding box.

Evaluates the bounding box and returns the minimum and maximum coordinates.

Please refer to the wiki for details on using this class member.

Getter Gets the bounding box

Type tuple

cpsize

Number of control points in all parametric directions.

Note: This is an expert property for getting and setting control point size(s) of the geometry.

Please refer to the wiki for details on using this class member.

Getter Gets the number of control points

Setter Sets the number of control points

Type list

ctrlpts

1-dimensional array of control points.

Please refer to the wiki for details on using this class member.

Getter Gets the control points

Setter Sets the control points

Type list

ctrlpts_size

Total number of control points.

Getter Gets the total number of control points

Type int

ctrlpts_size_u

Number of control points for the u-direction.

Please refer to the wiki for details on using this class member.

Getter Gets number of control points for the u-direction

Setter Sets number of control points for the u-direction

ctrlpts_size_v

Number of control points for the v-direction.

Please refer to the wiki for details on using this class member.

Getter Gets number of control points for the v-direction

Setter Sets number of control points for the v-direction

ctrlpts_size_w

Number of control points for the w-direction.

Please refer to the wiki for details on using this class member.

Getter Gets number of control points for the w-direction

Setter Sets number of control points for the w-direction

data
Returns a dict which contains the geometry data.

Please refer to the wiki for details on using this class member.

degree
Degree for u-, v- and w-directions

Getter Gets the degree

Setter Sets the degree

Type list

degree_u
Degree for the u-direction.

Please refer to the wiki for details on using this class member.

Getter Gets degree for the u-direction

Setter Sets degree for the u-direction

Type int

degree_v
Degree for the v-direction.

Please refer to the wiki for details on using this class member.

Getter Gets degree for the v-direction

Setter Sets degree for the v-direction

Type int

degree_w
Degree for the w-direction.

Please refer to the wiki for details on using this class member.

Getter Gets degree for the w-direction

Setter Sets degree for the w-direction

Type int

delta
Evaluation delta for u-, v- and w-directions.

Evaluation delta corresponds to the *step size* while `evaluate()` function iterates on the knot vector to generate surface points. Decreasing step size results in generation of more surface points. Therefore; smaller the delta value, smoother the surface.

Please note that `delta` and `sample_size` properties correspond to the same variable with different descriptions. Therefore, setting `delta` will also set `sample_size`.

The following figure illustrates the working principles of the delta property:

$$[u_0, u_{start} + \delta, (u_{start} + \delta) + \delta, \dots, u_{end}]$$

Please refer to the wiki for details on using this class member.

Getter Gets evaluation delta as a tuple of values corresponding to u-, v- and w-directions

Setter Sets evaluation delta for u-, v- and w-directions

Type float

delta_u

Evaluation delta for the u-direction.

Evaluation delta corresponds to the *step size* while `evaluate()` function iterates on the knot vector to generate surface points. Decreasing step size results in generation of more surface points. Therefore; smaller the delta value, smoother the surface.

Please note that `delta_u` and `sample_size_u` properties correspond to the same variable with different descriptions. Therefore, setting `delta_u` will also set `sample_size_u`.

Please refer to the wiki for details on using this class member.

Getter Gets evaluation delta for the u-direction

Setter Sets evaluation delta for the u-direction

Type float

delta_v

Evaluation delta for the v-direction.

Evaluation delta corresponds to the *step size* while `evaluate()` function iterates on the knot vector to generate surface points. Decreasing step size results in generation of more surface points. Therefore; smaller the delta value, smoother the surface.

Please note that `delta_v` and `sample_size_v` properties correspond to the same variable with different descriptions. Therefore, setting `delta_v` will also set `sample_size_v`.

Please refer to the wiki for details on using this class member.

Getter Gets evaluation delta for the v-direction

Setter Sets evaluation delta for the v-direction

Type float

delta_w

Evaluation delta for the w-direction.

Evaluation delta corresponds to the *step size* while `evaluate()` function iterates on the knot vector to generate surface points. Decreasing step size results in generation of more surface points. Therefore; smaller the delta value, smoother the surface.

Please note that `delta_w` and `sample_size_w` properties correspond to the same variable with different descriptions. Therefore, setting `delta_w` will also set `sample_size_w`.

Please refer to the wiki for details on using this class member.

Getter Gets evaluation delta for the w-direction

Setter Sets evaluation delta for the w-direction

Type float

dimension

Spatial dimension.

Spatial dimension will be automatically estimated from the first element of the control points array.

Please refer to the wiki for details on using this class member.

Getter Gets the spatial dimension, e.g. 2D, 3D, etc.

Type int

domain
Domain.

Domain is determined using the knot vector(s).

Getter Gets the domain

evalpts
Evaluated points.

Please refer to the wiki for details on using this class member.

Getter Gets the coordinates of the evaluated points

Type list

evaluate(***kwargs*)
Evaluates the volume.

The evaluated points are stored in `evalpts` property.

Keyword arguments:

- `start_u`: start parameter on the u-direction
- `stop_u`: stop parameter on the u-direction
- `start_v`: start parameter on the v-direction
- `stop_v`: stop parameter on the v-direction
- `start_w`: start parameter on the w-direction
- `stop_w`: stop parameter on the w-direction

evaluate_list(*param_list*)
Evaluates the volume for a given list of (u, v, w) parameters.

Parameters **param_list** (`list, tuple`) – list of parameters in format (u, v, w)

Returns evaluated surface point at the input parameter pairs

Return type tuple

evaluate_single(*param*)
Evaluates the volume at the input (u, v, w) parameter.

Parameters **param** (`list, tuple`) – parameter (u, v, w)

Returns evaluated surface point at the given parameter pair

Return type list

evaluator
Evaluator instance.

Evaluators allow users to use different algorithms for B-Spline and NURBS evaluations. Please see the documentation on `Evaluator` classes.

Please refer to the wiki for details on using this class member.

Getter Gets the current Evaluator instance

Setter Sets the Evaluator instance

Type *evaluators.AbstractEvaluator*

id
Object ID (as an integer).

Please refer to the wiki for details on using this class member.

Getter Gets the object ID

Setter Sets the object ID

Type int

insert_knot (*u=None*, *v=None*, *w=None*, ***kwargs*)
Inserts knot(s) on the u-, v- and w-directions

Keyword Arguments:

- `num_u`: Number of knot insertions on the u-direction. *Default: 1*
- `num_v`: Number of knot insertions on the v-direction. *Default: 1*
- `num_w`: Number of knot insertions on the w-direction. *Default: 1*

Parameters

- **u** (*float*) – knot to be inserted on the u-direction
- **v** (*float*) – knot to be inserted on the v-direction
- **w** (*float*) – knot to be inserted on the w-direction

knotvector
Knot vector for u-, v- and w-directions

Getter Gets the knot vector

Setter Sets the knot vector

Type list

knotvector_u
Knot vector for the u-direction.

The knot vector will be normalized to [0, 1] domain if the class is initialized with `normalize_kv=True` argument.

Please refer to the wiki for details on using this class member.

Getter Gets knot vector for the u-direction

Setter Sets knot vector for the u-direction

Type list

knotvector_v
Knot vector for the v-direction.

The knot vector will be normalized to [0, 1] domain if the class is initialized with `normalize_kv=True` argument.

Please refer to the wiki for details on using this class member.

Getter Gets knot vector for the v-direction

Setter Sets knot vector for the v-direction

Type list

knotvector_w
Knot vector for the w-direction.

The knot vector will be normalized to [0, 1] domain if the class is initialized with `normalize_kv=True` argument.

Please refer to the wiki for details on using this class member.

Getter Gets knot vector for the w-direction

Setter Sets knot vector for the w-direction

Type list

load (*file_name*)
Loads the volume from a pickled file.

Deprecated since version 5.2.4: Use `exchange.import_json()` instead.

Parameters **file_name** (`str`) – name of the file to be loaded

name
Object name (as a string)

Please refer to the wiki for details on using this class member.

Getter Gets the object name

Setter Sets the object name

Type str

opt
Dictionary for storing custom data in the current geometry object.

`opt` is a wrapper to a dict in *key* => *value* format, where *key* is string, *value* is any Python object. You can use `opt` property to store custom data inside the geometry object. For instance:

```
geom.opt = ["face_id", 4]  # creates "face_id" key and sets its value to an integer
geom.opt = ["contents", "data values"]  # creates "face_id" key and sets its value to a string
print(geom.opt)  # will print: {'face_id': 4, 'contents': 'data values'}

del geom.opt  # deletes the contents of the hash map
print(geom.opt)  # will print: {}

geom.opt = ["body_id", 1]  # creates "body_id" key  and sets its value to 1
geom.opt = ["body_id", 12]  # changes the value of "body_id" to 12
print(geom.opt)  # will print: {'body_id': 12}

geom.opt = ["body_id", None]  # deletes "body_id"
print(geom.opt)  # will print: {}
```

Please refer to the wiki for details on using this class member.

Getter Gets the dict

Setter Adds key and value pair to the dict

Deleter Deletes the contents of the dict

opt_get (*value*)
Safely query for the value from the `opt` property.

Parameters **value** (*str*) – a key in the *opt* property

Returns the corresponding value, if the key exists. None, otherwise.

order_u
Order for the u-direction.

Defined as order = degree + 1

Please refer to the wiki for details on using this class member.

Getter Gets the surface order for u-direction

Setter Sets the surface order for u-direction

Type int

order_v
Order for the v-direction.

Defined as order = degree + 1

Please refer to the wiki for details on using this class member.

Getter Gets the surface order for v-direction

Setter Sets the surface order for v-direction

Type int

order_w
Order for the w-direction.

Defined as order = degree + 1

Please refer to the wiki for details on using this class member.

Getter Gets the surface order for v-direction

Setter Sets the surface order for v-direction

Type int

pdimension
Parametric dimension.

Please refer to the wiki for details on using this class member.

Getter Gets the parametric dimension

Type int

range
Domain range.

Getter Gets the range

rational
Defines the rational and non-rational B-spline shapes.

Rational shapes use homogeneous coordinates which includes a weight alongside with the Cartesian coordinates. Rational B-splines are also named as NURBS (Non-uniform rational basis spline) and non-rational B-splines are sometimes named as NUBS (Non-uniform basis spline) or directly as B-splines.

Please refer to the wiki for details on using this class member.

Getter Returns True is the B-spline object is rational (NURBS)

Type bool

remove_knot (*u=None*, *v=None*, *w=None*, ***kwargs*)
Inserts knot(s) on the u-, v- and w-directions

Keyword Arguments:

- `num_u`: Number of knot removals on the u-direction. *Default: 1*
- `num_v`: Number of knot removals on the v-direction. *Default: 1*
- `num_w`: Number of knot removals on the w-direction. *Default: 1*

Parameters

- **u** (*float*) – knot to be removed on the u-direction
- **v** (*float*) – knot to be removed on the v-direction
- **w** (*float*) – knot to be removed on the w-direction

render (***kwargs*)
Renders the volume using the visualization component.

The visualization component must be set using *vis* property before calling this method.

Keyword Arguments:

- `cpcolor`: sets the color of the control points
- `evalcolor`: sets the color of the volume
- `filename`: saves the plot with the input name
- `plot`: controls plot window visibility. *Default: True*
- `animate`: activates animation (if supported). *Default: False*
- `grid_size`: grid size for voxelization. *Default: (8, 8, 8)*
- `use_cubes`: use cube voxels instead of cuboid ones. *Default: False*
- `num_procs`: number of concurrent processes for voxelization. *Default: 1*

The `plot` argument is useful when you would like to work on the command line without any window context. If `plot` flag is False, this method saves the plot as an image file (.png file where possible) and disables plot window popping out. If you don't provide a file name, the name of the image file will be pulled from the configuration class.

`extras` argument can be used to add extra line plots to the figure. This argument expects a list of dicts in the format described below:

```
[
    dict(  # line plot 1
        points=[[1, 2, 3], [4, 5, 6]],  # list of points
        name="My line Plot 1",  # name displayed on the legend
        color="red",  # color of the line plot
        size=6.5  # size of the line plot
    ),
    dict(  # line plot 2
        points=[[7, 8, 9], [10, 11, 12]],  # list of points
        name="My line Plot 2",  # name displayed on the legend
        color="navy",  # color of the line plot
        size=12.5  # size of the line plot
    )
]
```

Returns the figure object

reset(***kwargs*)
Resets control points and/or evaluated points.

Keyword Arguments:

- `evalpts`: if True, then resets evaluated points
- `ctrlpts` if True, then resets control points

sample_size
Sample size for both u- and v-directions.

Sample size defines the number of surface points to generate. It also sets the `delta` property.

The following figure illustrates the working principles of sample size property:

$$\underbrace{[u_{start}, \ldots, u_{end}]}_{n_{sample}}$$

Please refer to the wiki for details on using this class member.

Getter Gets sample size as a tuple of values corresponding to u-, v- and w-directions

Setter Sets sample size value for both u-, v- and w-directions

Type int

sample_size_u
Sample size for the u-direction.

Sample size defines the number of evaluated points to generate. It also sets the `delta_u` property.

Please refer to the wiki for details on using this class member.

Getter Gets sample size for the u-direction

Setter Sets sample size for the u-direction

Type int

sample_size_v
Sample size for the v-direction.

Sample size defines the number of evaluated points to generate. It also sets the `delta_v` property.

Please refer to the wiki for details on using this class member.

Getter Gets sample size for the v-direction

Setter Sets sample size for the v-direction

Type int

sample_size_w
Sample size for the w-direction.

Sample size defines the number of evaluated points to generate. It also sets the `delta_w` property.

Please refer to the wiki for details on using this class member.

Getter Gets sample size for the w-direction

Setter Sets sample size for the w-direction

Type int

save (*file_name*)

Saves the volume as a pickled file.

Deprecated since version 5.2.4: Use `exchange.export_json()` instead.

Parameters **file_name** (*str*) – name of the file to be saved

set_ctrlpts (*ctrlpts*, **args*, ***kwargs*)

Sets the control points and checks if the data is consistent.

This method is designed to provide a consistent way to set control points whether they are weighted or not. It directly sets the control points member of the class, and therefore it doesn't return any values. The input will be an array of coordinates. If you are working in the 3-dimensional space, then your coordinates will be an array of 3 elements representing *(x, y, z)* coordinates.

Parameters

- **ctrlpts** (*list*) – input control points as a list of coordinates
- **args** (*tuple[int, int, int]*) – number of control points corresponding to each parametric dimension

trims

Trimming surfaces.

Please refer to the wiki for details on using this class member.

Getter Gets the array of trim surfaces

Setter Sets the array of trim surfaces

type

Geometry type

Please refer to the wiki for details on using this class member.

Getter Gets the geometry type

Type str

vis

Visualization component.

Please refer to the wiki for details on using this class member.

Getter Gets the visualization component

Setter Sets the visualization component

Type vis.VisAbstract

weights

Weights.

Note: Only available for rational spline geometries. Getter return `None` otherwise.

Please refer to the wiki for details on using this class member.

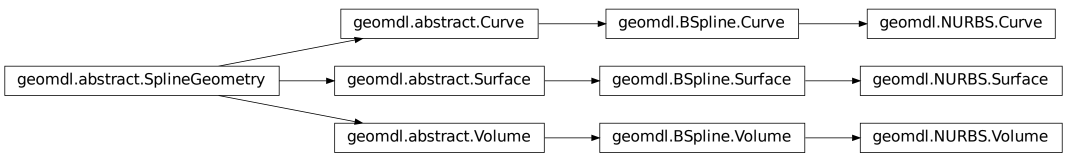
Getter Gets the weights

Setter Sets the weights

17.1.2 NURBS Geometry

`NURBS` module provides data storage and evaluation functions for rational spline geometries.

Inheritance Diagram



NURBS Curve

class geomdl.NURBS.**Curve**(***kwargs*)

Bases: *geomdl.BSpline.Curve*

Data storage and evaluation class for n-variate NURBS (rational) curves.

The rational shapes have some minor differences between the non-rational ones. This class is designed to operate with weighted control points (Pw) as described in *The NURBS Book* by Piegl and Tiller. Therefore, it provides a different set of properties (i.e. getters and setters):

- `ctrlptsw`: 1-dimensional array of weighted control points
- `ctrlpts`: 1-dimensional array of control points
- `weights`: 1-dimensional array of weights

You may also use `set_ctrlpts()` function which is designed to work with all types of control points.

This class provides the following properties:

- *order*
- *degree*
- *knotvector*
- *ctrlptsw*
- *ctrlpts*
- *weights*
- *delta*
- *sample_size*
- *bbox*
- *vis*
- *name*
- *dimension*

- *evaluator*
- *rational*

The following code segment illustrates the usage of Curve class:

```
from geomdl import NURBS

# Create a 3-dimensional B-spline Curve
curve = NURBS.Curve()

# Set degree
curve.degree = 3

# Set control points (weights vector will be 1 by default)
# Use curve.ctrlptsw is if you are using homogeneous points as Pw
curve.ctrlpts = [[10, 5, 10], [10, 20, -30], [40, 10, 25], [-10, 5, 0]]

# Set knot vector
curve.knotvector = [0, 0, 0, 0, 1, 1, 1, 1]

# Set evaluation delta (controls the number of curve points)
curve.delta = 0.05

# Get curve points (the curve will be automatically evaluated)
curve_points = curve.evalpts
```

Keyword Arguments:

- `precision`: number of decimal places to round to. *Default: 18*
- `normalize_kv`: activates knot vector normalization. *Default: True*
- `find_span_func`: sets knot span search implementation. *Default:* *helpers.find_span_linear()*
- `insert_knot_func`: sets knot insertion implementation. *Default:* *operations.insert_knot()*
- `remove_knot_func`: sets knot removal implementation. *Default:* *operations.remove_knot()*

Please refer to the *abstract.Curve()* documentation for more details.

bbox
Bounding box.

Evaluates the bounding box and returns the minimum and maximum coordinates.

Please refer to the wiki for details on using this class member.

Getter Gets the bounding box

Type tuple

binormal (*parpos*, ***kwargs*)
Evaluates the binormal vector of the curve at the given parametric position(s).

Parameters **parpos** (*float, list or tuple*) – parametric position(s) where the evaluation will be executed

Returns binormal vector as a tuple of the origin point and the vector components

Return type tuple

cpsize
Number of control points in all parametric directions.

Note: This is an expert property for getting and setting control point size(s) of the geometry.

Please refer to the wiki for details on using this class member.

Getter Gets the number of control points

Setter Sets the number of control points

Type list

ctrlpts
Control points (P).

Please refer to the wiki for details on using this class member.

Getter Gets unweighted control points. Use `weights` to get weights vector.

Setter Sets unweighted control points

Type list

ctrlpts_size
Total number of control points.

Getter Gets the total number of control points

Type int

ctrlptsw
Weighted control points (Pw).

Weighted control points are in (x*w, y*w, z*w, w) format; where x,y,z are the coordinates and w is the weight.

Please refer to the wiki for details on using this class member.

Getter Gets the weighted control points

Setter Sets the weighted control points

data
Returns a dict which contains the geometry data.

Please refer to the wiki for details on using this class member.

degree
Degree.

Please refer to the wiki for details on using this class member.

Getter Gets the degree

Setter Sets the degree

Type int

delta
Evaluation delta.

Evaluation delta corresponds to the *step size* while `evaluate` function iterates on the knot vector to generate curve points. Decreasing step size results in generation of more curve points. Therefore; smaller the delta value, smoother the curve.

The following figure illustrates the working principles of the delta property:

$$[u_{start}, u_{start} + \delta, (u_{start} + \delta) + \delta, \dots, u_{end}]$$

Please refer to the wiki for details on using this class member.

Getter Gets the delta value

Setter Sets the delta value

Type float

derivatives (*u*, *order=0*, ***kwargs*)

Evaluates n-th order curve derivatives at the given parameter value.

The output of this method is list of n-th order derivatives. If `order` is `0`, then it will only output the evaluated point. Similarly, if `order` is `2`, then it will output the evaluated point, 1st derivative and the 2nd derivative. For instance;

```
# Assuming a curve (crv) is defined on a parametric domain [0.0, 1.0]
# Let's take the curve derivative at the parametric position u = 0.35
ders = crv.derivatives(u=0.35, order=2)
ders[0]  # evaluated point, equal to crv.evaluate_single(0.35)
ders[1]  # 1st derivative at u = 0.35
ders[2]  @ 2nd derivative at u = 0.35
```

Parameters

- **u** (*float*) – parameter value
- **order** (*int*) – derivative order

Returns a list containing up to {order}-th derivative of the curve

Return type list

dimension

Spatial dimension.

Spatial dimension will be automatically estimated from the first element of the control points array.

Please refer to the wiki for details on using this class member.

Getter Gets the spatial dimension, e.g. 2D, 3D, etc.

Type int

domain

Domain.

Domain is determined using the knot vector(s).

Getter Gets the domain

evalpts

Evaluated points.

Please refer to the wiki for details on using this class member.

Getter Gets the coordinates of the evaluated points

Type list

evaluate(***kwargs*)
Evaluates the curve.

The evaluated points are stored in `evalpts` property.

Keyword arguments:

- `start`: start parameter
- `stop`: stop parameter

The `start` and `stop` parameters allow evaluation of a curve segment in the range *[start, stop]*, i.e. the curve will also be evaluated at the `stop` parameter value.

The following examples illustrate the usage of the keyword arguments.

```
# Start evaluating from u=0.2 to u=1.0
curve.evaluate(start=0.2)

# Start evaluating from u=0.0 to u=0.7
curve.evaluate(stop=0.7)

# Start evaluating from u=0.1 to u=0.5
curve.evaluate(start=0.1, stop=0.5)

# Get the evaluated points
curve_points = curve.evalpts
```

evaluate_list(*param_list*)
Evaluates the curve for an input range of parameters.

Parameters **param_list** (`list, tuple`) – list of parameters

Returns evaluated surface points at the input parameters

Return type list

evaluate_single(*param*)
Evaluates the curve at the input parameter.

Parameters **param** (`float`) – parameter

Returns evaluated surface point at the given parameter

Return type list

evaluator
Evaluator instance.

Evaluators allow users to use different algorithms for B-Spline and NURBS evaluations. Please see the documentation on `Evaluator` classes.

Please refer to the wiki for details on using this class member.

Getter Gets the current Evaluator instance

Setter Sets the Evaluator instance

Type *evaluators.AbstractEvaluator*

id
Object ID (as an integer).

Please refer to the wiki for details on using this class member.

Getter Gets the object ID

Setter Sets the object ID

Type int

insert_knot (*param*, ***kwargs*)

Inserts the knot and updates the control points array and the knot vector.

Keyword Arguments:

- `num`: Number of knot insertions. *Default: 1*

Parameters **param** (*float*) – knot to be inserted

knotvector

Knot vector.

The knot vector will be normalized to [0, 1] domain if the class is initialized with `normalize_kv=True` argument.

Please refer to the wiki for details on using this class member.

Getter Gets the knot vector

Setter Sets the knot vector

Type list

load (*file_name*)

Loads the curve from a pickled file.

Deprecated since version 5.2.4: Use *exchange.import_json()* instead.

Parameters **file_name** (*str*) – name of the file to be loaded

name

Object name (as a string)

Please refer to the wiki for details on using this class member.

Getter Gets the object name

Setter Sets the object name

Type str

normal (*parpos*, ***kwargs*)

Evaluates the normal to the tangent vector of the curve at the given parametric position(s).

Parameters **parpos** (*float, list or tuple*) – parametric position(s) where the evaluation will be executed

Returns normal vector as a tuple of the origin point and the vector components

Return type tuple

opt

Dictionary for storing custom data in the current geometry object.

`opt` is a wrapper to a dict in *key* => *value* format, where *key* is string, *value* is any Python object. You can use `opt` property to store custom data inside the geometry object. For instance:

```
geom.opt = ["face_id", 4]  # creates "face_id" key and sets its value to an integer
geom.opt = ["contents", "data values"]  # creates "face_id" key and sets its value to a string
```

(continues on next page)

(continued from previous page)

```
print(geom.opt)  # will print: {'face_id': 4, 'contents': 'data values'}

del geom.opt  # deletes the contents of the hash map
print(geom.opt)  # will print: {}

geom.opt = ["body_id", 1]  # creates "body_id" key  and sets its value to 1
geom.opt = ["body_id", 12]  # changes the value of "body_id" to 12
print(geom.opt)  # will print: {'body_id': 12}

geom.opt = ["body_id", None]  # deletes "body_id"
print(geom.opt)  # will print: {}
```

Please refer to the wiki for details on using this class member.

Getter Gets the dict

Setter Adds key and value pair to the dict

Deleter Deletes the contents of the dict

opt_get (*value*)

Safely query for the value from the `opt` property.

Parameters **value** (`str`) – a key in the `opt` property

Returns the corresponding value, if the key exists. `None`, otherwise.

order

Order.

Defined as `order = degree + 1`

Please refer to the wiki for details on using this class member.

Getter Gets the order

Setter Sets the order

Type int

pdimension

Parametric dimension.

Please refer to the wiki for details on using this class member.

Getter Gets the parametric dimension

Type int

range

Domain range.

Getter Gets the range

rational

Defines the rational and non-rational B-spline shapes.

Rational shapes use homogeneous coordinates which includes a weight alongside with the Cartesian coordinates. Rational B-splines are also named as NURBS (Non-uniform rational basis spline) and non-rational B-splines are sometimes named as NUBS (Non-uniform basis spline) or directly as B-splines.

Please refer to the wiki for details on using this class member.

Getter Returns True is the B-spline object is rational (NURBS)

Type bool

remove_knot (*param*, ***kwargs*)
Removes the knot and updates the control points array and the knot vector.

Keyword Arguments:

- `num`: Number of knot removals. *Default: 1*

Parameters **param** (*float*) – knot to be removed

render (***kwargs*)
Renders the curve using the visualization component

The visualization component must be set using `vis` property before calling this method.

Keyword Arguments:

- `cpcolor`: sets the color of the control points polygon
- `evalcolor`: sets the color of the curve
- `bboxcolor`: sets the color of the bounding box
- `filename`: saves the plot with the input name
- `plot`: controls plot window visibility. *Default: True*
- `animate`: activates animation (if supported). *Default: False*
- `extras`: adds line plots to the figure. *Default: None*

`plot` argument is useful when you would like to work on the command line without any window context. If `plot` flag is False, this method saves the plot as an image file (.png file where possible) and disables plot window popping out. If you don't provide a file name, the name of the image file will be pulled from the configuration class.

`extras` argument can be used to add extra line plots to the figure. This argument expects a list of dicts in the format described below:

```
[
    dict(  # line plot 1
        points=[[1, 2, 3], [4, 5, 6]],  # list of points
        name="My line Plot 1",  # name displayed on the legend
        color="red",   # color of the line plot
        size=6.5  # size of the line plot
    ),
    dict(  # line plot 2
        points=[[7, 8, 9], [10, 11, 12]],  # list of points
        name="My line Plot 2",  # name displayed on the legend
        color="navy",   # color of the line plot
        size=12.5  # size of the line plot
    )
]
```

Returns the figure object

reset (***kwargs*)
Resets control points and/or evaluated points.

Keyword Arguments:

- `evalpts`: if True, then resets evaluated points

- `ctrlpts` if True, then resets control points

reverse()
Reverses the curve

sample_size
Sample size.

Sample size defines the number of evaluated points to generate. It also sets the `delta` property.

The following figure illustrates the working principles of sample size property:

$$\underbrace{[u_{start}, \ldots, u_{end}]}_{n_{sample}}$$

Please refer to the wiki for details on using this class member.

Getter Gets sample size

Setter Sets sample size

Type int

save(*file_name*)
Saves the curve as a pickled file.

Deprecated since version 5.2.4: Use *exchange.export_json()* instead.

Parameters **file_name** (*str*) – name of the file to be saved

set_ctrlpts(*ctrlpts*, **args*, ***kwargs*)
Sets control points and checks if the data is consistent.

This method is designed to provide a consistent way to set control points whether they are weighted or not. It directly sets the control points member of the class, and therefore it doesn't return any values. The input will be an array of coordinates. If you are working in the 3-dimensional space, then your coordinates will be an array of 3 elements representing *(x, y, z)* coordinates.

Parameters **ctrlpts** (*list*) – input control points as a list of coordinates

tangent(*parpos*, ***kwargs*)
Evaluates the tangent vector of the curve at the given parametric position(s).

Parameters **parpos** (*float, list or tuple*) – parametric position(s) where the evaluation will be executed

Returns tangent vector as a tuple of the origin point and the vector components

Return type tuple

type
Geometry type

Please refer to the wiki for details on using this class member.

Getter Gets the geometry type

Type str

vis
Visualization component.

Please refer to the wiki for details on using this class member.

Getter Gets the visualization component

Setter Sets the visualization component

Type vis.VisAbstract

weights
Weights vector.

Please refer to the wiki for details on using this class member.

Getter Gets the weights vector

Setter Sets the weights vector

Type list

NURBS Surface

class geomdl.NURBS.**Surface**(***kwargs*)
Bases: *geomdl.BSpline.Surface*

Data storage and evaluation class for NURBS (rational) surfaces.

The rational shapes have some minor differences between the non-rational ones. This class is designed to operate with weighted control points (Pw) as described in *The NURBS Book* by Piegl and Tiller. Therefore, it provides a different set of properties (i.e. getters and setters):

- `ctrlptsw`: 1-dimensional array of weighted control points
- `ctrlpts2d`: 2-dimensional array of weighted control points
- `ctrlpts`: 1-dimensional array of control points
- `weights`: 1-dimensional array of weights

You may also use `set_ctrlpts()` function which is designed to work with all types of control points.

This class provides the following properties:

- *order_u*
- *order_v*
- *degree_u*
- *degree_v*
- *knotvector_u*
- *knotvector_v*
- *ctrlptsw*
- *ctrlpts*
- *weights*
- *ctrlpts_size_u*
- *ctrlpts_size_v*
- *ctrlpts2d*
- *delta*
- *delta_u*
- *delta_v*
- *sample_size*

- *sample_size_u*
- *sample_size_v*
- *bbox*
- *name*
- *dimension*
- *vis*
- *evaluator*
- *tessellator*
- *rational*
- *trims*

The following code segment illustrates the usage of Surface class:

```
from geomdl import NURBS

# Create a NURBS surface instance
surf = NURBS.Surface()

# Set degrees
surf.degree_u = 3
surf.degree_v = 2

# Set control points (weights vector will be 1 by default)
# Use curve.ctrlptsw is if you are using homogeneous points as Pw
control_points = [[0, 0, 0], [0, 4, 0], [0, 8, -3],
                  [2, 0, 6], [2, 4, 0], [2, 8, 0],
                  [4, 0, 0], [4, 4, 0], [4, 8, 3],
                  [6, 0, 0], [6, 4, -3], [6, 8, 0]]
surf.set_ctrlpts(control_points, 4, 3)

# Set knot vectors
surf.knotvector_u = [0, 0, 0, 0, 1, 1, 1, 1]
surf.knotvector_v = [0, 0, 0, 1, 1, 1]

# Set evaluation delta (control the number of surface points)
surf.delta = 0.05

# Get surface points (the surface will be automatically evaluated)
surface_points = surf.evalpts
```

Keyword Arguments:

- `precision`: number of decimal places to round to. *Default: 18*
- `normalize_kv`: activates knot vector normalization. *Default: True*
- `find_span_func`: sets knot span search implementation. *Default:* *helpers.find_span_linear()*
- `insert_knot_func`: sets knot insertion implementation. *Default:* *operations.insert_knot()*
- `remove_knot_func`: sets knot removal implementation. *Default:* *operations.remove_knot()*

Please refer to the *abstract.Surface()* documentation for more details.

add_trim(*trim*)

Adds a trim to the surface.

A trim is a 2-dimensional curve defined on the parametric domain of the surface. Therefore, x-coordinate of the trimming curve corresponds to u parametric direction of the surfaceand y-coordinate of the trimming curve corresponds to v parametric direction of the surface.

`trims` uses this method to add trims to the surface.

Parameters **trim** (`abstract.Geometry`) – surface trimming curve

bbox

Bounding box.

Evaluates the bounding box and returns the minimum and maximum coordinates.

Please refer to the wiki for details on using this class member.

Getter Gets the bounding box

Type tuple

cpsize

Number of control points in all parametric directions.

Note: This is an expert property for getting and setting control point size(s) of the geometry.

Please refer to the wiki for details on using this class member.

Getter Gets the number of control points

Setter Sets the number of control points

Type list

ctrlpts

1-dimensional array of control points (P).

This property sets and gets the control points in 1-D.

Getter Gets unweighted control points. Use `weights` to get weights vector.

Setter Sets unweighted control points.

Type list

ctrlpts2d

2-dimensional array of control points.

The getter returns a tuple of 2D control points (weighted control points + weights if NURBS) in *[u][v]* format. The rows of the returned tuple correspond to v-direction and the columns correspond to u-direction.

The following example can be used to traverse 2D control points:

```
# Create a BSpline surface
surf_bs = BSpline.Surface()

# Do degree, control points and knot vector assignments here

# Each u includes a row of v values
for u in surf_bs.ctrlpts2d:
    # Each row contains the coordinates of the control points
    for v in u:
```

(continues on next page)

(continued from previous page)

```
        print(str(v))  # will be something like (1.0, 2.0, 3.0)

# Create a NURBS surface
surf_nb = NURBS.Surface()

# Do degree, weighted control points and knot vector assignments here

# Each u includes a row of v values
for u in surf_nb.ctrlpts2d:
    # Each row contains the coordinates of the weighted control points
    for v in u:
        print(str(v))  # will be something like (0.5, 1.0, 1.5, 0.5)
```

When using **NURBS.Surface** class, the output of `ctrlpts2d` property could be confusing since, `ctrlpts` always returns the unweighted control points, i.e. `ctrlpts` property returns 3D control points all divided by the weights and you can use `weights` property to access the weights vector, but `ctrlpts2d` returns the weighted ones plus weights as the last element. This difference is intentionally added for compatibility and interoperability purposes.

To explain this situation in a simple way;

- If you need the weighted control points directly, use `ctrlpts2d`
- If you need the control points and the weights separately, use `ctrlpts` and `weights`

Note: Please note that the setter doesn't check for inconsistencies and using the setter is not recommended. Instead of the setter property, please use `set_ctrlpts()` function.

Please refer to the wiki for details on using this class member.

Getter Gets the control points as a 2-dimensional array in [u][v] format

Setter Sets the control points as a 2-dimensional array in [u][v] format

Type list

ctrlpts_size

Total number of control points.

Getter Gets the total number of control points

Type int

ctrlpts_size_u

Number of control points for the u-direction.

Please refer to the wiki for details on using this class member.

Getter Gets number of control points for the u-direction

Setter Sets number of control points for the u-direction

ctrlpts_size_v

Number of control points for the v-direction.

Please refer to the wiki for details on using this class member.

Getter Gets number of control points on the v-direction

Setter Sets number of control points on the v-direction

ctrlptsw

1-dimensional array of weighted control points (Pw).

Weighted control points are in (x*w, y*w, z*w, w) format; where x,y,z are the coordinates and w is the weight.

This property sets and gets the control points in 1-D.

Getter Gets weighted control points

Setter Sets weighted control points

data

Returns a dict which contains the geometry data.

Please refer to the wiki for details on using this class member.

degree

Degree for u- and v-directions

Getter Gets the degree

Setter Sets the degree

Type list

degree_u

Degree for the u-direction.

Please refer to the wiki for details on using this class member.

Getter Gets degree for the u-direction

Setter Sets degree for the u-direction

Type int

degree_v

Degree for the v-direction.

Please refer to the wiki for details on using this class member.

Getter Gets degree for the v-direction

Setter Sets degree for the v-direction

Type int

delta

Evaluation delta for both u- and v-directions.

Evaluation delta corresponds to the *step size* while `evaluate()` function iterates on the knot vector to generate surface points. Decreasing step size results in generation of more surface points. Therefore; smaller the delta value, smoother the surface.

Please note that `delta` and `sample_size` properties correspond to the same variable with different descriptions. Therefore, setting `delta` will also set `sample_size`.

The following figure illustrates the working principles of the delta property:

$$[u_0, u_{start} + \delta, (u_{start} + \delta) + \delta, \dots, u_{end}]$$

Please refer to the wiki for details on using this class member.

Getter Gets evaluation delta as a tuple of values corresponding to u- and v-directions

Setter Sets evaluation delta for both u- and v-directions

Type float

delta_u
Evaluation delta for the u-direction.

Evaluation delta corresponds to the *step size* while `evaluate()` function iterates on the knot vector to generate surface points. Decreasing step size results in generation of more surface points. Therefore; smaller the delta value, smoother the surface.

Please note that `delta_u` and `sample_size_u` properties correspond to the same variable with different descriptions. Therefore, setting `delta_u` will also set `sample_size_u`.

Please refer to the wiki for details on using this class member.

Getter Gets evaluation delta for the u-direction

Setter Sets evaluation delta for the u-direction

Type float

delta_v
Evaluation delta for the v-direction.

Evaluation delta corresponds to the *step size* while `evaluate()` function iterates on the knot vector to generate surface points. Decreasing step size results in generation of more surface points. Therefore; smaller the delta value, smoother the surface.

Please note that `delta_v` and `sample_size_v` properties correspond to the same variable with different descriptions. Therefore, setting `delta_v` will also set `sample_size_v`.

Please refer to the wiki for details on using this class member.

Getter Gets evaluation delta for the v-direction

Setter Sets evaluation delta for the v-direction

Type float

derivatives(*u*, *v*, *order=0*, ***kwargs*)
Evaluates n-th order surface derivatives at the given (u, v) parameter pair.

- SKL[0][0] will be the surface point itself
- SKL[0][1] will be the 1st derivative w.r.t. v
- SKL[2][1] will be the 2nd derivative w.r.t. u and 1st derivative w.r.t. v

Parameters

- **u** (*float*) – parameter on the u-direction
- **v** (*float*) – parameter on the v-direction
- **order** (*integer*) – derivative order

Returns A list SKL, where SKL[k][l] is the derivative of the surface S(u,v) w.r.t. u k times and v l times

Return type list

dimension
Spatial dimension.

Spatial dimension will be automatically estimated from the first element of the control points array.

Please refer to the wiki for details on using this class member.

Getter Gets the spatial dimension, e.g. 2D, 3D, etc.

Type int

domain
Domain.

Domain is determined using the knot vector(s).

Getter Gets the domain

evalpts
Evaluated points.

Please refer to the wiki for details on using this class member.

Getter Gets the coordinates of the evaluated points

Type list

evaluate(***kwargs*)
Evaluates the surface.

The evaluated points are stored in `evalpts` property.

Keyword arguments:

- `start_u`: start parameter on the u-direction
- `stop_u`: stop parameter on the u-direction
- `start_v`: start parameter on the v-direction
- `stop_v`: stop parameter on the v-direction

The `start_u`, `start_v` and `stop_u` and `stop_v` parameters allow evaluation of a surface segment in the range *[start_u, stop_u][start_v, stop_v]* i.e. the surface will also be evaluated at the `stop_u` and `stop_v` parameter values.

The following examples illustrate the usage of the keyword arguments.

```
# Start evaluating in range u=[0, 0.7] and v=[0.1, 1]
surf.evaluate(stop_u=0.7, start_v=0.1)

# Start evaluating in range u=[0, 1] and v=[0.1, 0.3]
surf.evaluate(start_v=0.1, stop_v=0.3)

# Get the evaluated points
surface_points = surf.evalpts
```

evaluate_list(*param_list*)
Evaluates the surface for a given list of (u, v) parameters.

Parameters **param_list** (*list, tuple*) – list of parameter pairs (u, v)

Returns evaluated surface point at the input parameter pairs

Return type tuple

evaluate_single(*param*)
Evaluates the surface at the input (u, v) parameter pair.

Parameters **param** (*list, tuple*) – parameter pair (u, v)

Returns evaluated surface point at the given parameter pair

Return type list

evaluator

Evaluator instance.

Evaluators allow users to use different algorithms for B-Spline and NURBS evaluations. Please see the documentation on `Evaluator` classes.

Please refer to the wiki for details on using this class member.

Getter Gets the current Evaluator instance

Setter Sets the Evaluator instance

Type *evaluators.AbstractEvaluator*

faces

Faces (triangles, quads, etc.) generated by the tessellation operation.

If the tessellation component is set to None, the result will be an empty list.

Getter Gets the faces

id

Object ID (as an integer).

Please refer to the wiki for details on using this class member.

Getter Gets the object ID

Setter Sets the object ID

Type int

insert_knot (*u=None*, *v=None*, ***kwargs*)

Inserts knot(s) on the u- or v-directions

Keyword Arguments:

- `num_u`: Number of knot insertions on the u-direction. *Default: 1*
- `num_v`: Number of knot insertions on the v-direction. *Default: 1*

Parameters

- **u** (*float*) – knot to be inserted on the u-direction
- **v** (*float*) – knot to be inserted on the v-direction

knotvector

Knot vector for u- and v-directions

Getter Gets the knot vector

Setter Sets the knot vector

Type list

knotvector_u

Knot vector for the u-direction.

The knot vector will be normalized to [0, 1] domain if the class is initialized with `normalize_kv=True` argument.

Please refer to the wiki for details on using this class member.

Getter Gets knot vector for the u-direction

Setter Sets knot vector for the u-direction

Type list

knotvector_v
Knot vector for the v-direction.

The knot vector will be normalized to [0, 1] domain if the class is initialized with `normalize_kv=True` argument.

Please refer to the wiki for details on using this class member.

Getter Gets knot vector for the v-direction

Setter Sets knot vector for the v-direction

Type list

load (*file_name*)
Loads the surface from a pickled file.

Deprecated since version 5.2.4: Use *exchange.import_json()* instead.

Parameters file_name (*str*) – name of the file to be loaded

name
Object name (as a string)

Please refer to the wiki for details on using this class member.

Getter Gets the object name

Setter Sets the object name

Type str

normal (*parpos*, ***kwargs*)
Evaluates the normal vector of the surface at the given parametric position(s).

Parameters parpos (*list or tuple*) – parametric position(s) where the evaluation will be executed

Returns an array containing "point" and "vector" pairs

Return type tuple

opt
Dictionary for storing custom data in the current geometry object.

`opt` is a wrapper to a dict in *key* => *value* format, where *key* is string, *value* is any Python object. You can use `opt` property to store custom data inside the geometry object. For instance:

```
geom.opt = ["face_id", 4]  # creates "face_id" key and sets its value to an␣
↪integer
geom.opt = ["contents", "data values"]  # creates "face_id" key and sets its␣
↪value to a string
print(geom.opt)  # will print: {'face_id': 4, 'contents': 'data values'}

del geom.opt  # deletes the contents of the hash map
print(geom.opt)  # will print: {}

geom.opt = ["body_id", 1]  # creates "body_id" key  and sets its value to 1
geom.opt = ["body_id", 12]  # changes the value of "body_id" to 12
print(geom.opt)  # will print: {'body_id': 12}

geom.opt = ["body_id", None]  # deletes "body_id"
print(geom.opt)  # will print: {}
```

Please refer to the wiki for details on using this class member.

Getter Gets the dict

Setter Adds key and value pair to the dict

Deleter Deletes the contents of the dict

opt_get (*value*)

Safely query for the value from the `opt` property.

Parameters **value** (*str*) – a key in the `opt` property

Returns the corresponding value, if the key exists. `None`, otherwise.

order_u

Order for the u-direction.

Defined as `order = degree + 1`

Please refer to the wiki for details on using this class member.

Getter Gets order for the u-direction

Setter Sets order for the u-direction

Type int

order_v

Order for the v-direction.

Defined as `order = degree + 1`

Please refer to the wiki for details on using this class member.

Getter Gets surface order for the v-direction

Setter Sets surface order for the v-direction

Type int

pdimension

Parametric dimension.

Please refer to the wiki for details on using this class member.

Getter Gets the parametric dimension

Type int

range

Domain range.

Getter Gets the range

rational

Defines the rational and non-rational B-spline shapes.

Rational shapes use homogeneous coordinates which includes a weight alongside with the Cartesian coordinates. Rational B-splines are also named as NURBS (Non-uniform rational basis spline) and non-rational B-splines are sometimes named as NUBS (Non-uniform basis spline) or directly as B-splines.

Please refer to the wiki for details on using this class member.

Getter Returns True is the B-spline object is rational (NURBS)

Type bool

remove_knot (*u=None*, *v=None*, ***kwargs*)
Inserts knot(s) on the u- or v-directions

Keyword Arguments:

- `num_u`: Number of knot removals on the u-direction. *Default: 1*
- `num_v`: Number of knot removals on the v-direction. *Default: 1*

Parameters

- **u** (`float`) – knot to be removed on the u-direction
- **v** (`float`) – knot to be removed on the v-direction

render (***kwargs*)
Renders the surface using the visualization component.

The visualization component must be set using `vis` property before calling this method.

Keyword Arguments:

- `cpcolor`: sets the color of the control points grid
- `evalcolor`: sets the color of the surface
- `trimcolor`: sets the color of the trim curves
- `filename`: saves the plot with the input name
- `plot`: controls plot window visibility. *Default: True*
- `animate`: activates animation (if supported). *Default: False*
- `extras`: adds line plots to the figure. *Default: None*
- `colormap`: sets the colormap of the surface

The `plot` argument is useful when you would like to work on the command line without any window context. If `plot` flag is False, this method saves the plot as an image file (.png file where possible) and disables plot window popping out. If you don't provide a file name, the name of the image file will be pulled from the configuration class.

`extras` argument can be used to add extra line plots to the figure. This argument expects a list of dicts in the format described below:

```
[
    dict(  # line plot 1
        points=[[1, 2, 3], [4, 5, 6]],  # list of points
        name="My line Plot 1",  # name displayed on the legend
        color="red",  # color of the line plot
        size=6.5  # size of the line plot
    ),
    dict(  # line plot 2
        points=[[7, 8, 9], [10, 11, 12]],  # list of points
        name="My line Plot 2",  # name displayed on the legend
        color="navy",  # color of the line plot
        size=12.5  # size of the line plot
    )
]
```

Please note that `colormap` argument can only work with visualization classes that support colormaps. As an example, please see `VisMPL.VisSurfTriangle()` class documentation. This method expects a single colormap input.

Returns the figure object

reset (***kwargs*)

Resets control points and/or evaluated points.

Keyword Arguments:

- `evalpts`: if True, then resets evaluated points
- `ctrlpts` if True, then resets control points

sample_size

Sample size for both u- and v-directions.

Sample size defines the number of surface points to generate. It also sets the `delta` property.

The following figure illustrates the working principles of sample size property:

$$\underbrace{\left[u_{start}, \ldots, u_{end}\right]}_{n_{sample}}$$

Please refer to the wiki for details on using this class member.

Getter Gets sample size as a tuple of values corresponding to u- and v-directions

Setter Sets sample size for both u- and v-directions

Type int

sample_size_u

Sample size for the u-direction.

Sample size defines the number of surface points to generate. It also sets the `delta_u` property.

Please refer to the wiki for details on using this class member.

Getter Gets sample size for the u-direction

Setter Sets sample size for the u-direction

Type int

sample_size_v

Sample size for the v-direction.

Sample size defines the number of surface points to generate. It also sets the `delta_v` property.

Please refer to the wiki for details on using this class member.

Getter Gets sample size for the v-direction

Setter Sets sample size for the v-direction

Type int

save (*file_name*)

Saves the surface as a pickled file.

Deprecated since version 5.2.4: Use `exchange.export_json()` instead.

Parameters **file_name** (*str*) – name of the file to be saved

set_ctrlpts (*ctrlpts*, **args*, ***kwargs*)

Sets the control points and checks if the data is consistent.

This method is designed to provide a consistent way to set control points whether they are weighted or not. It directly sets the control points member of the class, and therefore it doesn't return any values. The input will be an array of coordinates. If you are working in the 3-dimensional space, then your coordinates will be an array of 3 elements representing *(x, y, z)* coordinates.

This method also generates 2D control points in *[u][v]* format which can be accessed via `ctrlpts2d`.

Note: The v index varies first. That is, a row of v control points for the first u value is found first. Then, the row of v control points for the next u value.

Parameters **ctrlpts** (*list*) – input control points as a list of coordinates

tangent(*parpos*, ***kwargs*)

Evaluates the tangent vectors of the surface at the given parametric position(s).

Parameters **parpos** (*list or tuple*) – parametric position(s) where the evaluation will be executed

Returns an array containing "point" and "vector"s on u- and v-directions, respectively

Return type tuple

tessellate(***kwargs*)

Tessellates the surface.

Keyword arguments are directly passed to the tessellation component.

tessellator

Tessellation component.

Please refer to the wiki for details on using this class member.

Getter Gets the tessellation component

Setter Sets the tessellation component

transpose()

Transposes the surface by swapping u and v parametric directions.

trims

Curves for trimming the surface.

Surface trims are 2-dimensional curves which are introduced on the parametric space of the surfaces. Trim curves can be a spline curve, an analytic curve or a 2-dimensional freeform shape. To visualize the trimmed surfaces, you need to use a tessellator that supports trimming. The following code snippet illustrates changing the default surface tessellator to the trimmed surface tessellator, `tessellate.TrimTessellate`.

```
from geomdl import tessellate

# Assuming that "surf" variable stores the surface instance
surf.tessellator = tessellate.TrimTessellate()
```

In addition, using *trims* initialization argument of the visualization classes, trim curves can be visualized together with their underlying surfaces. Please refer to the visualization configuration class initialization arguments for more details.

Please refer to the wiki for details on using this class member.

Getter Gets the array of trim curves

Setter Sets the array of trim curves

type
Geometry type

Please refer to the wiki for details on using this class member.

Getter Gets the geometry type

Type str

vertices
Vertices generated by the tessellation operation.

If the tessellation component is set to None, the result will be an empty list.

Getter Gets the vertices

vis
Visualization component.

Please refer to the wiki for details on using this class member.

Getter Gets the visualization component

Setter Sets the visualization component

Type vis.VisAbstract

weights
Weights vector.

Getter Gets the weights vector

Setter Sets the weights vector

Type list

NURBS Volume

New in version 5.0.

class geomdl.NURBS.**Volume**(***kwargs*)
Bases: `geomdl.BSpline.Volume`

Data storage and evaluation class for NURBS (rational) volumes.

The rational shapes have some minor differences between the non-rational ones. This class is designed to operate with weighted control points (Pw) as described in *The NURBS Book* by Piegl and Tiller. Therefore, it provides a different set of properties (i.e. getters and setters):

- `ctrlptsw`: 1-dimensional array of weighted control points
- `ctrlpts`: 1-dimensional array of control points
- `weights`: 1-dimensional array of weights

This class provides the following properties:

- `order_u`
- `order_v`
- `order_w`
- `degree_u`
- `degree_v`

- *degree_w*
- *knotvector_u*
- *knotvector_v*
- *knotvector_w*
- *ctrlptsw*
- *ctrlpts*
- *weights*
- *ctrlpts_size_u*
- *ctrlpts_size_v*
- *ctrlpts_size_w*
- *delta*
- *delta_u*
- *delta_v*
- *delta_w*
- *sample_size*
- *sample_size_u*
- *sample_size_v*
- *sample_size_w*
- *bbox*
- *name*
- *dimension*
- *vis*
- *evaluator*
- *rational*

Keyword Arguments:

- `precision`: number of decimal places to round to. *Default: 18*
- `normalize_kv`: activates knot vector normalization. *Default: True*
- `find_span_func`: sets knot span search implementation. *Default:* *helpers.find_span_linear()*
- `insert_knot_func`: sets knot insertion implementation. *Default:* *operations.insert_knot()*
- `remove_knot_func`: sets knot removal implementation. *Default:* *operations.remove_knot()*

Please refer to the *abstract.Volume()* documentation for more details.

add_trim(*trim*)

Adds a trim to the volume.

trims uses this method to add trims to the volume.

Parameters **trim** (`abstract.Surface`) – trimming surface

bbox

Bounding box.

Evaluates the bounding box and returns the minimum and maximum coordinates.

Please refer to the wiki for details on using this class member.

Getter Gets the bounding box

Type tuple

cpsize

Number of control points in all parametric directions.

Note: This is an expert property for getting and setting control point size(s) of the geometry.

Please refer to the wiki for details on using this class member.

Getter Gets the number of control points

Setter Sets the number of control points

Type list

ctrlpts

1-dimensional array of control points (P).

This property sets and gets the control points in 1-D.

Getter Gets unweighted control points. Use *weights* to get weights vector.

Setter Sets unweighted control points.

Type list

ctrlpts_size

Total number of control points.

Getter Gets the total number of control points

Type int

ctrlpts_size_u

Number of control points for the u-direction.

Please refer to the wiki for details on using this class member.

Getter Gets number of control points for the u-direction

Setter Sets number of control points for the u-direction

ctrlpts_size_v

Number of control points for the v-direction.

Please refer to the wiki for details on using this class member.

Getter Gets number of control points for the v-direction

Setter Sets number of control points for the v-direction

ctrlpts_size_w

Number of control points for the w-direction.

Please refer to the wiki for details on using this class member.

Getter Gets number of control points for the w-direction

Setter Sets number of control points for the w-direction

ctrlptsw
1-dimensional array of weighted control points (Pw).

Weighted control points are in (x*w, y*w, z*w, w) format; where x,y,z are the coordinates and w is the weight.

This property sets and gets the control points in 1-D.

Getter Gets weighted control points

Setter Sets weighted control points

data
Returns a dict which contains the geometry data.

Please refer to the wiki for details on using this class member.

degree
Degree for u-, v- and w-directions

Getter Gets the degree

Setter Sets the degree

Type list

degree_u
Degree for the u-direction.

Please refer to the wiki for details on using this class member.

Getter Gets degree for the u-direction

Setter Sets degree for the u-direction

Type int

degree_v
Degree for the v-direction.

Please refer to the wiki for details on using this class member.

Getter Gets degree for the v-direction

Setter Sets degree for the v-direction

Type int

degree_w
Degree for the w-direction.

Please refer to the wiki for details on using this class member.

Getter Gets degree for the w-direction

Setter Sets degree for the w-direction

Type int

delta
Evaluation delta for u-, v- and w-directions.

Evaluation delta corresponds to the *step size* while `evaluate()` function iterates on the knot vector to generate surface points. Decreasing step size results in generation of more surface points. Therefore; smaller the delta value, smoother the surface.

Please note that `delta` and `sample_size` properties correspond to the same variable with different descriptions. Therefore, setting `delta` will also set `sample_size`.

The following figure illustrates the working principles of the delta property:

$$[u_0, u_{start} + \delta, (u_{start} + \delta) + \delta, \dots, u_{end}]$$

Please refer to the wiki for details on using this class member.

Getter Gets evaluation delta as a tuple of values corresponding to u-, v- and w-directions

Setter Sets evaluation delta for u-, v- and w-directions

Type float

delta_u

Evaluation delta for the u-direction.

Evaluation delta corresponds to the *step size* while `evaluate()` function iterates on the knot vector to generate surface points. Decreasing step size results in generation of more surface points. Therefore; smaller the delta value, smoother the surface.

Please note that `delta_u` and `sample_size_u` properties correspond to the same variable with different descriptions. Therefore, setting `delta_u` will also set `sample_size_u`.

Please refer to the wiki for details on using this class member.

Getter Gets evaluation delta for the u-direction

Setter Sets evaluation delta for the u-direction

Type float

delta_v

Evaluation delta for the v-direction.

Evaluation delta corresponds to the *step size* while `evaluate()` function iterates on the knot vector to generate surface points. Decreasing step size results in generation of more surface points. Therefore; smaller the delta value, smoother the surface.

Please note that `delta_v` and `sample_size_v` properties correspond to the same variable with different descriptions. Therefore, setting `delta_v` will also set `sample_size_v`.

Please refer to the wiki for details on using this class member.

Getter Gets evaluation delta for the v-direction

Setter Sets evaluation delta for the v-direction

Type float

delta_w

Evaluation delta for the w-direction.

Evaluation delta corresponds to the *step size* while `evaluate()` function iterates on the knot vector to generate surface points. Decreasing step size results in generation of more surface points. Therefore; smaller the delta value, smoother the surface.

Please note that `delta_w` and `sample_size_w` properties correspond to the same variable with different descriptions. Therefore, setting `delta_w` will also set `sample_size_w`.

Please refer to the wiki for details on using this class member.

Getter Gets evaluation delta for the w-direction

Setter Sets evaluation delta for the w-direction

Type float

dimension
Spatial dimension.

Spatial dimension will be automatically estimated from the first element of the control points array.

Please refer to the wiki for details on using this class member.

Getter Gets the spatial dimension, e.g. 2D, 3D, etc.

Type int

domain
Domain.

Domain is determined using the knot vector(s).

Getter Gets the domain

evalpts
Evaluated points.

Please refer to the wiki for details on using this class member.

Getter Gets the coordinates of the evaluated points

Type list

evaluate(***kwargs*)
Evaluates the volume.

The evaluated points are stored in `evalpts` property.

Keyword arguments:

- `start_u`: start parameter on the u-direction
- `stop_u`: stop parameter on the u-direction
- `start_v`: start parameter on the v-direction
- `stop_v`: stop parameter on the v-direction
- `start_w`: start parameter on the w-direction
- `stop_w`: stop parameter on the w-direction

evaluate_list(*param_list*)
Evaluates the volume for a given list of (u, v, w) parameters.

Parameters **param_list** (*list, tuple*) – list of parameters in format (u, v, w)

Returns evaluated surface point at the input parameter pairs

Return type tuple

evaluate_single(*param*)
Evaluates the volume at the input (u, v, w) parameter.

Parameters **param** (*list, tuple*) – parameter (u, v, w)

Returns evaluated surface point at the given parameter pair

Return type list

evaluator

Evaluator instance.

Evaluators allow users to use different algorithms for B-Spline and NURBS evaluations. Please see the documentation on `Evaluator` classes.

Please refer to the wiki for details on using this class member.

Getter Gets the current Evaluator instance

Setter Sets the Evaluator instance

Type *evaluators.AbstractEvaluator*

id

Object ID (as an integer).

Please refer to the wiki for details on using this class member.

Getter Gets the object ID

Setter Sets the object ID

Type int

insert_knot (*u=None*, *v=None*, *w=None*, ***kwargs*)

Inserts knot(s) on the u-, v- and w-directions

Keyword Arguments:

- `num_u`: Number of knot insertions on the u-direction. *Default: 1*
- `num_v`: Number of knot insertions on the v-direction. *Default: 1*
- `num_w`: Number of knot insertions on the w-direction. *Default: 1*

Parameters

- **u** (*float*) – knot to be inserted on the u-direction
- **v** (*float*) – knot to be inserted on the v-direction
- **w** (*float*) – knot to be inserted on the w-direction

knotvector

Knot vector for u-, v- and w-directions

Getter Gets the knot vector

Setter Sets the knot vector

Type list

knotvector_u

Knot vector for the u-direction.

The knot vector will be normalized to [0, 1] domain if the class is initialized with `normalize_kv=True` argument.

Please refer to the wiki for details on using this class member.

Getter Gets knot vector for the u-direction

Setter Sets knot vector for the u-direction

Type list

knotvector_v

Knot vector for the v-direction.

The knot vector will be normalized to [0, 1] domain if the class is initialized with `normalize_kv=True` argument.

Please refer to the wiki for details on using this class member.

Getter Gets knot vector for the v-direction

Setter Sets knot vector for the v-direction

Type list

knotvector_w

Knot vector for the w-direction.

The knot vector will be normalized to [0, 1] domain if the class is initialized with `normalize_kv=True` argument.

Please refer to the wiki for details on using this class member.

Getter Gets knot vector for the w-direction

Setter Sets knot vector for the w-direction

Type list

load(*file_name*)

Loads the volume from a pickled file.

Deprecated since version 5.2.4: Use `exchange.import_json()` instead.

Parameters **file_name** (`str`) – name of the file to be loaded

name

Object name (as a string)

Please refer to the wiki for details on using this class member.

Getter Gets the object name

Setter Sets the object name

Type str

opt

Dictionary for storing custom data in the current geometry object.

`opt` is a wrapper to a dict in *key* => *value* format, where *key* is string, *value* is any Python object. You can use `opt` property to store custom data inside the geometry object. For instance:

```
geom.opt = ["face_id", 4]  # creates "face_id" key and sets its value to an␣
↪integer
geom.opt = ["contents", "data values"]  # creates "face_id" key and sets its␣
↪value to a string
print(geom.opt)  # will print: {'face_id': 4, 'contents': 'data values'}

del geom.opt  # deletes the contents of the hash map
print(geom.opt)  # will print: {}

geom.opt = ["body_id", 1]  # creates "body_id" key  and sets its value to 1
geom.opt = ["body_id", 12]  # changes the value of "body_id" to 12
print(geom.opt)  # will print: {'body_id': 12}
```

(continues on next page)

(continued from previous page)

```
geom.opt = ["body_id", None]  # deletes "body_id"
print(geom.opt)  # will print: {}
```

Please refer to the wiki for details on using this class member.

Getter Gets the dict

Setter Adds key and value pair to the dict

Deleter Deletes the contents of the dict

opt_get(*value*)

Safely query for the value from the `opt` property.

Parameters **value** (*str*) – a key in the `opt` property

Returns the corresponding value, if the key exists. `None`, otherwise.

order_u

Order for the u-direction.

Defined as `order = degree + 1`

Please refer to the wiki for details on using this class member.

Getter Gets the surface order for u-direction

Setter Sets the surface order for u-direction

Type int

order_v

Order for the v-direction.

Defined as `order = degree + 1`

Please refer to the wiki for details on using this class member.

Getter Gets the surface order for v-direction

Setter Sets the surface order for v-direction

Type int

order_w

Order for the w-direction.

Defined as `order = degree + 1`

Please refer to the wiki for details on using this class member.

Getter Gets the surface order for v-direction

Setter Sets the surface order for v-direction

Type int

pdimension

Parametric dimension.

Please refer to the wiki for details on using this class member.

Getter Gets the parametric dimension

Type int

range
Domain range.

Getter Gets the range

rational
Defines the rational and non-rational B-spline shapes.

Rational shapes use homogeneous coordinates which includes a weight alongside with the Cartesian coordinates. Rational B-splines are also named as NURBS (Non-uniform rational basis spline) and non-rational B-splines are sometimes named as NUBS (Non-uniform basis spline) or directly as B-splines.

Please refer to the wiki for details on using this class member.

Getter Returns True is the B-spline object is rational (NURBS)

Type bool

remove_knot (*u=None*, *v=None*, *w=None*, ***kwargs*)
Inserts knot(s) on the u-, v- and w-directions

Keyword Arguments:

- `num_u`: Number of knot removals on the u-direction. *Default: 1*
- `num_v`: Number of knot removals on the v-direction. *Default: 1*
- `num_w`: Number of knot removals on the w-direction. *Default: 1*

Parameters

- **u** (*float*) – knot to be removed on the u-direction
- **v** (*float*) – knot to be removed on the v-direction
- **w** (*float*) – knot to be removed on the w-direction

render (***kwargs*)
Renders the volume using the visualization component.

The visualization component must be set using `vis` property before calling this method.

Keyword Arguments:

- `cpcolor`: sets the color of the control points
- `evalcolor`: sets the color of the volume
- `filename`: saves the plot with the input name
- `plot`: controls plot window visibility. *Default: True*
- `animate`: activates animation (if supported). *Default: False*
- `grid_size`: grid size for voxelization. *Default: (8, 8, 8)*
- `use_cubes`: use cube voxels instead of cuboid ones. *Default: False*
- `num_procs`: number of concurrent processes for voxelization. *Default: 1*

The `plot` argument is useful when you would like to work on the command line without any window context. If `plot` flag is False, this method saves the plot as an image file (.png file where possible) and disables plot window popping out. If you don't provide a file name, the name of the image file will be pulled from the configuration class.

`extras` argument can be used to add extra line plots to the figure. This argument expects a list of dicts in the format described below:

```
[
    dict(  # line plot 1
        points=[[1, 2, 3], [4, 5, 6]],  # list of points
        name="My line Plot 1",  # name displayed on the legend
        color="red",   # color of the line plot
        size=6.5  # size of the line plot
    ),
    dict(  # line plot 2
        points=[[7, 8, 9], [10, 11, 12]],  # list of points
        name="My line Plot 2",  # name displayed on the legend
        color="navy",   # color of the line plot
        size=12.5  # size of the line plot
    )
]
```

Returns the figure object

reset(***kwargs*)

Resets control points and/or evaluated points.

Keyword Arguments:

- `evalpts`: if True, then resets the evaluated points
- `ctrlpts` if True, then resets the control points

sample_size

Sample size for both u- and v-directions.

Sample size defines the number of surface points to generate. It also sets the `delta` property.

The following figure illustrates the working principles of sample size property:

$$\underbrace{\left[u_{start}, \ldots, u_{end}\right]}_{n_{sample}}$$

Please refer to the wiki for details on using this class member.

Getter Gets sample size as a tuple of values corresponding to u-, v- and w-directions

Setter Sets sample size value for both u-, v- and w-directions

Type int

sample_size_u

Sample size for the u-direction.

Sample size defines the number of evaluated points to generate. It also sets the `delta_u` property.

Please refer to the wiki for details on using this class member.

Getter Gets sample size for the u-direction

Setter Sets sample size for the u-direction

Type int

sample_size_v

Sample size for the v-direction.

Sample size defines the number of evaluated points to generate. It also sets the `delta_v` property.

Please refer to the wiki for details on using this class member.

Getter Gets sample size for the v-direction

Setter Sets sample size for the v-direction

Type int

sample_size_w
Sample size for the w-direction.

Sample size defines the number of evaluated points to generate. It also sets the `delta_w` property.

Please refer to the wiki for details on using this class member.

Getter Gets sample size for the w-direction

Setter Sets sample size for the w-direction

Type int

save (*file_name*)
Saves the volume as a pickled file.

Deprecated since version 5.2.4: Use `exchange.export_json()` instead.

Parameters **file_name** (`str`) – name of the file to be saved

set_ctrlpts (*ctrlpts*, **args*, ***kwargs*)
Sets the control points and checks if the data is consistent.

This method is designed to provide a consistent way to set control points whether they are weighted or not. It directly sets the control points member of the class, and therefore it doesn't return any values. The input will be an array of coordinates. If you are working in the 3-dimensional space, then your coordinates will be an array of 3 elements representing *(x, y, z)* coordinates.

Parameters

- **ctrlpts** (`list`) – input control points as a list of coordinates
- **args** (`tuple[int, int, int]`) – number of control points corresponding to each parametric dimension

trims
Trimming surfaces.

Please refer to the wiki for details on using this class member.

Getter Gets the array of trim surfaces

Setter Sets the array of trim surfaces

type
Geometry type

Please refer to the wiki for details on using this class member.

Getter Gets the geometry type

Type str

vis
Visualization component.

Please refer to the wiki for details on using this class member.

Getter Gets the visualization component

Setter Sets the visualization component

Type vis.VisAbstract

weights
Weights vector.

Getter Gets the weights vector

Setter Sets the weights vector

Type list

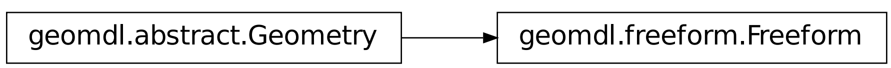
17.1.3 Freeform Geometry

New in version 5.2.

`freeform` module provides classes for representing freeform geometry objects.

Freeform class provides a basis for storing freeform geometries. The points of the geometry can be set via the *evaluate()* method using a keyword argument.

Inheritance Diagram



Class Reference

class geomdl.freeform.**Freeform**(***kwargs*)
Bases: *geomdl.abstract.Geometry*

n-dimensional freeform geometry

data
Returns a dict which contains the geometry data.

Please refer to the wiki for details on using this class member.

dimension
Spatial dimension.

Please refer to the wiki for details on using this class member.

Getter Gets the spatial dimension, e.g. 2D, 3D, etc.

Type int

evalpts
Evaluated points.

Please refer to the wiki for details on using this class member.

Getter Gets the coordinates of the evaluated points

Type list

evaluate (***kwargs*)
Sets points that form the geometry.

Keyword Arguments:

- `points`: sets the points

id
Object ID (as an integer).

Please refer to the wiki for details on using this class member.

Getter Gets the object ID

Setter Sets the object ID

Type int

name
Object name (as a string)

Please refer to the wiki for details on using this class member.

Getter Gets the object name

Setter Sets the object name

Type str

opt
Dictionary for storing custom data in the current geometry object.

`opt` is a wrapper to a dict in *key* => *value* format, where *key* is string, *value* is any Python object. You can use `opt` property to store custom data inside the geometry object. For instance:

```
geom.opt = ["face_id", 4]  # creates "face_id" key and sets its value to an␣
↪integer
geom.opt = ["contents", "data values"]  # creates "face_id" key and sets its␣
↪value to a string
print(geom.opt)  # will print: {'face_id': 4, 'contents': 'data values'}

del geom.opt  # deletes the contents of the hash map
print(geom.opt)  # will print: {}

geom.opt = ["body_id", 1]  # creates "body_id" key  and sets its value to 1
geom.opt = ["body_id", 12]  # changes the value of "body_id" to 12
print(geom.opt)  # will print: {'body_id': 12}

geom.opt = ["body_id", None]  # deletes "body_id"
print(geom.opt)  # will print: {}
```

Please refer to the wiki for details on using this class member.

Getter Gets the dict

Setter Adds key and value pair to the dict

Deleter Deletes the contents of the dict

opt_get (*value*)
Safely query for the value from the `opt` property.

Parameters **value** (`str`) – a key in the `opt` property

Returns the corresponding value, if the key exists. None, otherwise.

type
Geometry type

Please refer to the wiki for details on using this class member.

Getter Gets the geometry type

Type str

17.1.4 Geometry Containers

The multi module provides specialized geometry containers. A container is a holder object that stores a collection of other objects, i.e. its elements. In NURBS-Python, containers can be generated as a result of

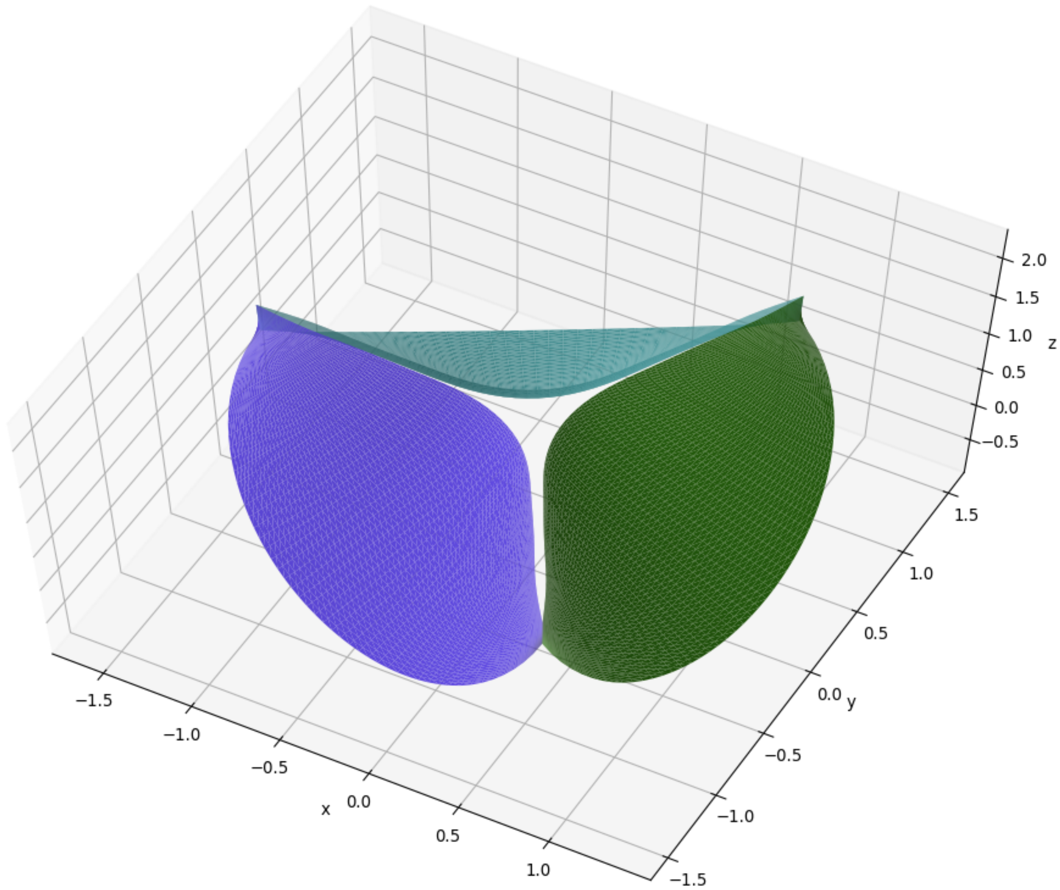
- A geometric operation, such as **splitting**
- File import, e.g. reading a file or a set of files containing multiple surfaces

The multi module contains the following classes:

- *AbstractContainer* abstract base class for containers
- *CurveContainer* for storing multiple curves
- *SurfaceContainer* for storing multiple surfaces
- *VolumeContainer* for storing multiple volumes

How to Use

These containers can be used for many purposes, such as visualization of a multi-component geometry or file export. For instance, the following figure shows a heart valve with 3 leaflets:



Each leaflet is a NURBS surface added to a *SurfaceContainer* and rendered via Matplotlib visualization module. It is possible to input a list of colors to the `render` method, otherwise it will automatically pick an arbitrary color.

Inheritance Diagram

Abstract Container

class geomdl.multi.**AbstractContainer**(**args*, ***kwargs*)

Bases: *geomdl.abstract.GeomdlBase*

Abstract class for geometry containers.

This class implements Python Iterator Protocol and therefore any instance of this class can be directly used in a for loop.

This class provides the following properties:

- `type` = container
- `id`
- `name`
- `dimension`
- `opt`
- `pdimension`
- `evalpts`
- `bbox`
- `vis`
- `delta`
- `sample_size`

add(*element*)

Adds geometry objects to the container.

The input can be a single geometry, a list of geometry objects or a geometry container object.

Parameters element – geometry object

append(*element*)

Adds geometry objects to the container.

The input can be a single geometry, a list of geometry objects or a geometry container object.

Parameters element – geometry object

bbox

Bounding box.

Please refer to the wiki for details on using this class member.

Getter Gets the bounding box of all contained geometries

data

Returns a dict which contains the geometry data.

Please refer to the wiki for details on using this class member.

delta

Evaluation delta (for all parametric directions).

Evaluation delta corresponds to the *step size*. Decreasing the step size results in evaluation of more points. Therefore; smaller the delta value, smoother the shape.

The following figure illustrates the working principles of the delta property:

$$[u_{start}, u_{start} + \delta, (u_{start} + \delta) + \delta, \dots, u_{end}]$$

Please refer to the wiki for details on using this class member.

Getter Gets the delta value

Setter Sets the delta value

dimension

Spatial dimension.

Please refer to the wiki for details on using this class member.

Getter Gets the spatial dimension, e.g. 2D, 3D, etc.

Type int

evalpts

Evaluated points.

Since there are multiple geometry objects contained in the multi objects, the evaluated points will be returned in the format of list of individual evaluated points which is also a list of Cartesian coordinates.

The following code example illustrates these details:

```
multi_obj = multi.SurfaceContainer()  # it can also be multi.CurveContainer()
# Add geometries to multi_obj via multi_obj.add() method
# Then, the following loop will print all the evaluated points of the Multi object
for idx, mpt in enumerate(multi_obj.evalpts):
    print("Shape", idx+1, "contains", len(mpt), "points. These points are:")
    for pt in mpt:
        line = ", ".join([str(p) for p in pt])
        print(line)
```

Please refer to the wiki for details on using this class member.

Getter Gets the evaluated points of all contained geometries

id

Object ID (as an integer).

Please refer to the wiki for details on using this class member.

Getter Gets the object ID

Setter Sets the object ID

Type int

name

Object name (as a string)

Please refer to the wiki for details on using this class member.

Getter Gets the object name

Setter Sets the object name

Type str

opt

Dictionary for storing custom data in the current geometry object.

`opt` is a wrapper to a dict in *key* => *value* format, where *key* is string, *value* is any Python object. You can use `opt` property to store custom data inside the geometry object. For instance:

```
geom.opt = ["face_id", 4]  # creates "face_id" key and sets its value to an integer
geom.opt = ["contents", "data values"]  # creates "face_id" key and sets its value to a string
```

(continues on next page)

(continued from previous page)

```
print(geom.opt)  # will print: {'face_id': 4, 'contents': 'data values'}

del geom.opt  # deletes the contents of the hash map
print(geom.opt)  # will print: {}

geom.opt = ["body_id", 1]  # creates "body_id" key  and sets its value to 1
geom.opt = ["body_id", 12]  # changes the value of "body_id" to 12
print(geom.opt)  # will print: {'body_id': 12}

geom.opt = ["body_id", None]  # deletes "body_id"
print(geom.opt)  # will print: {}
```

Please refer to the wiki for details on using this class member.

Getter Gets the dict

Setter Adds key and value pair to the dict

Deleter Deletes the contents of the dict

opt_get(*value*)

Safely query for the value from the `opt` property.

Parameters **value** (`str`) – a key in the `opt` property

Returns the corresponding value, if the key exists. `None`, otherwise.

pdimension

Parametric dimension.

Please refer to the wiki for details on using this class member.

Getter Gets the parametric dimension

Type int

render(***kwargs*)

Renders plots using the visualization component.

Note: This is an abstract method and it must be implemented in the subclass.

reset()

Resets the cache.

sample_size

Sample size (for all parametric directions).

Sample size defines the number of points to evaluate. It also sets the `delta` property.

The following figure illustrates the working principles of sample size property:

$$\underbrace{[u_{start}, \ldots, u_{end}]}_{n_{sample}}$$

Please refer to the wiki for details on using this class member.

Getter Gets sample size

Setter Sets sample size

type
Geometry type

Please refer to the wiki for details on using this class member.

Getter Gets the geometry type

Type str

vis
Visualization component.

Please refer to the wiki for details on using this class member.

Getter Gets the visualization component

Setter Sets the visualization component

Curve Container

class geomdl.multi.**CurveContainer**(**args*, ***kwargs*)
Bases: *geomdl.multi.AbstractContainer*

Container class for storing multiple curves.

This class implements Python Iterator Protocol and therefore any instance of this class can be directly used in a for loop.

This class provides the following properties:

- *type* = container
- *id*
- *name*
- *dimension*
- *opt*
- *pdimension*
- *evalpts*
- *bbox*
- *vis*
- *delta*
- *sample_size*

The following code example illustrates the usage of the Python properties:

```
# Create a multi-curve container instance
mcrv = multi.CurveContainer()

# Add single or multi curves to the multi container using mcrv.add() command
# Addition operator, e.g. mcrv1 + mcrv2, also works

# Set the evaluation delta of the multi-curve
mcrv.delta = 0.05

# Get the evaluated points
curve_points = mcrv.evalpts
```

add (*element*)
Adds geometry objects to the container.

The input can be a single geometry, a list of geometry objects or a geometry container object.

Parameters element – geometry object

append (*element*)
Adds geometry objects to the container.

The input can be a single geometry, a list of geometry objects or a geometry container object.

Parameters element – geometry object

bbox
Bounding box.

Please refer to the wiki for details on using this class member.

Getter Gets the bounding box of all contained geometries

data
Returns a dict which contains the geometry data.

Please refer to the wiki for details on using this class member.

delta
Evaluation delta (for all parametric directions).

Evaluation delta corresponds to the *step size*. Decreasing the step size results in evaluation of more points. Therefore; smaller the delta value, smoother the shape.

The following figure illustrates the working principles of the delta property:

$$[u_{start}, u_{start} + \delta, (u_{start} + \delta) + \delta, \dots, u_{end}]$$

Please refer to the wiki for details on using this class member.

Getter Gets the delta value

Setter Sets the delta value

dimension
Spatial dimension.

Please refer to the wiki for details on using this class member.

Getter Gets the spatial dimension, e.g. 2D, 3D, etc.

Type int

evalpts
Evaluated points.

Since there are multiple geometry objects contained in the multi objects, the evaluated points will be returned in the format of list of individual evaluated points which is also a list of Cartesian coordinates.

The following code example illustrates these details:

```
multi_obj = multi.SurfaceContainer()  # it can also be multi.CurveContainer()
# Add geometries to multi_obj via multi_obj.add() method
# Then, the following loop will print all the evaluated points of the Multi␣
↪object
for idx, mpt in enumerate(multi_obj.evalpts):
    print("Shape", idx+1, "contains", len(mpt), "points. These points are:")
```

(continues on next page)

(continued from previous page)

```
    for pt in mpt:
        line = ", ".join([str(p) for p in pt])
        print(line)
```

Please refer to the wiki for details on using this class member.

Getter Gets the evaluated points of all contained geometries

id

Object ID (as an integer).

Please refer to the wiki for details on using this class member.

Getter Gets the object ID

Setter Sets the object ID

Type int

name

Object name (as a string)

Please refer to the wiki for details on using this class member.

Getter Gets the object name

Setter Sets the object name

Type str

opt

Dictionary for storing custom data in the current geometry object.

`opt` is a wrapper to a dict in *key* => *value* format, where *key* is string, *value* is any Python object. You can use `opt` property to store custom data inside the geometry object. For instance:

```
geom.opt = ["face_id", 4]  # creates "face_id" key and sets its value to an␣
↪integer
geom.opt = ["contents", "data values"]  # creates "face_id" key and sets its␣
↪value to a string
print(geom.opt)  # will print: {'face_id': 4, 'contents': 'data values'}

del geom.opt  # deletes the contents of the hash map
print(geom.opt)  # will print: {}

geom.opt = ["body_id", 1]  # creates "body_id" key  and sets its value to 1
geom.opt = ["body_id", 12]  # changes the value of "body_id" to 12
print(geom.opt)  # will print: {'body_id': 12}

geom.opt = ["body_id", None]  # deletes "body_id"
print(geom.opt)  # will print: {}
```

Please refer to the wiki for details on using this class member.

Getter Gets the dict

Setter Adds key and value pair to the dict

Deleter Deletes the contents of the dict

opt_get (*value*)

Safely query for the value from the `opt` property.

Parameters **value** (*str*) – a key in the *opt* property

Returns the corresponding value, if the key exists. `None`, otherwise.

pdimension

Parametric dimension.

Please refer to the wiki for details on using this class member.

Getter Gets the parametric dimension

Type int

render (***kwargs*)

Renders the curves.

The visualization component must be set using *vis* property before calling this method.

Keyword Arguments:

- `cpcolor`: sets the color of the control points grid
- `evalcolor`: sets the color of the surface
- `filename`: saves the plot with the input name
- `plot`: controls plot window visibility. *Default: True*
- `animate`: activates animation (if supported). *Default: False*
- `delta`: if True, the evaluation delta of the container object will be used. *Default: True*
- `reset_names`: resets the name of the curves inside the container. *Default: False*

The `cpcolor` and `evalcolor` arguments can be a string or a list of strings corresponding to the color values. Both arguments are processed separately, e.g. `cpcolor` can be a string whereas `evalcolor` can be a list or a tuple, or vice versa. A single string value sets the color to the same value. List input allows customization over the color values. If none provided, a random color will be selected.

The `plot` argument is useful when you would like to work on the command line without any window context. If `plot` flag is False, this method saves the plot as an image file (.png file where possible) and disables plot window popping out. If you don't provide a file name, the name of the image file will be pulled from the configuration class.

reset ()

Resets the cache.

sample_size

Sample size (for all parametric directions).

Sample size defines the number of points to evaluate. It also sets the `delta` property.

The following figure illustrates the working principles of sample size property:

$$\underbrace{\left[u_{start}, \ldots, u_{end}\right]}_{n_{sample}}$$

Please refer to the wiki for details on using this class member.

Getter Gets sample size

Setter Sets sample size

type

Geometry type

Please refer to the wiki for details on using this class member.

Getter Gets the geometry type

Type str

vis

Visualization component.

Please refer to the wiki for details on using this class member.

Getter Gets the visualization component

Setter Sets the visualization component

Surface Container

class geomdl.multi.**SurfaceContainer**(**args*, ***kwargs*)

Bases: *geomdl.multi.AbstractContainer*

Container class for storing multiple surfaces.

This class implements Python Iterator Protocol and therefore any instance of this class can be directly used in a for loop.

This class provides the following properties:

- *type* = container
- *id*
- *name*
- *dimension*
- *opt*
- *pdimension*
- *evalpts*
- *bbox*
- *vis*
- *delta*
- *delta_u*
- *delta_v*
- *sample_size*
- *sample_size_u*
- *sample_size_v*
- *tessellator*
- *vertices*
- *faces*

The following code example illustrates the usage of these Python properties:

```
# Create a multi-surface container instance
msurf = multi.SurfaceContainer()

# Add single or multi surfaces to the multi container using msurf.add() command
# Addition operator, e.g. msurf1 + msurf2, also works

# Set the evaluation delta of the multi-surface
msurf.delta = 0.05

# Get the evaluated points
surface_points = msurf.evalpts
```

add(*element*)

Adds geometry objects to the container.

The input can be a single geometry, a list of geometry objects or a geometry container object.

Parameters **element** – geometry object

append(*element*)

Adds geometry objects to the container.

The input can be a single geometry, a list of geometry objects or a geometry container object.

Parameters **element** – geometry object

bbox

Bounding box.

Please refer to the wiki for details on using this class member.

Getter Gets the bounding box of all contained geometries

data

Returns a dict which contains the geometry data.

Please refer to the wiki for details on using this class member.

delta

Evaluation delta (for all parametric directions).

Evaluation delta corresponds to the *step size*. Decreasing the step size results in evaluation of more points. Therefore; smaller the delta value, smoother the shape.

The following figure illustrates the working principles of the delta property:

$$[u_{start}, u_{start} + \delta, (u_{start} + \delta) + \delta, \dots, u_{end}]$$

Please refer to the wiki for details on using this class member.

Getter Gets the delta value

Setter Sets the delta value

delta_u

Evaluation delta for the u-direction.

Evaluation delta corresponds to the *step size*. Decreasing the step size results in evaluation of more points. Therefore; smaller the delta, smoother the shape.

Please note that `delta_u` and `sample_size_u` properties correspond to the same variable with different descriptions. Therefore, setting `delta_u` will also set `sample_size_u`.

Please refer to the wiki for details on using this class member.

Getter Gets the delta value for the u-direction

Setter Sets the delta value for the u-direction

Type float

delta_v

Evaluation delta for the v-direction.

Evaluation delta corresponds to the *step size*. Decreasing the step size results in evaluation of more points. Therefore; smaller the delta, smoother the shape.

Please note that `delta_v` and `sample_size_v` properties correspond to the same variable with different descriptions. Therefore, setting `delta_v` will also set `sample_size_v`.

Please refer to the wiki for details on using this class member.

Getter Gets the delta value for the v-direction

Setter Sets the delta value for the v-direction

Type float

dimension

Spatial dimension.

Please refer to the wiki for details on using this class member.

Getter Gets the spatial dimension, e.g. 2D, 3D, etc.

Type int

evalpts

Evaluated points.

Since there are multiple geometry objects contained in the multi objects, the evaluated points will be returned in the format of list of individual evaluated points which is also a list of Cartesian coordinates.

The following code example illustrates these details:

```
multi_obj = multi.SurfaceContainer()  # it can also be multi.CurveContainer()
# Add geometries to multi_obj via multi_obj.add() method
# Then, the following loop will print all the evaluated points of the Multi␣
↪object
for idx, mpt in enumerate(multi_obj.evalpts):
    print("Shape", idx+1, "contains", len(mpt), "points. These points are:")
    for pt in mpt:
        line = ", ".join([str(p) for p in pt])
        print(line)
```

Please refer to the wiki for details on using this class member.

Getter Gets the evaluated points of all contained geometries

faces

Faces (triangles, quads, etc.) generated by the tessellation operation.

If the tessellation component is set to None, the result will be an empty list.

Getter Gets the faces

id

Object ID (as an integer).

Please refer to the wiki for details on using this class member.

Getter Gets the object ID

Setter Sets the object ID

Type int

name
Object name (as a string)

Please refer to the wiki for details on using this class member.

Getter Gets the object name

Setter Sets the object name

Type str

opt
Dictionary for storing custom data in the current geometry object.

opt is a wrapper to a dict in *key* => *value* format, where *key* is string, *value* is any Python object. You can use opt property to store custom data inside the geometry object. For instance:

```
geom.opt = ["face_id", 4]  # creates "face_id" key and sets its value to an␣
↪integer
geom.opt = ["contents", "data values"]  # creates "face_id" key and sets its␣
↪value to a string
print(geom.opt)  # will print: {'face_id': 4, 'contents': 'data values'}

del geom.opt  # deletes the contents of the hash map
print(geom.opt)  # will print: {}

geom.opt = ["body_id", 1]  # creates "body_id" key  and sets its value to 1
geom.opt = ["body_id", 12]  # changes the value of "body_id" to 12
print(geom.opt)  # will print: {'body_id': 12}

geom.opt = ["body_id", None]  # deletes "body_id"
print(geom.opt)  # will print: {}
```

Please refer to the wiki for details on using this class member.

Getter Gets the dict

Setter Adds key and value pair to the dict

Deleter Deletes the contents of the dict

opt_get (*value*)
Safely query for the value from the opt property.

Parameters **value** (*str*) – a key in the opt property

Returns the corresponding value, if the key exists. None, otherwise.

pdimension
Parametric dimension.

Please refer to the wiki for details on using this class member.

Getter Gets the parametric dimension

Type int

render (***kwargs*)
Renders the surfaces.

The visualization component must be set using `vis` property before calling this method.

Keyword Arguments:

- `cpcolor`: sets the color of the control points grids
- `evalcolor`: sets the color of the surface
- `filename`: saves the plot with the input name
- `plot`: controls plot window visibility. *Default: True*
- `animate`: activates animation (if supported). *Default: False*
- `colormap`: sets the colormap of the surfaces
- `delta`: if True, the evaluation delta of the container object will be used. *Default: True*
- `reset_names`: resets the name of the surfaces inside the container. *Default: False*
- `num_procs`: number of concurrent processes for rendering the surfaces. *Default: 1*

The `cpcolor` and `evalcolor` arguments can be a string or a list of strings corresponding to the color values. Both arguments are processed separately, e.g. `cpcolor` can be a string whereas `evalcolor` can be a list or a tuple, or vice versa. A single string value sets the color to the same value. List input allows customization over the color values. If none provided, a random color will be selected.

The `plot` argument is useful when you would like to work on the command line without any window context. If `plot` flag is False, this method saves the plot as an image file (.png file where possible) and disables plot window popping out. If you don't provide a file name, the name of the image file will be pulled from the configuration class.

Please note that `colormap` argument can only work with visualization classes that support colormaps. As an example, please see `VisMPL.VisSurfTriangle()` class documentation. This method expects multiple colormap inputs as a list or tuple, preferable the input list size is the same as the number of surfaces contained in the class. In the case of number of surfaces is bigger than number of input colormaps, this method will automatically assign a random color for the remaining surfaces.

reset()

Resets the cache.

sample_size

Sample size (for all parametric directions).

Sample size defines the number of points to evaluate. It also sets the `delta` property.

The following figure illustrates the working principles of sample size property:

$$\underbrace{\left[u_{start}, \ldots, u_{end}\right]}_{n_{sample}}$$

Please refer to the wiki for details on using this class member.

Getter Gets sample size

Setter Sets sample size

sample_size_u

Sample size for the u-direction.

Sample size defines the number of points to evaluate. It also sets the `delta_u` property.

Please refer to the wiki for details on using this class member.

Getter Gets sample size for the u-direction

Setter Sets sample size for the u-direction

Type int

sample_size_v
Sample size for the v-direction.

Sample size defines the number of points to evaluate. It also sets the `delta_v` property.

Please refer to the wiki for details on using this class member.

Getter Gets sample size for the v-direction

Setter Sets sample size for the v-direction

Type int

tessellate(***kwargs*)
Tessellates the surfaces inside the container.

Keyword arguments are directly passed to the tessellation component.

The following code snippet illustrates getting the vertices and faces of the surfaces inside the container:

```
# Tessellate the surfaces inside the container
surf_container.tessellate()

# Vertices and faces are stored inside the tessellator component
tsl = surf_container.tessellator

# Loop through all tessellator components
for t in tsl:
    # Get the vertices
    vertices = t.tessellator.vertices
    # Get the faces (triangles, quads, etc.)
    faces = t.tessellator.faces
```

Keyword Arguments:

- `num_procs`: number of concurrent processes for tessellating the surfaces. *Default: 1*
- `delta`: if True, the evaluation delta of the container object will be used. *Default: True*
- `force`: flag to force tessellation. *Default: False*

tessellator
Tessellation component of the surfaces inside the container.

Please refer to *Tessellation* documentation for details.

```
from geomdl import multi
from geomdl import tessellate

# Create the surface container
surf_container = multi.SurfaceContainer(surf_list)

# Set tessellator component
surf_container.tessellator = tessellate.TrimTessellate()
```

Getter gets the tessellation component

Setter sets the tessellation component

type

Geometry type

Please refer to the wiki for details on using this class member.

Getter Gets the geometry type

Type str

vertices

Vertices generated by the tessellation operation.

If the tessellation component is set to None, the result will be an empty list.

Getter Gets the vertices

vis

Visualization component.

Please refer to the wiki for details on using this class member.

Getter Gets the visualization component

Setter Sets the visualization component

Volume Container

class geomdl.multi.**VolumeContainer**(**args*, ***kwargs*)

Bases: *geomdl.multi.AbstractContainer*

Container class for storing multiple volumes.

This class implements Python Iterator Protocol and therefore any instance of this class can be directly used in a for loop.

This class provides the following properties:

- *type*
- *id*
- *name*
- *dimension*
- *opt*
- *pdimension*
- *evalpts*
- *bbox*
- *vis*
- *delta*
- *delta_u*
- *delta_v*
- *delta_w*
- *sample_size*
- *sample_size_u*
- *sample_size_v*

- *sample_size_w*

The following code example illustrates the usage of these Python properties:

```
# Create a multi-volume container instance
mvol = multi.VolumeContainer()

# Add single or multi volumes to the multi container using mvol.add() command
# Addition operator, e.g. mvol1 + mvol2, also works

# Set the evaluation delta of the multi-volume
mvol.delta = 0.05

# Get the evaluated points
volume_points = mvol.evalpts
```

add(*element*)
Adds geometry objects to the container.

The input can be a single geometry, a list of geometry objects or a geometry container object.

Parameters element – geometry object

append(*element*)
Adds geometry objects to the container.

The input can be a single geometry, a list of geometry objects or a geometry container object.

Parameters element – geometry object

bbox
Bounding box.

Please refer to the wiki for details on using this class member.

Getter Gets the bounding box of all contained geometries

data
Returns a dict which contains the geometry data.

Please refer to the wiki for details on using this class member.

delta
Evaluation delta (for all parametric directions).

Evaluation delta corresponds to the *step size*. Decreasing the step size results in evaluation of more points. Therefore; smaller the delta value, smoother the shape.

The following figure illustrates the working principles of the delta property:

$$[u_{start}, u_{start} + \delta, (u_{start} + \delta) + \delta, \dots, u_{end}]$$

Please refer to the wiki for details on using this class member.

Getter Gets the delta value

Setter Sets the delta value

delta_u
Evaluation delta for the u-direction.

Evaluation delta corresponds to the *step size*. Decreasing the step size results in evaluation of more points. Therefore; smaller the delta, smoother the shape.

Please note that `delta_u` and `sample_size_u` properties correspond to the same variable with different descriptions. Therefore, setting `delta_u` will also set `sample_size_u`.

Please refer to the wiki for details on using this class member.

Getter Gets the delta value for the u-direction

Setter Sets the delta value for the u-direction

Type float

delta_v
Evaluation delta for the v-direction.

Evaluation delta corresponds to the *step size*. Decreasing the step size results in evaluation of more points. Therefore; smaller the delta, smoother the shape.

Please note that `delta_v` and `sample_size_v` properties correspond to the same variable with different descriptions. Therefore, setting `delta_v` will also set `sample_size_v`.

Please refer to the wiki for details on using this class member.

Getter Gets the delta value for the v-direction

Setter Sets the delta value for the v-direction

Type float

delta_w
Evaluation delta for the w-direction.

Evaluation delta corresponds to the *step size*. Decreasing the step size results in evaluation of more points. Therefore; smaller the delta, smoother the shape.

Please note that `delta_w` and `sample_size_w` properties correspond to the same variable with different descriptions. Therefore, setting `delta_w` will also set `sample_size_w`.

Please refer to the wiki for details on using this class member.

Getter Gets the delta value for the w-direction

Setter Sets the delta value for the w-direction

Type float

dimension
Spatial dimension.

Please refer to the wiki for details on using this class member.

Getter Gets the spatial dimension, e.g. 2D, 3D, etc.

Type int

evalpts
Evaluated points.

Since there are multiple geometry objects contained in the multi objects, the evaluated points will be returned in the format of list of individual evaluated points which is also a list of Cartesian coordinates.

The following code example illustrates these details:

```
multi_obj = multi.SurfaceContainer()  # it can also be multi.CurveContainer()
# Add geometries to multi_obj via multi_obj.add() method
# Then, the following loop will print all the evaluated points of the Multi␣
↪object
```

(continues on next page)

(continued from previous page)

```
for idx, mpt in enumerate(multi_obj.evalpts):
    print("Shape", idx+1, "contains", len(mpt), "points. These points are:")
    for pt in mpt:
        line = ", ".join([str(p) for p in pt])
        print(line)
```

Please refer to the wiki for details on using this class member.

Getter Gets the evaluated points of all contained geometries

id

Object ID (as an integer).

Please refer to the wiki for details on using this class member.

Getter Gets the object ID

Setter Sets the object ID

Type int

name

Object name (as a string)

Please refer to the wiki for details on using this class member.

Getter Gets the object name

Setter Sets the object name

Type str

opt

Dictionary for storing custom data in the current geometry object.

`opt` is a wrapper to a dict in *key* => *value* format, where *key* is string, *value* is any Python object. You can use `opt` property to store custom data inside the geometry object. For instance:

```
geom.opt = ["face_id", 4]  # creates "face_id" key and sets its value to an␣
↪integer
geom.opt = ["contents", "data values"]  # creates "face_id" key and sets its␣
↪value to a string
print(geom.opt)  # will print: {'face_id': 4, 'contents': 'data values'}

del geom.opt  # deletes the contents of the hash map
print(geom.opt)  # will print: {}

geom.opt = ["body_id", 1]  # creates "body_id" key  and sets its value to 1
geom.opt = ["body_id", 12]  # changes the value of "body_id" to 12
print(geom.opt)  # will print: {'body_id': 12}

geom.opt = ["body_id", None]  # deletes "body_id"
print(geom.opt)  # will print: {}
```

Please refer to the wiki for details on using this class member.

Getter Gets the dict

Setter Adds key and value pair to the dict

Deleter Deletes the contents of the dict

opt_get (*value*)
Safely query for the value from the `opt` property.

Parameters **value** (`str`) – a key in the `opt` property

Returns the corresponding value, if the key exists. `None`, otherwise.

pdimension
Parametric dimension.

Please refer to the wiki for details on using this class member.

Getter Gets the parametric dimension

Type int

render (***kwargs*)
Renders the volumes.

The visualization component must be set using `vis` property before calling this method.

Keyword Arguments:

- `cpcolor`: sets the color of the control points plot
- `evalcolor`: sets the color of the volume
- `filename`: saves the plot with the input name
- `plot`: controls plot window visibility. *Default: True*
- `animate`: activates animation (if supported). *Default: False*
- `delta`: if True, the evaluation delta of the container object will be used. *Default: True*
- `reset_names`: resets the name of the volumes inside the container. *Default: False*
- `grid_size`: grid size for voxelization. *Default: (16, 16, 16)*
- `num_procs`: number of concurrent processes for voxelization. *Default: 1*

The `cpcolor` and `evalcolor` arguments can be a string or a list of strings corresponding to the color values. Both arguments are processed separately, e.g. `cpcolor` can be a string whereas `evalcolor` can be a list or a tuple, or vice versa. A single string value sets the color to the same value. List input allows customization over the color values. If none provided, a random color will be selected.

The `plot` argument is useful when you would like to work on the command line without any window context. If `plot` flag is False, this method saves the plot as an image file (.png file where possible) and disables plot window popping out. If you don't provide a file name, the name of the image file will be pulled from the configuration class.

reset ()
Resets the cache.

sample_size
Sample size (for all parametric directions).

Sample size defines the number of points to evaluate. It also sets the `delta` property.

The following figure illustrates the working principles of sample size property:

$$\underbrace{\left[u_{start}, \ldots, u_{end}\right]}_{n_{sample}}$$

Please refer to the wiki for details on using this class member.

Getter Gets sample size

Setter Sets sample size

sample_size_u
Sample size for the u-direction.

Sample size defines the number of points to evaluate. It also sets the `delta_u` property.

Please refer to the wiki for details on using this class member.

Getter Gets sample size for the u-direction

Setter Sets sample size for the u-direction

Type int

sample_size_v
Sample size for the v-direction.

Sample size defines the number of points to evaluate. It also sets the `delta_v` property.

Please refer to the wiki for details on using this class member.

Getter Gets sample size for the v-direction

Setter Sets sample size for the v-direction

Type int

sample_size_w
Sample size for the w-direction.

Sample size defines the number of points to evaluate. It also sets the `delta_w` property.

Please refer to the wiki for details on using this class member.

Getter Gets sample size for the w-direction

Setter Sets sample size for the w-direction

Type int

type
Geometry type

Please refer to the wiki for details on using this class member.

Getter Gets the geometry type

Type str

vis
Visualization component.

Please refer to the wiki for details on using this class member.

Getter Gets the visualization component

Setter Sets the visualization component

The following is the list of the features and geometric operations included in the library:

17.1.5 Geometric Operations

This module provides common geometric operations for curves and surfaces. It includes the following operations:

- Knot insertion, removal and refinement
- Curve and surface splitting / Bézier decomposition

- Tangent, normal and binormal evaluations
- Hodograph curve and surface computations
- Translation, rotation and scaling

Function Reference

geomdl.operations.**insert_knot**(*obj*, *param*, *num*, ***kwargs*)

Inserts knots n-times to a spline geometry.

The following code snippet illustrates the usage of this function:

```
# Insert knot u=0.5 to a curve 2 times
operations.insert_knot(curve, [0.5], [2])

# Insert knot v=0.25 to a surface 1 time
operations.insert_knot(surface, [None, 0.25], [0, 1])

# Insert knots u=0.75, v=0.25 to a surface 2 and 1 times, respectively
operations.insert_knot(surface, [0.75, 0.25], [2, 1])

# Insert knot w=0.5 to a volume 1 time
operations.insert_knot(volume, [None, None, 0.5], [0, 0, 1])
```

Please note that input spline geometry object will always be updated if the knot insertion operation is successful.

Keyword Arguments:

- `check_num`: enables/disables operation validity checks. *Default: True*

Parameters

- **obj** (`abstract.SplineGeometry`) – spline geometry
- **param** (*list, tuple*) – knot(s) to be inserted in [u, v, w] format
- **num** (*list, tuple*) – number of knot insertions in [num_u, num_v, num_w] format

Returns updated spline geometry

geomdl.operations.**remove_knot**(*obj*, *param*, *num*, ***kwargs*)

Removes knots n-times from a spline geometry.

The following code snippet illustrates the usage of this function:

```
# Remove knot u=0.5 from a curve 2 times
operations.remove_knot(curve, [0.5], [2])

# Remove knot v=0.25 from a surface 1 time
operations.remove_knot(surface, [None, 0.25], [0, 1])

# Remove knots u=0.75, v=0.25 from a surface 2 and 1 times, respectively
operations.remove_knot(surface, [0.75, 0.25], [2, 1])

# Remove knot w=0.5 from a volume 1 time
operations.remove_knot(volume, [None, None, 0.5], [0, 0, 1])
```

Please note that input spline geometry object will always be updated if the knot removal operation is successful.

Keyword Arguments:

- `check_num`: enables/disables operation validity checks. *Default: True*

Parameters

- **obj** (`abstract.SplineGeometry`) – spline geometry
- **param** (*list, tuple*) – knot(s) to be removed in [u, v, w] format
- **num** (*list, tuple*) – number of knot removals in [num_u, num_v, num_w] format

Returns updated spline geometry

geomdl.operations.**refine_knotvector**(*obj*, *param*, ***kwargs*)

Refines the knot vector(s) of a spline geometry.

The following code snippet illustrates the usage of this function:

```
# Refines the knot vector of a curve
operations.refine_knotvector(curve, [1])

# Refines the knot vector on the v-direction of a surface
operations.refine_knotvector(surface, [0, 1])

# Refines the both knot vectors of a surface
operations.refine_knotvector(surface, [1, 1])

# Refines the knot vector on the w-direction of a volume
operations.refine_knotvector(volume, [0, 0, 1])
```

The values of `param` argument can be used to set the *knot refinement density*. If *density* is bigger than 1, then the algorithm finds the middle knots in each internal knot span to increase the number of knots to be refined.

Example: Let the degree is 2 and the knot vector to be refined is `[0, 2, 4]` with the superfluous knots from the start and end are removed. Knot vectors with the changing `density (d)` value will be:

- `d = 1`, knot vector `[0, 1, 1, 2, 2, 3, 3, 4]`
- `d = 2`, knot vector `[0, 0.5, 0.5, 1, 1, 1.5, 1.5, 2, 2, 2.5, 2.5, 3, 3, 3.5, 3.5, 4]`

The following code snippet illustrates the usage of knot refinement densities:

```
# Refines the knot vector of a curve with density = 3
operations.refine_knotvector(curve, [3])

# Refines the knot vectors of a surface with density for
# u-dir = 2 and v-dir = 3
operations.refine_knotvector(surface, [2, 3])

# Refines only the knot vector on the v-direction of a surface with density = 1
operations.refine_knotvector(surface, [0, 1])

# Refines the knot vectors of a volume with density for
# u-dir = 1, v-dir = 3 and w-dir = 2
operations.refine_knotvector(volume, [1, 3, 2])
```

Please refer to *helpers.knot_refinement()* function for more usage options.

Keyword Arguments:

- `check_num`: enables/disables operation validity checks. *Default: True*

Parameters

- **obj** (abstract.SplineGeometry) – spline geometry
- **param** (*list, tuple*) – parametric dimensions to be refined in [u, v, w] format

Returns updated spline geometry

geomdl.operations.**add_dimension**(*obj*, ***kwargs*)

Elevates the spatial dimension of the spline geometry.

If you pass `inplace=True` keyword argument, the input will be updated. Otherwise, this function does not change the input but returns a new instance with the updated data.

Parameters **obj** (abstract.SplineGeometry) – spline geometry

Returns updated spline geometry

Return type *abstract.SplineGeometry*

geomdl.operations.**split_curve**(*obj*, *param*, ***kwargs*)

Splits the curve at the input parametric coordinate.

This method splits the curve into two pieces at the given parametric coordinate, generates two different curve objects and returns them. It does not modify the input curve.

Keyword Arguments:

- `find_span_func`: FindSpan implementation. *Default:* *helpers.find_span_linear()*
- `insert_knot_func`: knot insertion algorithm implementation. *Default:* *operations.insert_knot()*

Parameters

- **obj** (abstract.Curve) – Curve to be split
- **param** (*float*) – parameter

Returns a list of curve segments

Return type list

geomdl.operations.**decompose_curve**(*obj*, ***kwargs*)

Decomposes the curve into Bezier curve segments of the same degree.

This operation does not modify the input curve, instead it returns the split curve segments.

Keyword Arguments:

- `find_span_func`: FindSpan implementation. *Default:* *helpers.find_span_linear()*
- `insert_knot_func`: knot insertion algorithm implementation. *Default:* *operations.insert_knot()*

Parameters **obj** (abstract.Curve) – Curve to be decomposed

Returns a list of Bezier segments

Return type list

geomdl.operations.**derivative_curve**(*obj*)

Computes the hodograph (first derivative) curve of the input curve.

This function constructs the hodograph (first derivative) curve from the input curve by computing the degrees, knot vectors and the control points of the derivative curve.

Parameters **obj** (`abstract.Curve`) – input curve

Returns derivative curve

`geomdl.operations.`**`length_curve`**(*obj*)

Computes the approximate length of the parametric curve.

Uses the following equation to compute the approximate length:

$$\sum_{i=0}^{n-1} \sqrt{P_{i+1}^2 - P_i^2}$$

where n is number of evaluated curve points and P is the n-dimensional point.

Parameters **obj** (`abstract.Curve`) – input curve

Returns length

Return type float

`geomdl.operations.`**`split_surface_u`**(*obj*, *param*, ***kwargs*)

Splits the surface at the input parametric coordinate on the u-direction.

This method splits the surface into two pieces at the given parametric coordinate on the u-direction, generates two different surface objects and returns them. It does not modify the input surface.

Keyword Arguments:

- `find_span_func`: FindSpan implementation. *Default:* `helpers.find_span_linear()`
- `insert_knot_func`: knot insertion algorithm implementation. *Default:* `operations.insert_knot()`

Parameters

- **obj** (`abstract.Surface`) – surface
- **param** (*float*) – parameter for the u-direction

Returns a list of surface patches

Return type list

`geomdl.operations.`**`split_surface_v`**(*obj*, *param*, ***kwargs*)

Splits the surface at the input parametric coordinate on the v-direction.

This method splits the surface into two pieces at the given parametric coordinate on the v-direction, generates two different surface objects and returns them. It does not modify the input surface.

Keyword Arguments:

- `find_span_func`: FindSpan implementation. *Default:* `helpers.find_span_linear()`
- `insert_knot_func`: knot insertion algorithm implementation. *Default:* `operations.insert_knot()`

Parameters

- **obj** (`abstract.Surface`) – surface
- **param** (*float*) – parameter for the v-direction

Returns a list of surface patches

Return type list

`geomdl.operations.`**`decompose_surface`**(*obj*, ***kwargs*)

Decomposes the surface into Bezier surface patches of the same degree.

This operation does not modify the input surface, instead it returns the surface patches.

Keyword Arguments:

- `find_span_func`: FindSpan implementation. *Default:* `helpers.find_span_linear()`
- `insert_knot_func`: knot insertion algorithm implementation. *Default:* `operations.insert_knot()`

Parameters **obj** (`abstract.Surface`) – surface

Returns a list of Bezier patches

Return type list

`geomdl.operations.`**`derivative_surface`**(*obj*)

Computes the hodograph (first derivative) surface of the input surface.

This function constructs the hodograph (first derivative) surface from the input surface by computing the degrees, knot vectors and the control points of the derivative surface.

The return value of this function is a tuple containing the following derivative surfaces in the given order:

- U-derivative surface (derivative taken only on the u-direction)
- V-derivative surface (derivative taken only on the v-direction)
- UV-derivative surface (derivative taken on both the u- and the v-direction)

Parameters **obj** (`abstract.Surface`) – input surface

Returns derivative surfaces w.r.t. u, v and both u-v

Return type tuple

`geomdl.operations.`**`find_ctrlpts`**(*obj*, *u*, *v=None*, ***kwargs*)

Finds the control points involved in the evaluation of the curve/surface point defined by the input parameter(s).

Parameters

- **obj** (`abstract.Curve` *or* `abstract.Surface`) – curve or surface
- **u** (*`float`*) – parameter (for curve), parameter on the u-direction (for surface)
- **v** (*`float`*) – parameter on the v-direction (for surface only)

Returns control points; 1-dimensional array for curve, 2-dimensional array for surface

Return type list

`geomdl.operations.`**`tangent`**(*obj*, *params*, ***kwargs*)

Evaluates the tangent vector of the curves or surfaces at the input parameter values.

This function is designed to evaluate tangent vectors of the B-Spline and NURBS shapes at single or multiple parameter positions.

Parameters

- **obj** (`abstract.Curve` *or* `abstract.Surface`) – input shape

- **params** (*float, list or tuple*) – parameters

Returns a list containing "point" and "vector" pairs

Return type tuple

`geomdl.operations.`**`normal`**(*obj*, *params*, ***kwargs*)

Evaluates the normal vector of the curves or surfaces at the input parameter values.

This function is designed to evaluate normal vectors of the B-Spline and NURBS shapes at single or multiple parameter positions.

Parameters

- **obj** (`abstract.Curve` *or* `abstract.Surface`) – input geometry
- **params** (*float, list or tuple*) – parameters

Returns a list containing "point" and "vector" pairs

Return type tuple

`geomdl.operations.`**`translate`**(*obj*, *vec*, ***kwargs*)

Translates curves, surface or volumes by the input vector.

Keyword Arguments:

- `inplace`: if False, operation applied to a copy of the object. *Default: False*

Parameters

- **obj** (`abstract.SplineGeometry` *or* `multi.AbstractContainer`) – input geometry
- **vec** (*list, tuple*) – translation vector

Returns translated geometry object

`geomdl.operations.`**`rotate`**(*obj*, *angle*, ***kwargs*)

Rotates curves, surfaces or volumes about the chosen axis.

Keyword Arguments:

- `axis`: rotation axis; x, y, z correspond to 0, 1, 2 respectively. *Default: 2*
- `inplace`: if False, operation applied to a copy of the object. *Default: False*

Parameters

- **obj** (`abstract.SplineGeometry`, *multi.AbstractGeometry*) – input geometry
- **angle** (*float*) – angle of rotation (in degrees)

Returns rotated geometry object

`geomdl.operations.`**`scale`**(*obj*, *multiplier*, ***kwargs*)

Scales curves, surfaces or volumes by the input multiplier.

Keyword Arguments:

- `inplace`: if False, operation applied to a copy of the object. *Default: False*

Parameters

- **obj** (`abstract.SplineGeometry`, *multi.AbstractGeometry*) – input geometry
- **multiplier** (*float*) – scaling multiplier

Returns scaled geometry object

`geomdl.operations.`**transpose**(*surf*, ***kwargs*)

Transposes the input surface(s) by swapping u and v parametric directions.

Keyword Arguments:

- `inplace`: if False, operation applied to a copy of the object. *Default: False*

Parameters **surf** (`abstract.Surface`, `multi.SurfaceContainer`) – input surface(s)

Returns transposed surface(s)

`geomdl.operations.`**flip**(*surf*, ***kwargs*)

Flips the control points grid of the input surface(s).

Keyword Arguments:

- `inplace`: if False, operation applied to a copy of the object. *Default: False*

Parameters **surf** (`abstract.Surface`, `multi.SurfaceContainer`) – input surface(s)

Returns flipped surface(s)

17.1.6 Compatibility and Conversion

This module contains conversion operations related to control points, such as flipping arrays and adding weights.

Function Reference

`geomdl.compatibility.`**combine_ctrlpts_weights**(*ctrlpts*, *weights=None*)

Multiplies control points by the weights to generate weighted control points.

This function is dimension agnostic, i.e. control points can be in any dimension but weights should be 1D.

The `weights` function parameter can be set to None to let the function generate a weights vector composed of 1.0 values. This feature can be used to convert B-Spline basis to NURBS basis.

Parameters

- **ctrlpts** (*list, tuple*) – unweighted control points
- **weights** (*list, tuple or None*) – weights vector; if set to None, a weights vector of 1.0s will be automatically generated

Returns weighted control points

Return type list

`geomdl.compatibility.`**flip_ctrlpts**(*ctrlpts*, *size_u*, *size_v*)

Flips a list of 1-dimensional control points from v-row order to u-row order.

u-row order: each row corresponds to a list of u values

v-row order: each row corresponds to a list of v values

Parameters

- **ctrlpts** (*list, tuple*) – control points in v-row order
- **size_u** (*int*) – size in u-direction
- **size_v** (*int*) – size in v-direction

Returns control points in u-row order

Return type list

geomdl.compatibility.**flip_ctrlpts2d**(*ctrlpts2d*, *size_u=0*, *size_v=0*)

Flips a list of surface 2-D control points from *[u][v]* to *[v][u]* order.

Parameters

- **ctrlpts2d** (*list, tuple*) – 2-D control points
- **size_u** (*int*) – size in U-direction (row length)
- **size_v** (*int*) – size in V-direction (column length)

Returns flipped 2-D control points

Return type list

geomdl.compatibility.**flip_ctrlpts2d_file**(*file_in=''*, *file_out='ctrlpts_flip.txt'*)

Flips u and v directions of a 2D control points file and saves flipped coordinates to a file.

Parameters

- **file_in** (*str*) – name of the input file (to be read)
- **file_out** (*str*) – name of the output file (to be saved)

Raises **IOError** – an error occurred reading or writing the file

geomdl.compatibility.**flip_ctrlpts_u**(*ctrlpts*, *size_u*, *size_v*)

Flips a list of 1-dimensional control points from u-row order to v-row order.

u-row order: each row corresponds to a list of u values

v-row order: each row corresponds to a list of v values

Parameters

- **ctrlpts** (*list, tuple*) – control points in u-row order
- **size_u** (*int*) – size in u-direction
- **size_v** (*int*) – size in v-direction

Returns control points in v-row order

Return type list

geomdl.compatibility.**generate_ctrlpts2d_weights**(*ctrlpts2d*)

Generates unweighted control points from weighted ones in 2-D.

This function

1. Takes in 2-D control points list whose coordinates are organized like (x*w, y*w, z*w, w)
2. Converts the input control points list into (x, y, z, w) format
3. Returns the result

Parameters **ctrlpts2d** (*list*) – 2-D control points (P)

Returns 2-D weighted control points (Pw)

Return type list

`geomdl.compatibility.generate_ctrlpts2d_weights_file(file_in='', file_out='ctrlpts_weights.txt')`

Generates unweighted control points from weighted ones in 2-D.

1. Takes in 2-D control points list whose coordinates are organized like (x*w, y*w, z*w, w)
2. Converts the input control points list into (x, y, z, w) format
3. Saves the result to a file

Parameters

- **file_in** (*str*) – name of the input file (to be read)
- **file_out** (*str*) – name of the output file (to be saved)

Raises **IOError** – an error occurred reading or writing the file

`geomdl.compatibility.generate_ctrlpts_weights(ctrlpts)`

Generates unweighted control points from weighted ones in 1-D.

This function

1. Takes in 1-D control points list whose coordinates are organized in (x*w, y*w, z*w, w) format
2. Converts the input control points list into (x, y, z, w) format
3. Returns the result

Parameters **ctrlpts** (*list*) – 1-D control points (P)

Returns 1-D weighted control points (Pw)

Return type list

`geomdl.compatibility.generate_ctrlptsw(ctrlpts)`

Generates weighted control points from unweighted ones in 1-D.

This function

1. Takes in a 1-D control points list whose coordinates are organized in (x, y, z, w) format
2. converts into (x*w, y*w, z*w, w) format
3. Returns the result

Parameters **ctrlpts** (*list*) – 1-D control points (P)

Returns 1-D weighted control points (Pw)

Return type list

`geomdl.compatibility.generate_ctrlptsw2d(ctrlpts2d)`

Generates weighted control points from unweighted ones in 2-D.

This function

1. Takes in a 2D control points list whose coordinates are organized in (x, y, z, w) format
2. converts into (x*w, y*w, z*w, w) format
3. Returns the result

Therefore, the returned list could be a direct input of the NURBS.Surface class.

Parameters **ctrlpts2d** (*list*) – 2-D control points (P)

Returns 2-D weighted control points (Pw)

Return type list

geomdl.compatibility.**generate_ctrlptsw2d_file**(*file_in=”*, *file_out='ctrlptsw.txt'*)

Generates weighted control points from unweighted ones in 2-D.

This function

1. Takes in a 2-D control points file whose coordinates are organized in (x, y, z, w) format
2. Converts into (x*w, y*w, z*w, w) format
3. Saves the result to a file

Therefore, the resultant file could be a direct input of the NURBS.Surface class.

Parameters

- **file_in** (*str*) – name of the input file (to be read)
- **file_out** (*str*) – name of the output file (to be saved)

Raises **IOError** – an error occurred reading or writing the file

geomdl.compatibility.**separate_ctrlpts_weights**(*ctrlptsw*)

Divides weighted control points by weights to generate unweighted control points and weights vector.

This function is dimension agnostic, i.e. control points can be in any dimension but the last element of the array should indicate the weight.

Parameters **ctrlptsw** (*list, tuple*) – weighted control points

Returns unweighted control points and weights vector

Return type list

17.1.7 Geometry Converters

convert module provides functions for converting non-rational and rational geometries to each other.

Function Reference

geomdl.convert.**bspline_to_nurbs**(*obj*, ***kwargs*)

Converts non-rational splines to rational ones.

Parameters **obj** (*BSpline.Curve, BSpline.Surface or BSpline.Volume*) – non-rational spline geometry

Returns rational spline geometry

Return type *NURBS.Curve*, *NURBS.Surface* or *NURBS.Volume*

Raises TypeError

geomdl.convert.**nurbs_to_bspline**(*obj*, ***kwargs*)

Converts rational splines to non-rational ones (if possible).

The possibility of converting a rational spline geometry to a non-rational one depends on the weights vector.

Parameters **obj** (*NURBS.Curve, NURBS.Surface or NURBS.Volume*) – rational spline geometry

Returns non-rational spline geometry

Return type *BSpline.Curve*, *BSpline.Surface* or *BSpline.Volume*

Raises TypeError

17.1.8 Geometry Constructors and Extractors

New in version 5.0.

`construct` module provides functions for constructing and extracting parametric shapes. A surface can be constructed from curves and a volume can be constructed from surfaces. Moreover, a surface can be extracted to curves and a volume can be extracted to surfaces in all parametric directions.

Function Reference

`geomdl.construct.`**`construct_surface`**(*direction*, **args*, ***kwargs*)

Generates surfaces from curves.

Arguments:

- `args`: a list of curve instances

Keyword Arguments (optional):

- `degree`: degree of the 2nd parametric direction
- `knotvector`: knot vector of the 2nd parametric direction
- `rational`: flag to generate rational surfaces

Parameters **`direction`** (`str`) – the direction that the input curves lies, i.e. u or v

Returns Surface constructed from the curves on the given parametric direction

`geomdl.construct.`**`construct_volume`**(*direction*, **args*, ***kwargs*)

Generates volumes from surfaces.

Arguments:

- `args`: a list of surface instances

Keyword Arguments (optional):

- `degree`: degree of the 3rd parametric direction
- `knotvector`: knot vector of the 3rd parametric direction
- `rational`: flag to generate rational volumes

Parameters **`direction`** (`str`) – the direction that the input surfaces lies, i.e. u, v, w

Returns Volume constructed from the surfaces on the given parametric direction

`geomdl.construct.`**`extract_curves`**(*psurf*, ***kwargs*)

Extracts curves from a surface.

The return value is a `dict` object containing the following keys:

- `u`: the curves which generate u-direction (or which lie on the v-direction)
- `v`: the curves which generate v-direction (or which lie on the u-direction)

As an example; if a curve lies on the u-direction, then its knotvector is equal to surface's knotvector on the v-direction and vice versa.

The curve extraction process can be controlled via `extract_u` and `extract_v` boolean keyword arguments.

Parameters **psurf** (`abstract.Surface`) – input surface

Returns extracted curves

Return type dict

`geomdl.construct.`**`extract_isosurface`**(*pvol*)

Extracts the largest isosurface from a volume.

The following example illustrates one of the usage scenarios:

```
from geomdl import construct, multi
from geomdl.visualization import VisMPL

# Assuming that "myvol" variable stores your spline volume information
isosrf = construct.extract_isosurface(myvol)

# Create a surface container to store extracted isosurface
msurf = multi.SurfaceContainer(isosrf)

# Set visualization components
msurf.vis = VisMPL.VisSurface(VisMPL.VisConfig(ctrlpts=False))

# Render isosurface
msurf.render()
```

Parameters **pvol** (`abstract.Volume`) – input volume

Returns isosurface (as a tuple of surfaces)

Return type tuple

`geomdl.construct.`**`extract_surfaces`**(*pvol*)

Extracts surfaces from a volume.

Parameters **pvol** (`abstract.Volume`) – input volume

Returns extracted surface

Return type dict

17.1.9 Curve and Surface Fitting

New in version 5.0.

`fitting` module provides functions for interpolating and approximating B-spline curves and surfaces from data points. Approximation uses least squares algorithm.

Please see the following functions for details:

- *`interpolate_curve()`*
- *`interpolate_surface()`*
- *`approximate_curve()`*
- *`approximate_surface()`*

Surface fitting generates control points grid defined in *u* and *v* parametric dimensions. Therefore, the input requires number of data points to be fitted in both parametric dimensions. In other words, `size_u` and `size_v` arguments are used to fit curves of the surface on the corresponding parametric dimension.

Degree of the output spline geometry is important to determine the knot vector(s), compute the basis functions and build the coefficient matrix, A. Most of the time, fitting to a quadratic (`degree = 2`) or a cubic (`degree = 3`) B-spline geometry should be good enough.

In the array structure, the data points on the v-direction come the first and u-direction points come. The index of the data points can be found using the following formula:

$$index = v + (u * size_v)$$

Function Reference

`geomdl.fitting.`**`interpolate_curve`**(*points*, *degree*, ***kwargs*)

Curve interpolation through the data points.

Please refer to Algorithm A9.1 on The NURBS Book (2nd Edition), pp.369-370 for details.

Keyword Arguments:

- `centripetal`: activates centripetal parametrization method. *Default: False*

Parameters

- **points** (*list, tuple*) – data points
- **degree** (*int*) – degree of the output parametric curve

Returns interpolated B-Spline curve

Return type *BSpline.Curve*

`geomdl.fitting.`**`interpolate_surface`**(*points*, *size_u*, *size_v*, *degree_u*, *degree_v*, ***kwargs*)

Surface interpolation through the data points.

Please refer to the Algorithm A9.4 on The NURBS Book (2nd Edition), pp.380 for details.

Keyword Arguments:

- `centripetal`: activates centripetal parametrization method. *Default: False*

Parameters

- **points** (*list, tuple*) – data points
- **size_u** (*int*) – number of data points on the u-direction
- **size_v** (*int*) – number of data points on the v-direction
- **degree_u** (*int*) – degree of the output surface for the u-direction
- **degree_v** (*int*) – degree of the output surface for the v-direction

Returns interpolated B-Spline surface

Return type *BSpline.Surface*

`geomdl.fitting.`**`approximate_curve`**(*points*, *degree*, ***kwargs*)

Curve approximation using least squares method with fixed number of control points.

Please refer to The NURBS Book (2nd Edition), pp.410-413 for details.

Keyword Arguments:

- `centripetal`: activates centripetal parametrization method. *Default: False*
- `ctrlpts_size`: number of control points. *Default: len(points) - 1*

Parameters

- **points** (*list, tuple*) – data points
- **degree** (*int*) – degree of the output parametric curve

Returns approximated B-Spline curve

Return type *BSpline.Curve*

`geomdl.fitting.`**`approximate_surface`**(*points, size_u, size_v, degree_u, degree_v, **kwargs*)

Surface approximation using least squares method with fixed number of control points.

This algorithm interpolates the corner control points and approximates the remaining control points. Please refer to Algorithm A9.7 of The NURBS Book (2nd Edition), pp.422-423 for details.

Keyword Arguments:

- `centripetal`: activates centripetal parametrization method. *Default: False*
- `ctrlpts_size_u`: number of control points on the u-direction. *Default: size_u - 1*
- `ctrlpts_size_v`: number of control points on the v-direction. *Default: size_v - 1*

Parameters

- **points** (*list, tuple*) – data points
- **size_u** (*int*) – number of data points on the u-direction, r
- **size_v** (*int*) – number of data points on the v-direction, s
- **degree_u** (*int*) – degree of the output surface for the u-direction
- **degree_v** (*int*) – degree of the output surface for the v-direction

Returns approximated B-Spline surface

Return type *BSpline.Surface*

17.1.10 Tessellation

The `tessellate` module provides tessellation algorithms for surfaces. The following example illustrates the usage scenario of the tessellation algorithms with surfaces.

```
from geomdl import NURBS
from geomdl import tessellate

# Create a surface instance
surf = NURBS.Surface()

# Set tessellation algorithm (you can use another algorithm)
surf.tessellator = tessellate.TriangularTessellate()

# Tessellate surface
surf.tessellate()
```

NURBS-Python uses *TriangularTessellate* class for surface tessellation by default.

Note: To get better results with the surface trimming, you need to use a relatively smaller evaluation delta or a bigger sample size value. Recommended evaluation delta is $d = 0.01$.

Class Reference

Abstract Tessellator

class geomdl.tessellate.**AbstractTessellate**(***kwargs*)

Bases: object

Abstract base class for tessellation algorithms.

arguments

Arguments passed to the tessellation function.

This property allows customization of the tessellation algorithm, and mainly designed to allow users to pass additional arguments to the tessellation function or change the behavior of the algorithm at runtime. This property can be thought as a way to input and store extra data for the tessellation functionality.

Getter Gets the tessellation arguments (as a dict)

Setter Sets the tessellation arguments (as a dict)

faces

Objects generated after tessellation.

Getter Gets the faces

Type elements.AbstractEntity

is_tessellated()

Checks if vertices and faces are generated.

Returns tessellation status

Return type bool

reset()

Clears stored vertices and faces.

tessellate(*points*, ***kwargs*)

Abstract method for the implementation of the tessellation algorithm.

This algorithm should update *vertices* and *faces* properties.

Note: This is an abstract method and it must be implemented in the subclass.

Parameters **points** – points to be tessellated

vertices

Vertex objects generated after tessellation.

Getter Gets the vertices

Type elements.AbstractEntity

Triangular Tessellator

class geomdl.tessellate.**TriangularTessellate**(***kwargs*)

Bases: *geomdl.tessellate.AbstractTessellate*

Triangular tessellation algorithm for surfaces.

arguments

Arguments passed to the tessellation function.

This property allows customization of the tessellation algorithm, and mainly designed to allow users to pass additional arguments to the tessellation function or change the behavior of the algorithm at runtime. This property can be thought as a way to input and store extra data for the tessellation functionality.

Getter Gets the tessellation arguments (as a dict)

Setter Sets the tessellation arguments (as a dict)

faces

Objects generated after tessellation.

Getter Gets the faces

Type elements.AbstractEntity

is_tessellated()

Checks if vertices and faces are generated.

Returns tessellation status

Return type bool

reset()

Clears stored vertices and faces.

tessellate(*points*, ***kwargs*)

Applies triangular tessellation.

This function does not check if the points have already been tessellated.

Keyword Arguments:

- `size_u`: number of points on the u-direction
- `size_v`: number of points on the v-direction

Parameters points (*list, tuple*) – array of points

vertices

Vertex objects generated after tessellation.

Getter Gets the vertices

Type elements.AbstractEntity

Trim Tessellator

New in version 5.0.

class geomdl.tessellate.**TrimTessellate**(***kwargs*)

Bases: *geomdl.tessellate.AbstractTessellate*

Triangular tessellation algorithm for trimmed surfaces.

arguments
Arguments passed to the tessellation function.

This property allows customization of the tessellation algorithm, and mainly designed to allow users to pass additional arguments to the tessellation function or change the behavior of the algorithm at runtime. This property can be thought as a way to input and store extra data for the tessellation functionality.

Getter Gets the tessellation arguments (as a dict)

Setter Sets the tessellation arguments (as a dict)

faces
Objects generated after tessellation.

Getter Gets the faces

Type elements.AbstractEntity

is_tessellated()
Checks if vertices and faces are generated.

Returns tessellation status

Return type bool

reset()
Clears stored vertices and faces.

tessellate(*points*, ***kwargs*)
Applies triangular tessellation w/ trimming curves.

Keyword Arguments:

- `size_u`: number of points on the u-direction
- `size_v`: number of points on the v-direction

Parameters **points** (*list, tuple*) – array of points

vertices
Vertex objects generated after tessellation.

Getter Gets the vertices

Type elements.AbstractEntity

Quadrilateral Tessellator

New in version 5.2.

class geomdl.tessellate.**QuadTessellate**(***kwargs*)
Bases: *geomdl.tessellate.AbstractTessellate*

Quadrilateral tessellation algorithm for surfaces.

arguments
Arguments passed to the tessellation function.

This property allows customization of the tessellation algorithm, and mainly designed to allow users to pass additional arguments to the tessellation function or change the behavior of the algorithm at runtime. This property can be thought as a way to input and store extra data for the tessellation functionality.

Getter Gets the tessellation arguments (as a dict)

Setter Sets the tessellation arguments (as a dict)

faces

Objects generated after tessellation.

Getter Gets the faces

Type elements.AbstractEntity

is_tessellated()

Checks if vertices and faces are generated.

Returns tessellation status

Return type bool

reset()

Clears stored vertices and faces.

tessellate(*points*, ***kwargs*)

Applies quadrilateral tessellation.

This function does not check if the points have already been tessellated.

Keyword Arguments:

- `size_u`: number of points on the u-direction
- `size_v`: number of points on the v-direction

Parameters **points** (*list, tuple*) – array of points

vertices

Vertex objects generated after tessellation.

Getter Gets the vertices

Type elements.AbstractEntity

Function Reference

geomdl.tessellate.**make_triangle_mesh**(*points*, *size_u*, *size_v*, ***kwargs*)

Generates a triangular mesh from an array of points.

This function generates a triangular mesh for a NURBS or B-Spline surface on its parametric space. The input is the surface points and the number of points on the parametric dimensions u and v, indicated as row and column sizes in the function signature. This function should operate correctly if row and column sizes are input correctly, no matter what the points are v-ordered or u-ordered. Please see the documentation of `ctrlpts` and `ctrlpts2d` properties of the Surface class for more details on point ordering for the surfaces.

This function accepts the following keyword arguments:

- `vertex_spacing`: Defines the size of the triangles via setting the jump value between points
- `trims`: List of trim curves passed to the tessellation function
- `tessellate_func`: Function called for tessellation. *Default:* *tessellate.surface_tessellate()*
- `tessellate_args`: Arguments passed to the tessellation function (as a dict)

The tessellation function is designed to generate triangles from 4 vertices. It takes 4 `Vertex` objects, index values for setting the triangle and vertex IDs and additional parameters as its function arguments. It returns a tuple of `Vertex` and `Triangle` object lists generated from the input vertices. A default triangle generator is provided as a prototype for implementation in the source code.

The return value of this function is a tuple containing two lists. First one is the list of vertices and the second one is the list of triangles.

Parameters

- **points** (*list, tuple*) – input points
- **size_u** (*int*) – number of elements on the u-direction
- **size_v** (*int*) – number of elements on the v-direction

Returns a tuple containing lists of vertices and triangles

Return type tuple

`geomdl.tessellate.`**`polygon_triangulate`**(*tri_idx*, **args*)

Triangulates a monotone polygon defined by a list of vertices.

The input vertices must form a convex polygon and must be arranged in counter-clockwise order.

Parameters

- **tri_idx** (*int*) – triangle numbering start value
- **args** (`Vertex`) – list of Vertex objects

Returns list of Triangle objects

Return type list

`geomdl.tessellate.`**`make_quad_mesh`**(*points*, *size_u*, *size_v*)

Generates a mesh of quadrilateral elements.

Parameters

- **points** (*list, tuple*) – list of points
- **size_u** (*int*) – number of points on the u-direction (column)
- **size_v** (*int*) – number of points on the v-direction (row)

Returns a tuple containing lists of vertices and quads

Return type tuple

Helper Functions

`geomdl.tessellate.`**`surface_tessellate`**(*v1*, *v2*, *v3*, *v4*, *vidx*, *tidx*, *trim_curves*, *tessellate_args*)

Triangular tessellation algorithm for surfaces with no trims.

This function can be directly used as an input to `make_triangle_mesh()` using `tessellate_func` keyword argument.

Parameters

- **v1** (`Vertex`) – vertex 1
- **v2** (`Vertex`) – vertex 2
- **v3** (`Vertex`) – vertex 3
- **v4** (`Vertex`) – vertex 4

- **vidx** (*int*) – vertex numbering start value
- **tidx** (*int*) – triangle numbering start value
- **trim_curves** – trim curves
- **tessellate_args** (*dict*) – tessellation arguments

Type list, tuple

Returns lists of vertex and triangle objects in (vertex_list, triangle_list) format

Type tuple

geomdl.tessellate.**surface_trim_tessellate**(*v1*, *v2*, *v3*, *v4*, *vidx*, *tidx*, *trims*, *tessellate_args*)
Triangular tessellation algorithm for trimmed surfaces.

This function can be directly used as an input to *make_triangle_mesh()* using tessellate_func keyword argument.

Parameters

- **v1** (Vertex) – vertex 1
- **v2** (Vertex) – vertex 2
- **v3** (Vertex) – vertex 3
- **v4** (Vertex) – vertex 4
- **vidx** (*int*) – vertex numbering start value
- **tidx** (*int*) – triangle numbering start value
- **trims** (*list, tuple*) – trim curves
- **tessellate_args** (*dict*) – tessellation arguments

Returns lists of vertex and triangle objects in (vertex_list, triangle_list) format

Type tuple

17.1.11 Trimming

Tessellation

Please refer to *tessellate.TrimTessellate* for tessellating the surfaces with trims.

Function Reference

> **Warning:** The functions included in the trimming module are still work-in-progress and their functionality can change or they can be removed from the library in the next releases.
>
> Please contact the author if you encounter any problems.

geomdl.trimming.**map_trim_to_geometry**(*obj*, *trim_idx=-1*, ***kwargs*)
Generates 3-dimensional mapping of 2-dimensional trimming curves.

Description:

Trimming curves are defined on the parametric space of the surfaces. Therefore, all trimming curves are 2-dimensional. The coordinates of the trimming curves correspond to (u, v) parameters of the underlying surface geometry. When these (u, v) values are evaluated with respect to the underlying surface geometry, a 3-dimensional representation of the trimming curves is generated.

The resultant 3-dimensional curve is described using `freeform.Freeform` class. Using the `fitting` module, it is possible to generate the B-spline form of the freeform curve.

Remarks:

If *trim_idx=-1*, the function maps all 2-dimensional trims to their 3-dimensional correspondants.

Parameters

- **obj** (`abstract.SplineGeometry`) – spline geometry
- **trim_idx** (*int*) – index of the trimming curve in the geometry object

Returns 3-dimensional mapping of trimming curve(s)

Return type *freeform.Freeform*

`geomdl.trimming.`**`fix_multi_trim_curves`**(*obj*, ***kwargs*)

Fixes direction, connectivity and similar issues of the trim curves.

This function works for surface trims in curve containers, i.e. trims consisting of multiple curves.

Keyword Arguments:

- `tol`: tolerance value for comparing floats. *Default: 10e-8*
- `delta`: evaluation delta of the trim curves. *Default: 0.05*

Parameters **obj** (*abstract.BSplineGeometry*, `multi.AbstractContainer`) – input surface

Returns updated surface

`geomdl.trimming.`**`fix_trim_curves`**(*obj*)

Fixes direction, connectivity and similar issues of the trim curves.

This function works for surface trim curves consisting of a single curve.

Parameters **obj** (`abstract.Surface`) – input surface

17.1.12 Sweeping

Warning: `sweeping` is a highly experimental module. Please use it with caution.

Function Reference

`geomdl.sweeping.`**`sweep_vector`**(*obj*, *vec*, ***kwargs*)

Sweeps spline geometries along a vector.

This API call generates

- swept surfaces from curves
- swept volumes from surfaces

Parameters

- **obj** (abstract.SplineGeometry) – spline geometry
- **vec** (*list, tuple*) – vector to sweep along

Returns swept geometry

17.1.13 Import and Export Data

This module allows users to export/import NURBS shapes in common CAD exchange formats. The functions starting with *import_* are used for generating B-spline and NURBS objects from the input files. The functions starting with *export_* are used for saving B-spline and NURBS objects as files.

The following functions **import/export control points** or **export evaluated points**:

- *exchange.import_txt()*
- *exchange.export_txt()*
- *exchange.import_csv()*
- *exchange.export_csv()*

The following functions work with **single or multiple surfaces**:

- *exchange.import_obj()*
- *exchange.export_obj()*
- *exchange.export_stl()*
- *exchange.export_off()*
- *exchange.import_smesh()*
- *exchange.export_smesh()*

The following functions work with **single or multiple volumes**:

- *exchange.import_vmesh()*
- *exchange.export_vmesh()*

The following functions can be used to **import/export rational or non-rational spline geometries**:

- *exchange.import_yaml()*
- *exchange.export_yaml()*
- *exchange.import_cfg()*
- *exchange.export_cfg()*
- *exchange.import_json()*
- *exchange.export_json()*

The following functions work with **single or multiple curves and surfaces**:

- *exchange.import_3dm()*
- *exchange.export_3dm()*

Function Reference

geomdl.exchange.**import_txt**(*file_name*, *two_dimensional=False*, ***kwargs*)

Reads control points from a text file and generates a 1-dimensional list of control points.

The following code examples illustrate importing different types of text files for curves and surfaces:

```
# Import curve control points from a text file
curve_ctrlpts = exchange.import_txt(file_name="control_points.txt")

# Import surface control points from a text file (1-dimensional file)
surf_ctrlpts = exchange.import_txt(file_name="control_points.txt")

# Import surface control points from a text file (2-dimensional file)
surf_ctrlpts, size_u, size_v = exchange.import_txt(file_name="control_points.txt",
↪ two_dimensional=True)
```

If argument `jinja2=True` is set, then the input file is processed as a Jinja2 template. You can also use the following convenience template functions which correspond to the given mathematical equations:

- `sqrt(x)`: $\sqrt{x}$
- `cubert(x)`: $\sqrt[3]{x}$
- `pow(x, y)`: x^y

You may set the file delimiters using the keyword arguments `separator` and `col_separator`, respectively. `separator` is the delimiter between the coordinates of the control points. It could be comma `1, 2, 3` or space `1 2 3` or something else. `col_separator` is the delimiter between the control points and is only valid when `two_dimensional` is `True`. Assuming that `separator` is set to space, then `col_operator` could be semi-colon `1 2 3; 4 5 6` or pipe `1 2 3| 4 5 6` or comma `1 2 3, 4 5 6` or something else.

The defaults for `separator` and `col_separator` are *comma (,)* and *semi-colon (;)*, respectively.

The following code examples illustrate the usage of the keyword arguments discussed above.

```
# Import curve control points from a text file delimited with space
curve_ctrlpts = exchange.import_txt(file_name="control_points.txt", separator=" ")

# Import surface control points from a text file (2-dimensional file) w/ space␣
↪and comma delimiters
surf_ctrlpts, size_u, size_v = exchange.import_txt(file_name="control_points.txt",
↪ two_dimensional=True,
                                                   separator=" ", col_separator=",
↪")
```

Please note that this function does not check whether the user set delimiters to the same value or not.

Parameters

- **file_name** (*str*) – file name of the text file
- **two_dimensional** (*bool*) – type of the text file

Returns list of control points, if two_dimensional, then also returns size in u- and v-directions

Return type list

Raises **GeomdlException** – an error occurred reading the file

geomdl.exchange.**export_txt**(*obj*, *file_name*, *two_dimensional=False*, ***kwargs*)

Exports control points as a text file.

For curves the output is always a list of control points. For surfaces, it is possible to generate a 2-dimensional control point output file using `two_dimensional`.

Please see *exchange.import_txt()* for detailed description of the keyword arguments.

Parameters

- **obj** (`abstract.SplineGeometry`) – a spline geometry object
- **file_name** (*str*) – file name of the text file to be saved
- **two_dimensional** (*bool*) – type of the text file (only works for Surface objects)

Raises GeomdlException – an error occurred writing the file

geomdl.exchange.**import_csv**(*file_name*, ***kwargs*)

Reads control points from a CSV file and generates a 1-dimensional list of control points.

It is possible to use a different value separator via `separator` keyword argument. The following code segment illustrates the usage of `separator` keyword argument.

```
# By default, import_csv uses 'comma' as the value separator
ctrlpts = exchange.import_csv("control_points.csv")

# Alternatively, it is possible to import a file containing tab-separated values
ctrlpts = exchange.import_csv("control_points.csv", separator="\t")
```

The only difference of this function from *exchange.import_txt()* is skipping the first line of the input file which generally contains the column headings.

Parameters file_name (*str*) – file name of the text file

Returns list of control points

Return type list

Raises GeomdlException – an error occurred reading the file

geomdl.exchange.**export_csv**(*obj*, *file_name*, *point_type='evalpts'*, ***kwargs*)

Exports control points or evaluated points as a CSV file.

Parameters

- **obj** (`abstract.SplineGeometry`) – a spline geometry object
- **file_name** (*str*) – output file name
- **point_type** (*str*) – `ctrlpts` for control points or `evalpts` for evaluated points

Raises GeomdlException – an error occurred writing the file

geomdl.exchange.**import_cfg**(*file_name*, ***kwargs*)

Imports curves and surfaces from files in libconfig format.

Note: Requires libconf package.

Use `jinja2=True` to activate Jinja2 template processing. Please refer to the documentation for details.

Parameters file_name (*str*) – name of the input file

Returns a list of rational spline geometries

Return type list

Raises GeomdlException – an error occurred writing the file `geomdl.exchange.export_cfg(obj, file_name)`

Exports curves and surfaces in libconfig format.

Note: Requires libconf package.

Libconfig format is also used by the geomdl command-line application as a way to input shape data from the command line.

Parameters

- **obj** (`abstract.SplineGeometry`, `multi.AbstractContainer`) – input geometry
- **file_name** (*str*) – name of the output file

Raises **GeomdlException** – an error occurred writing the file

`geomdl.exchange.import_yaml(file_name, **kwargs)`

Imports curves and surfaces from files in YAML format.

Note: Requires ruamel.yaml package.

Use `jinja2=True` to activate Jinja2 template processing. Please refer to the documentation for details.

Parameters **file_name** (*str*) – name of the input file

Returns a list of rational spline geometries

Return type list

Raises **GeomdlException** – an error occurred reading the file

`geomdl.exchange.export_yaml(obj, file_name)`

Exports curves and surfaces in YAML format.

Note: Requires ruamel.yaml package.

YAML format is also used by the geomdl command-line application as a way to input shape data from the command line.

Parameters

- **obj** (`abstract.SplineGeometry`, `multi.AbstractContainer`) – input geometry
- **file_name** (*str*) – name of the output file

Raises **GeomdlException** – an error occurred writing the file

`geomdl.exchange.import_json(file_name, **kwargs)`

Imports curves and surfaces from files in JSON format.

Use `jinja2=True` to activate Jinja2 template processing. Please refer to the documentation for details.

Parameters **file_name** (*str*) – name of the input file

Returns a list of rational spline geometries

Return type list

Raises **GeomdlException** – an error occurred reading the file

geomdl.exchange.**export_json**(*obj*, *file_name*)
Exports curves and surfaces in JSON format.

JSON format is also used by the geomdl command-line application as a way to input shape data from the command line.

Parameters

- **obj** (abstract.SplineGeometry, multi.AbstractContainer) – input geometry
- **file_name** (*str*) – name of the output file

Raises GeomdlException – an error occurred writing the file

geomdl.exchange.**import_obj**(*file_name*, ***kwargs*)
Reads .obj files and generates faces.

Keyword Arguments:

- `callback`: reference to the function that processes the faces for customized output

The structure of the callback function is shown below:

```
def my_callback_function(face_list):
    # "face_list" will be a list of elements.Face class instances
    # The function should return a list
    return list()
```

Parameters **file_name** (*str*) – file name

Returns output of the callback function (default is a list of faces)

Return type list

geomdl.exchange.**export_obj**(*surface*, *file_name*, ***kwargs*)
Exports surface(s) as a .obj file.

Keyword Arguments:

- `vertex_spacing`: size of the triangle edge in terms of surface points sampled. *Default: 2*
- `vertex_normals`: if True, then computes vertex normals. *Default: False*
- `parametric_vertices`: if True, then adds parameter space vertices. *Default: False*
- `update_delta`: use multi-surface evaluation delta for all surfaces. *Default: True*

Parameters

- **surface** (abstract.Surface *or* multi.SurfaceContainer) – surface or surfaces to be saved
- **file_name** (*str*) – name of the output file

Raises GeomdlException – an error occurred writing the file

geomdl.exchange.**export_stl**(*surface*, *file_name*, ***kwargs*)
Exports surface(s) as a .stl file in plain text or binary format.

Keyword Arguments:

- `binary`: flag to generate a binary STL file. *Default: True*
- `vertex_spacing`: size of the triangle edge in terms of points sampled on the surface. *Default: 1*

- `update_delta`: use multi-surface evaluation delta for all surfaces. *Default: True*

Parameters

- **surface** (`abstract.Surface` *or* `multi.SurfaceContainer`) – surface or surfaces to be saved
- **file_name** (*str*) – name of the output file

Raises **GeomdlException** – an error occurred writing the file

`geomdl.exchange.`**`export_off`**(*surface*, *file_name*, ***kwargs*)

Exports surface(s) as a .off file.

Keyword Arguments:

- `vertex_spacing`: size of the triangle edge in terms of points sampled on the surface. *Default: 1*
- `update_delta`: use multi-surface evaluation delta for all surfaces. *Default: True*

Parameters

- **surface** (`abstract.Surface` *or* `multi.SurfaceContainer`) – surface or surfaces to be saved
- **file_name** (*str*) – name of the output file

Raises **GeomdlException** – an error occurred writing the file

`geomdl.exchange.`**`import_smesh`**(*file*)

Generates NURBS surface(s) from surface mesh (smesh) file(s).

smesh files are some text files which contain a set of NURBS surfaces. Each file in the set corresponds to one NURBS surface. Most of the time, you receive multiple *smesh* files corresponding to an complete object composed of several NURBS surfaces. The files have the extensions of `txt` or `dat` and they are named as

- `smesh.X.Y.txt`
- `smesh.X.dat`

where *X* and *Y* correspond to some integer value which defines the set the surface belongs to and part number of the surface inside the complete object.

Parameters **file** (*str*) – path to a directory containing mesh files or a single mesh file

Returns list of NURBS surfaces

Return type list

Raises **GeomdlException** – an error occurred reading the file

`geomdl.exchange.`**`export_smesh`**(*surface*, *file_name*, ***kwargs*)

Exports surface(s) as surface mesh (smesh) files.

Please see *`import_smesh()`* for details on the file format.

Parameters

- **surface** (`abstract.Surface` *or* `multi.SurfaceContainer`) – surface(s) to be exported
- **file_name** (*str*) – name of the output file

Raises **GeomdlException** – an error occurred writing the file `geomdl.exchange.`**`import_vmesh`**(*file*)

Imports NURBS volume(s) from volume mesh (vmesh) file(s).

Parameters **`file`** (`str`) – path to a directory containing mesh files or a single mesh file

Returns list of NURBS volumes

Return type list

Raises **`GeomdlException`** – an error occurred reading the file

`geomdl.exchange.`**`export_vmesh`**(*volume*, *file_name*, ***kwargs*)

Exports volume(s) as volume mesh (vmesh) files.

Parameters

- **`volume`** (`abstract.Volume`) – volume(s) to be exported
- **`file_name`** (`str`) – name of the output file

Raises **`GeomdlException`** – an error occurred writing the file

`geomdl.exchange.`**`import_3dm`**(*file_name*, ***kwargs*)

Imports curves and surfaces from Rhinoceros/OpenNURBS .3dm files.

Deprecated since version 5.2.2: `rw3dm` Python module is replaced by `on2json`. It can be used to convert .3dm files to geomdl JSON format. Please refer to https://github.com/orbingol/rw3dm for more details.

Parameters **`file_name`** (`str`) – input file name

`geomdl.exchange.`**`export_3dm`**(*obj*, *file_name*, ***kwargs*)

Exports NURBS curves and surfaces to Rhinoceros/OpenNURBS .3dm files.

Deprecated since version 5.2.2: `rw3dm` Python module is replaced by `json2on`. It can be used to convert geomdl JSON format to .3dm files. Please refer to https://github.com/orbingol/rw3dm for more details.

Parameters

- **`obj`** (`abstract.Curve`, `abstract.Surface`, `multi.CurveContainer`, `multi.SurfaceContainer`) – curves/surfaces to be exported
- **`file_name`** (`str`) – file name

VTK Support

The following functions export control points and evaluated points as VTK files (in legacy format).

`geomdl.exchange_vtk.`**`export_polydata`**(*obj*, *file_name*, ***kwargs*)

Exports control points or evaluated points in VTK Polydata format.

Please see the following document for details: http://www.vtk.org/VTK/img/file-formats.pdf

Keyword Arguments:

- `point_type`: **ctrlpts** for control points or **evalpts** for evaluated points
- `tessellate`: tessellates the points (works only for surfaces)

Parameters

- **`obj`** (`abstract.SplineGeometry`, `multi.AbstractContainer`) – geometry object
- **`file_name`** (`str`) – output file name

Raises **`GeomdlException`** – an error occurred writing the file

17.2 Geometry Generators

The following list contains the geometry generators/managers included in the library:

17.2.1 Knot Vector Generator

The `knotvector` module provides utility functions related to knot vector generation and validation.

Function Reference

`geomdl.knotvector.`**`generate`**(*degree*, *num_ctrlpts*, ***kwargs*)

Generates an equally spaced knot vector.

It uses the following equality to generate knot vector: $m = n + p + 1$

where;

- p, degree
- $n + 1$, number of control points
- $m + 1$, number of knots

Keyword Arguments:

- `clamped`: Flag to choose from clamped or unclamped knot vector options. *Default: True*

Parameters

- **degree** (*int*) – degree
- **num_ctrlpts** (*int*) – number of control points

Returns knot vector

Return type list

`geomdl.knotvector.`**`normalize`**(*knot_vector*, *decimals=18*)

Normalizes the input knot vector to [0, 1] domain.

Parameters

- **knot_vector** (*list, tuple*) – knot vector to be normalized
- **decimals** (*int*) – rounding number

Returns normalized knot vector

Return type list

`geomdl.knotvector.`**`check`**(*degree*, *knot_vector*, *num_ctrlpts*)

Checks the validity of the input knot vector.

Please refer to The NURBS Book (2nd Edition), p.50 for details.

Parameters

- **degree** (*int*) – degree of the curve or the surface
- **knot_vector** (*list, tuple*) – knot vector to be checked
- **num_ctrlpts** (*int*) – number of control points

Returns True if the knot vector is valid, False otherwise

Return type bool

17.2.2 Control Points Manager

The `control_points` module provides helper functions for managing control points. It is a better alternative to the *compatibility module* for managing control points. Please refer to the following class references for more details.

- *control_points.CurveManager*
- *control_points.SurfaceManager*
- *control_points.VolumeManager*

Class Reference

class geomdl.control_points.**AbstractManager**(**args*, ***kwargs*)

Bases: `object`

Abstract base class for control points manager classes.

Control points manager class provides an easy way to set control points without knowing the internal data structure of the geometry classes. The manager class is initialized with the number of control points in all parametric dimensions.

All classes extending this class should implement the following methods:

- `find_index`

This class provides the following properties:

- *ctrlpts*

This class provides the following methods:

- *get_ctrlpt()*
- *set_ctrlpt()*
- *get_ptdata()*
- *set_ptdata()*

ctrlpts

Control points.

Please refer to the wiki for details on using this class member.

Getter Gets the control points

Setter Sets the control points

find_index(**args*)

Finds the array index from the given parametric positions.

Note: This is an abstract method and it must be implemented in the subclass.

get_ctrlpt(**args*)

Gets the control point from the given location in the array.

get_ptdata(*dkey*, **args*)
Gets the data attached to the control point.

Parameters

- **dkey** – key of the attachment dictionary
- **dkey** – str

reset()
Resets/initializes the internal control points array.

set_ctrlpt(*pt*, **args*)
Puts the control point to the given location in the array.

Parameters **pt** (*list, tuple*) – control point

set_ptdata(*adct*, **args*)
Attaches the data to the control point.

Parameters

- **adct** – attachment dictionary
- **adct** – dict

class geomdl.control_points.**CurveManager**(**args*, ***kwargs*)
Bases: *geomdl.control_points.AbstractManager*

Curve control points manager.

Control points manager class provides an easy way to set control points without knowing the internal data structure of the geometry classes. The manager class is initialized with the number of control points in all parametric dimensions.

B-spline curves are defined in one parametric dimension. Therefore, this manager class should be initialized with a single integer value.

```
# Assuming that the curve has 10 control points
manager = CurveManager(10)
```

Getting the control points:

```
# Number of control points in all parametric dimensions
size_u = spline.ctrlpts_size_u

# Generate control points manager
cpt_manager = control_points.SurfaceManager(size_u)
cpt_manager.ctrlpts = spline.ctrlpts

# Control points array to be used externally
control_points = []

# Get control points from the spline geometry
for u in range(size_u):
    pt = cpt_manager.get_ctrlpt(u)
    control_points.append(pt)
```

Setting the control points:

```
# Number of control points in all parametric dimensions
size_u = 5
```

(continues on next page)

(continued from previous page)

```
# Create control points manager
points = control_points.SurfaceManager(size_u)

# Set control points
for u in range(size_u):
    # 'pt' is the control point, e.g. [10, 15, 12]
    points.set_ctrlpt(pt, u, v)

# Create spline geometry
curve = BSpline.Curve()

# Set control points
curve.ctrlpts = points.ctrlpts
```

ctrlpts
Control points.

Please refer to the wiki for details on using this class member.

Getter Gets the control points

Setter Sets the control points

find_index (**args*)
Finds the array index from the given parametric positions.

Note: This is an abstract method and it must be implemented in the subclass.

get_ctrlpt (**args*)
Gets the control point from the given location in the array.

get_ptdata (*dkey, *args*)
Gets the data attached to the control point.

Parameters

- **dkey** – key of the attachment dictionary
- **dkey** – str

reset ()
Resets/initializes the internal control points array.

set_ctrlpt (*pt, *args*)
Puts the control point to the given location in the array.

Parameters **pt** (`list, tuple`) – control point

set_ptdata (*adct, *args*)
Attaches the data to the control point.

Parameters

- **adct** – attachment dictionary
- **adct** – dict

class geomdl.control_points.**SurfaceManager** (**args, **kwargs*)
Bases: `geomdl.control_points.AbstractManager`

Surface control points manager.

Control points manager class provides an easy way to set control points without knowing the internal data structure of the geometry classes. The manager class is initialized with the number of control points in all parametric dimensions.

B-spline surfaces are defined in one parametric dimension. Therefore, this manager class should be initialized with two integer values.

```
# Assuming that the surface has size_u = 5 and size_v = 7 control points
manager = SurfaceManager(5, 7)
```

Getting the control points:

```
# Number of control points in all parametric dimensions
size_u = spline.ctrlpts_size_u
size_v = spline.ctrlpts_size_v

# Generate control points manager
cpt_manager = control_points.SurfaceManager(size_u, size_v)
cpt_manager.ctrlpts = spline.ctrlpts

# Control points array to be used externally
control_points = []

# Get control points from the spline geometry
for u in range(size_u):
    for v in range(size_v):
        pt = cpt_manager.get_ctrlpt(u, v)
        control_points.append(pt)
```

Setting the control points:

```
# Number of control points in all parametric dimensions
size_u = 5
size_v = 3

# Create control points manager
points = control_points.SurfaceManager(size_u, size_v)

# Set control points
for u in range(size_u):
    for v in range(size_v):
        # 'pt' is the control point, e.g. [10, 15, 12]
        points.set_ctrlpt(pt, u, v)

# Create spline geometry
surf = BSpline.Surface()

# Set control points
surf.ctrlpts = points.ctrlpts
```

ctrlpts

Control points.

Please refer to the wiki for details on using this class member.

Getter Gets the control points

Setter Sets the control points

find_index (**args*)
Finds the array index from the given parametric positions.

Note: This is an abstract method and it must be implemented in the subclass.

get_ctrlpt (**args*)
Gets the control point from the given location in the array.

get_ptdata (*dkey, *args*)
Gets the data attached to the control point.

Parameters

- **dkey** – key of the attachment dictionary
- **dkey** – str

reset ()
Resets/initializes the internal control points array.

set_ctrlpt (*pt, *args*)
Puts the control point to the given location in the array.

Parameters **pt** (*list, tuple*) – control point

set_ptdata (*adct, *args*)
Attaches the data to the control point.

Parameters

- **adct** – attachment dictionary
- **adct** – dict

class geomdl.control_points.**VolumeManager** (**args, **kwargs*)
Bases: *geomdl.control_points.AbstractManager*

Volume control points manager.

Control points manager class provides an easy way to set control points without knowing the internal data structure of the geometry classes. The manager class is initialized with the number of control points in all parametric dimensions.

B-spline volumes are defined in one parametric dimension. Therefore, this manager class should be initialized with there integer values.

```
# Assuming that the volume has size_u = 5, size_v = 12 and size_w = 3 control␣
↪points
manager = VolumeManager(5, 12, 3)
```

Gettting the control points:

```
# Number of control points in all parametric dimensions
size_u = spline.ctrlpts_size_u
size_v = spline.ctrlpts_size_v
size_w = spline.ctrlpts_size_w

# Generate control points manager
cpt_manager = control_points.SurfaceManager(size_u, size_v, size_w)
cpt_manager.ctrlpts = spline.ctrlpts

```

(continues on next page)

(continued from previous page)

```
# Control points array to be used externally
control_points = []

# Get control points from the spline geometry
for u in range(size_u):
    for v in range(size_v):
        for w in range(size_w):
            pt = cpt_manager.get_ctrlpt(u, v, w)
            control_points.append(pt)
```

Setting the control points:

```
# Number of control points in all parametric dimensions
size_u = 5
size_v = 3
size_w = 2

# Create control points manager
points = control_points.VolumeManager(size_u, size_v, size_w)

# Set control points
for u in range(size_u):
    for v in range(size_v):
        for w in range(size_w):
            # 'pt' is the control point, e.g. [10, 15, 12]
            points.set_ctrlpt(pt, u, v, w)

# Create spline geometry
volume = BSpline.Volume()

# Set control points
volume.ctrlpts = points.ctrlpts
```

ctrlpts

Control points.

Please refer to the wiki for details on using this class member.

Getter Gets the control points

Setter Sets the control points

find_index (**args*)

Finds the array index from the given parametric positions.

Note: This is an abstract method and it must be implemented in the subclass.

get_ctrlpt (**args*)

Gets the control point from the given location in the array.

get_ptdata (*dkey*, **args*)

Gets the data attached to the control point.

Parameters

- **dkey** – key of the attachment dictionary
- **dkey** – str

reset()
Resets/initializes the internal control points array.

set_ctrlpt(*pt*, **args*)
Puts the control point to the given location in the array.

Parameters pt (`list, tuple`) – control point

set_ptdata(*adct*, **args*)
Attaches the data to the control point.

Parameters

- **adct** – attachment dictionary
- **adct** – dict

17.2.3 Surface Generator

`CPGen` module allows users to generate control points grids as an input to *BSpline.Surface* and *NURBS.Surface* classes. This module is designed to enable more testing cases in a very simple way and it doesn't have the capabilities of a fully-featured grid generator, but it should be enough to be used side by side with `BSpline` and `NURBS` modules.

CPGen.Grid class provides an easy way to generate control point grids for use with *BSpline.Surface* class and *CPGen.GridWeighted* does the same for *NURBS.Surface* class.

Grid

class geomdl.CPGen.**Grid**(*size_x*, *size_y*, ***kwargs*)
Bases: `object`

Simple control points grid generator to use with non-rational surfaces.

This class stores grid points in [x, y, z] format and the grid (control) points can be retrieved from the *grid* attribute. The z-coordinate of the control points can be set via the keyword argument `z_value` while initializing the class.

Parameters

- **size_x** (`float`) – width of the grid
- **size_y** (`float`) – height of the grid

bumps(*num_bumps*, ***kwargs*)
Generates arbitrary bumps (i.e. hills) on the 2-dimensional grid.

This method generates hills on the grid defined by the **num_bumps** argument. It is possible to control the z-value using **bump_height** argument. **bump_height** can be a positive or negative numeric value or it can be a list of numeric values.

Please note that, not all grids can be modified to have **num_bumps** number of bumps. Therefore, this function uses a brute-force algorithm to determine whether the bumps can be generated or not. For instance:

```
test_grid = Grid(5, 10) # generates a 5x10 rectangle
test_grid.generate(4, 4) # splits the rectangle into 2x2 pieces
test_grid.bumps(100) # impossible, it will return an error message
test_grid.bumps(1) # You will get a bump at the center of the generated grid
```

This method accepts the following keyword arguments:

- `bump_height`: z-value of the generated bumps on the grid. *Default: 5.0*
- `base_extent`: extension of the hill base from its center in terms of grid points. *Default: 2*
- `base_adjust`: padding between the bases of the hills. *Default: 0*

Parameters **num_bumps** (*int*) – number of bumps (i.e. hills) to be generated on the 2D grid

generate(*num_u*, *num_v*)

Generates grid using the input division parameters.

Parameters

- **num_u** (*int*) – number of divisions in x-direction
- **num_v** (*int*) – number of divisions in y-direction

grid

Grid points.

Please refer to the wiki for details on using this class member.

Getter Gets the 2-dimensional list of points in [u][v] format

reset()

Resets the grid.

Weighted Grid

class geomdl.CPGen.**GridWeighted**(*size_x*, *size_y*, ***kwargs*)

Bases: *geomdl.CPGen.Grid*

Simple control points grid generator to use with rational surfaces.

This class stores grid points in [x*w, y*w, z*w, w] format and the grid (control) points can be retrieved from the *grid* attribute. The z-coordinate of the control points can be set via the keyword argument `z_value` while initializing the class.

Parameters

- **size_x** (*float*) – width of the grid
- **size_y** (*float*) – height of the grid

bumps(*num_bumps*, ***kwargs*)

Generates arbitrary bumps (i.e. hills) on the 2-dimensional grid.

This method generates hills on the grid defined by the **num_bumps** argument. It is possible to control the z-value using **bump_height** argument. **bump_height** can be a positive or negative numeric value or it can be a list of numeric values.

Please note that, not all grids can be modified to have **num_bumps** number of bumps. Therefore, this function uses a brute-force algorithm to determine whether the bumps can be generated or not. For instance:

```
test_grid = Grid(5, 10) # generates a 5x10 rectangle
test_grid.generate(4, 4) # splits the rectangle into 2x2 pieces
test_grid.bumps(100) # impossible, it will return an error message
test_grid.bumps(1) # You will get a bump at the center of the generated grid
```

This method accepts the following keyword arguments:

- `bump_height`: z-value of the generated bumps on the grid. *Default: 5.0*
- `base_extent`: extension of the hill base from its center in terms of grid points. *Default: 2*
- `base_adjust`: padding between the bases of the hills. *Default: 0*

Parameters **num_bumps** (*int*) – number of bumps (i.e. hills) to be generated on the 2D grid

generate (*num_u*, *num_v*)
Generates grid using the input division parameters.

Parameters

- **num_u** (*int*) – number of divisions in x-direction
- **num_v** (*int*) – number of divisions in y-direction

grid
Weighted grid points.

Please refer to the wiki for details on using this class member.

Getter Gets the 2-dimensional list of weighted points in [u][v] format

reset ()
Resets the grid.

weight
Weight (w) component of the grid points.

The input can be a single int or a float value, then all weights will be set to the same value.

Please refer to the wiki for details on using this class member.

Getter Gets the weights vector

Setter Sets the weights vector

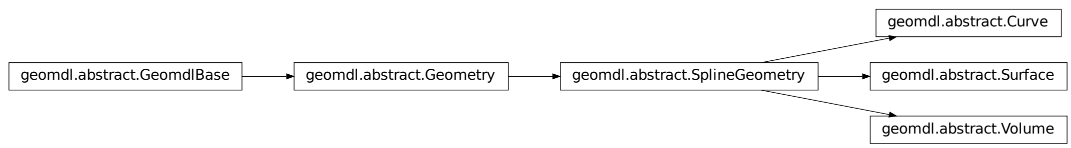
17.3 Advanced API

The following list contains the modules for advanced use:

17.3.1 Geometry Base

`abstract` module provides base classes for parametric curves, surfaces and volumes contained in this library and therefore, it provides an easy way to extend the library in the most proper way.

Inheritance Diagram



Abstract Curve

class geomdl.abstract.**Curve**(***kwargs*)

Bases: *geomdl.abstract.SplineGeometry*

Abstract base class for defining spline curves.

Curve ABC is inherited from abc.ABCMeta class which is included in Python standard library by default. Due to differences between Python 2 and 3 on defining a metaclass, the compatibility module `six` is employed. Using `six` to set metaclass allows users to use the abstract classes in a correct way.

The abstract base classes in this module are implemented using a feature called Python Properties. This feature allows users to use some of the functions as if they are class fields. You can also consider properties as a pythonic way to set getters and setters. You will see "getter" and "setter" descriptions on the documentation of these properties.

The Curve ABC allows users to set the *FindSpan* function to be used in evaluations with `find_span_func` keyword as an input to the class constructor. NURBS-Python includes a binary and a linear search variation of the FindSpan function in the `helpers` module. You may also implement and use your own *FindSpan* function. Please see the `helpers` module for details.

Code segment below illustrates a possible implementation of Curve abstract base class:

```
from geomdl import abstract

class MyCurveClass(abstract.Curve):
    def __init__(self, **kwargs):
    super(MyCurveClass, self).__init__(**kwargs)
    # Add your constructor code here

    def evaluate(self, **kwargs):
        # Implement this function
        pass

    def evaluate_single(self, uv):
        # Implement this function
        pass

    def evaluate_list(self, uv_list):
        # Implement this function
        pass

    def derivatives(self, u, v, order, **kwargs):
```

(continues on next page)

(continued from previous page)

```
        # Implement this function
        pass
```

The properties and functions defined in the abstract base class will be automatically available in the subclasses.

Keyword Arguments:

- `id`: object ID (as integer)
- `precision`: number of decimal places to round to. *Default: 18*
- `normalize_kv`: if True, knot vector(s) will be normalized to [0,1] domain. *Default: True*
- `find_span_func`: default knot span finding algorithm. *Default:* `helpers.find_span_linear()`

bbox
Bounding box.

Evaluates the bounding box and returns the minimum and maximum coordinates.

Please refer to the wiki for details on using this class member.

Getter Gets the bounding box

Type tuple

cpsize
Number of control points in all parametric directions.

Note: This is an expert property for getting and setting control point size(s) of the geometry.

Please refer to the wiki for details on using this class member.

Getter Gets the number of control points

Setter Sets the number of control points

Type list

ctrlpts
Control points.

Please refer to the wiki for details on using this class member.

Getter Gets the control points

Setter Sets the control points

Type list

ctrlpts_size
Total number of control points.

Getter Gets the total number of control points

Type int

data
Returns a dict which contains the geometry data.

Please refer to the wiki for details on using this class member.

degree
Degree.

Please refer to the wiki for details on using this class member.

Getter Gets the degree

Setter Sets the degree

Type int

delta
Evaluation delta.

Evaluation delta corresponds to the *step size* while `evaluate` function iterates on the knot vector to generate curve points. Decreasing step size results in generation of more curve points. Therefore; smaller the delta value, smoother the curve.

The following figure illustrates the working principles of the delta property:

$$[u_{start}, u_{start} + \delta, (u_{start} + \delta) + \delta, \dots, u_{end}]$$

Please refer to the wiki for details on using this class member.

Getter Gets the delta value

Setter Sets the delta value

Type float

derivatives (*u*, *order*, ***kwargs*)
Evaluates the derivatives of the curve at parameter u.

Note: This is an abstract method and it must be implemented in the subclass.

Parameters

- **u** (*float*) – parameter (u)
- **order** (*int*) – derivative order

dimension
Spatial dimension.

Spatial dimension will be automatically estimated from the first element of the control points array.

Please refer to the wiki for details on using this class member.

Getter Gets the spatial dimension, e.g. 2D, 3D, etc.

Type int

domain
Domain.

Domain is determined using the knot vector(s).

Getter Gets the domain

evalpts
Evaluated points.

Please refer to the wiki for details on using this class member.

Getter Gets the coordinates of the evaluated points

Type list

evaluate(***kwargs*)
Evaluates the curve.

Note: This is an abstract method and it must be implemented in the subclass.

evaluate_list(*param_list*)
Evaluates the curve for an input range of parameters.

Note: This is an abstract method and it must be implemented in the subclass.

Parameters **param_list** – array of parameters

evaluate_single(*param*)
Evaluates the curve at the given parameter.

Note: This is an abstract method and it must be implemented in the subclass.

Parameters **param** – parameter (u)

evaluator
Evaluator instance.

Evaluators allow users to use different algorithms for B-Spline and NURBS evaluations. Please see the documentation on `Evaluator` classes.

Please refer to the wiki for details on using this class member.

Getter Gets the current Evaluator instance

Setter Sets the Evaluator instance

Type *evaluators.AbstractEvaluator*

id
Object ID (as an integer).

Please refer to the wiki for details on using this class member.

Getter Gets the object ID

Setter Sets the object ID

Type int

knotvector
Knot vector.

The knot vector will be normalized to [0, 1] domain if the class is initialized with `normalize_kv=True` argument.

Please refer to the wiki for details on using this class member.

Getter Gets the knot vector

Setter Sets the knot vector

Type list

name
Object name (as a string)

Please refer to the wiki for details on using this class member.

Getter Gets the object name

Setter Sets the object name

Type str

opt
Dictionary for storing custom data in the current geometry object.

`opt` is a wrapper to a dict in *key* => *value* format, where *key* is string, *value* is any Python object. You can use `opt` property to store custom data inside the geometry object. For instance:

```
geom.opt = ["face_id", 4]  # creates "face_id" key and sets its value to an␣
↪integer
geom.opt = ["contents", "data values"]  # creates "face_id" key and sets its␣
↪value to a string
print(geom.opt)  # will print: {'face_id': 4, 'contents': 'data values'}

del geom.opt  # deletes the contents of the hash map
print(geom.opt)  # will print: {}

geom.opt = ["body_id", 1]  # creates "body_id" key  and sets its value to 1
geom.opt = ["body_id", 12]  # changes the value of "body_id" to 12
print(geom.opt)  # will print: {'body_id': 12}

geom.opt = ["body_id", None]  # deletes "body_id"
print(geom.opt)  # will print: {}
```

Please refer to the wiki for details on using this class member.

Getter Gets the dict

Setter Adds key and value pair to the dict

Deleter Deletes the contents of the dict

opt_get(*value*)
Safely query for the value from the *opt* property.

Parameters value (*str*) – a key in the *opt* property

Returns the corresponding value, if the key exists. `None`, otherwise.

order
Order.

Defined as `order = degree + 1`

Please refer to the wiki for details on using this class member.

Getter Gets the order

Setter Sets the order

Type int

pdimension
Parametric dimension.

Please refer to the wiki for details on using this class member.

Getter Gets the parametric dimension

Type int

range
Domain range.

Getter Gets the range

rational
Defines the rational and non-rational B-spline shapes.

Rational shapes use homogeneous coordinates which includes a weight alongside with the Cartesian coordinates. Rational B-splines are also named as NURBS (Non-uniform rational basis spline) and non-rational B-splines are sometimes named as NUBS (Non-uniform basis spline) or directly as B-splines.

Please refer to the wiki for details on using this class member.

Getter Returns True is the B-spline object is rational (NURBS)

Type bool

render(***kwargs*)
Renders the curve using the visualization component

The visualization component must be set using `vis` property before calling this method.

Keyword Arguments:

- `cpcolor`: sets the color of the control points polygon
- `evalcolor`: sets the color of the curve
- `bboxcolor`: sets the color of the bounding box
- `filename`: saves the plot with the input name
- `plot`: controls plot window visibility. *Default: True*
- `animate`: activates animation (if supported). *Default: False*
- `extras`: adds line plots to the figure. *Default: None*

`plot` argument is useful when you would like to work on the command line without any window context. If `plot` flag is False, this method saves the plot as an image file (.png file where possible) and disables plot window popping out. If you don't provide a file name, the name of the image file will be pulled from the configuration class.

`extras` argument can be used to add extra line plots to the figure. This argument expects a list of dicts in the format described below:

```
[
    dict(  # line plot 1
        points=[[1, 2, 3], [4, 5, 6]],  # list of points
        name="My line Plot 1",  # name displayed on the legend
        color="red",   # color of the line plot
        size=6.5  # size of the line plot
    ),
    dict(  # line plot 2
        points=[[7, 8, 9], [10, 11, 12]],  # list of points
```

(continues on next page)

(continued from previous page)

```
        name="My line Plot 2",  # name displayed on the legend
        color="navy",    # color of the line plot
        size=12.5   # size of the line plot
    )
]
```

Returns the figure object

reset (***kwargs*)
Resets control points and/or evaluated points.

Keyword Arguments:

- `evalpts`: if True, then resets evaluated points
- `ctrlpts` if True, then resets control points

reverse ()
Reverses the curve

sample_size
Sample size.

Sample size defines the number of evaluated points to generate. It also sets the `delta` property.

The following figure illustrates the working principles of sample size property:

$$\underbrace{[u_{start}, \ldots, u_{end}]}_{n_{sample}}$$

Please refer to the wiki for details on using this class member.

Getter Gets sample size

Setter Sets sample size

Type int

set_ctrlpts (*ctrlpts*, **args*, ***kwargs*)
Sets control points and checks if the data is consistent.

This method is designed to provide a consistent way to set control points whether they are weighted or not. It directly sets the control points member of the class, and therefore it doesn't return any values. The input will be an array of coordinates. If you are working in the 3-dimensional space, then your coordinates will be an array of 3 elements representing *(x, y, z)* coordinates.

Parameters **ctrlpts** (`list`) – input control points as a list of coordinates

type
Geometry type

Please refer to the wiki for details on using this class member.

Getter Gets the geometry type

Type str

vis
Visualization component.

Please refer to the wiki for details on using this class member.

Getter Gets the visualization component

Setter Sets the visualization component

Type vis.VisAbstract

weights

Weights.

Note: Only available for rational spline geometries. Getter return `None` otherwise.

Please refer to the wiki for details on using this class member.

Getter Gets the weights

Setter Sets the weights

Abstract Surface

class geomdl.abstract.**Surface**(***kwargs*)

Bases: *geomdl.abstract.SplineGeometry*

Abstract base class for defining spline surfaces.

Surface ABC is inherited from abc.ABCMeta class which is included in Python standard library by default. Due to differences between Python 2 and 3 on defining a metaclass, the compatibility module `six` is employed. Using `six` to set metaclass allows users to use the abstract classes in a correct way.

The abstract base classes in this module are implemented using a feature called Python Properties. This feature allows users to use some of the functions as if they are class fields. You can also consider properties as a pythonic way to set getters and setters. You will see "getter" and "setter" descriptions on the documentation of these properties.

The Surface ABC allows users to set the *FindSpan* function to be used in evaluations with `find_span_func` keyword as an input to the class constructor. NURBS-Python includes a binary and a linear search variation of the FindSpan function in the `helpers` module. You may also implement and use your own *FindSpan* function. Please see the `helpers` module for details.

Code segment below illustrates a possible implementation of Surface abstract base class:

```
from geomdl import abstract

class MySurfaceClass(abstract.Surface):
    def __init__(self, **kwargs):
    super(MySurfaceClass, self).__init__(**kwargs)
    # Add your constructor code here

    def evaluate(self, **kwargs):
        # Implement this function
        pass

    def evaluate_single(self, uv):
        # Implement this function
        pass

    def evaluate_list(self, uv_list):
        # Implement this function
        pass

    def derivatives(self, u, v, order, **kwargs):
```

(continues on next page)

(continued from previous page)

```
        # Implement this function
        pass
```

The properties and functions defined in the abstract base class will be automatically available in the subclasses.

Keyword Arguments:

- `id`: object ID (as integer)
- `precision`: number of decimal places to round to. *Default: 18*
- `normalize_kv`: if True, knot vector(s) will be normalized to [0,1] domain. *Default: True*
- `find_span_func`: default knot span finding algorithm. *Default:* `helpers.find_span_linear()`

add_trim(*trim*)

Adds a trim to the surface.

A trim is a 2-dimensional curve defined on the parametric domain of the surface. Therefore, x-coordinate of the trimming curve corresponds to u parametric direction of the surfaceand y-coordinate of the trimming curve corresponds to v parametric direction of the surface.

`trims` uses this method to add trims to the surface.

Parameters **trim** (`abstract.Geometry`) – surface trimming curve

bbox

Bounding box.

Evaluates the bounding box and returns the minimum and maximum coordinates.

Please refer to the wiki for details on using this class member.

Getter Gets the bounding box

Type tuple

cpsize

Number of control points in all parametric directions.

Note: This is an expert property for getting and setting control point size(s) of the geometry.

Please refer to the wiki for details on using this class member.

Getter Gets the number of control points

Setter Sets the number of control points

Type list

ctrlpts

1-dimensional array of control points.

Note: The v index varies first. That is, a row of v control points for the first u value is found first. Then, the row of v control points for the next u value.

Please refer to the wiki for details on using this class member.

Getter Gets the control points

Setter Sets the control points

Type list

ctrlpts_size
Total number of control points.

Getter Gets the total number of control points

Type int

ctrlpts_size_u
Number of control points for the u-direction.

Please refer to the wiki for details on using this class member.

Getter Gets number of control points for the u-direction

Setter Sets number of control points for the u-direction

ctrlpts_size_v
Number of control points for the v-direction.

Please refer to the wiki for details on using this class member.

Getter Gets number of control points on the v-direction

Setter Sets number of control points on the v-direction

data
Returns a dict which contains the geometry data.

Please refer to the wiki for details on using this class member.

degree
Degree for u- and v-directions

Getter Gets the degree

Setter Sets the degree

Type list

degree_u
Degree for the u-direction.

Please refer to the wiki for details on using this class member.

Getter Gets degree for the u-direction

Setter Sets degree for the u-direction

Type int

degree_v
Degree for the v-direction.

Please refer to the wiki for details on using this class member.

Getter Gets degree for the v-direction

Setter Sets degree for the v-direction

Type int

delta
Evaluation delta for both u- and v-directions.

Evaluation delta corresponds to the *step size* while `evaluate()` function iterates on the knot vector to generate surface points. Decreasing step size results in generation of more surface points. Therefore; smaller the delta value, smoother the surface.

Please note that `delta` and `sample_size` properties correspond to the same variable with different descriptions. Therefore, setting `delta` will also set `sample_size`.

The following figure illustrates the working principles of the delta property:

$$[u_0, u_{start} + \delta, (u_{start} + \delta) + \delta, \dots, u_{end}]$$

Please refer to the wiki for details on using this class member.

Getter Gets evaluation delta as a tuple of values corresponding to u- and v-directions

Setter Sets evaluation delta for both u- and v-directions

Type float

delta_u

Evaluation delta for the u-direction.

Evaluation delta corresponds to the *step size* while `evaluate()` function iterates on the knot vector to generate surface points. Decreasing step size results in generation of more surface points. Therefore; smaller the delta value, smoother the surface.

Please note that `delta_u` and `sample_size_u` properties correspond to the same variable with different descriptions. Therefore, setting `delta_u` will also set `sample_size_u`.

Please refer to the wiki for details on using this class member.

Getter Gets evaluation delta for the u-direction

Setter Sets evaluation delta for the u-direction

Type float

delta_v

Evaluation delta for the v-direction.

Evaluation delta corresponds to the *step size* while `evaluate()` function iterates on the knot vector to generate surface points. Decreasing step size results in generation of more surface points. Therefore; smaller the delta value, smoother the surface.

Please note that `delta_v` and `sample_size_v` properties correspond to the same variable with different descriptions. Therefore, setting `delta_v` will also set `sample_size_v`.

Please refer to the wiki for details on using this class member.

Getter Gets evaluation delta for the v-direction

Setter Sets evaluation delta for the v-direction

Type float

derivatives(*u*, *v*, *order*, ***kwargs*)

Evaluates the derivatives of the parametric surface at parameter (u, v).

Note: This is an abstract method and it must be implemented in the subclass.

Parameters

- **u** (*float*) – parameter on the u-direction

- **v** (*float*) – parameter on the v-direction
- **order** (*int*) – derivative order

dimension
Spatial dimension.

Spatial dimension will be automatically estimated from the first element of the control points array.

Please refer to the wiki for details on using this class member.

Getter Gets the spatial dimension, e.g. 2D, 3D, etc.

Type int

domain
Domain.

Domain is determined using the knot vector(s).

Getter Gets the domain

evalpts
Evaluated points.

Please refer to the wiki for details on using this class member.

Getter Gets the coordinates of the evaluated points

Type list

evaluate(***kwargs*)
Evaluates the parametric surface.

Note: This is an abstract method and it must be implemented in the subclass.

evaluate_list(*param_list*)
Evaluates the parametric surface for an input range of (u, v) parameters.

Note: This is an abstract method and it must be implemented in the subclass.

Parameters **param_list** – array of parameters (u, v)

evaluate_single(*param*)
Evaluates the parametric surface at the given (u, v) parameter.

Note: This is an abstract method and it must be implemented in the subclass.

Parameters **param** – parameter (u, v)

evaluator
Evaluator instance.

Evaluators allow users to use different algorithms for B-Spline and NURBS evaluations. Please see the documentation on `Evaluator` classes.

Please refer to the wiki for details on using this class member.

Getter Gets the current Evaluator instance

Setter Sets the Evaluator instance

Type *evaluators.AbstractEvaluator*

faces
Faces (triangles, quads, etc.) generated by the tessellation operation.

If the tessellation component is set to None, the result will be an empty list.

Getter Gets the faces

id
Object ID (as an integer).

Please refer to the wiki for details on using this class member.

Getter Gets the object ID

Setter Sets the object ID

Type int

knotvector
Knot vector for u- and v-directions

Getter Gets the knot vector

Setter Sets the knot vector

Type list

knotvector_u
Knot vector for the u-direction.

The knot vector will be normalized to [0, 1] domain if the class is initialized with `normalize_kv=True` argument.

Please refer to the wiki for details on using this class member.

Getter Gets knot vector for the u-direction

Setter Sets knot vector for the u-direction

Type list

knotvector_v
Knot vector for the v-direction.

The knot vector will be normalized to [0, 1] domain if the class is initialized with `normalize_kv=True` argument.

Please refer to the wiki for details on using this class member.

Getter Gets knot vector for the v-direction

Setter Sets knot vector for the v-direction

Type list

name
Object name (as a string)

Please refer to the wiki for details on using this class member.

Getter Gets the object name

Setter Sets the object name

Type str

opt

Dictionary for storing custom data in the current geometry object.

`opt` is a wrapper to a dict in *key* => *value* format, where *key* is string, *value* is any Python object. You can use `opt` property to store custom data inside the geometry object. For instance:

```
geom.opt = ["face_id", 4]  # creates "face_id" key and sets its value to an␣
↪integer
geom.opt = ["contents", "data values"]  # creates "face_id" key and sets its␣
↪value to a string
print(geom.opt)  # will print: {'face_id': 4, 'contents': 'data values'}

del geom.opt  # deletes the contents of the hash map
print(geom.opt)  # will print: {}

geom.opt = ["body_id", 1]  # creates "body_id" key  and sets its value to 1
geom.opt = ["body_id", 12]  # changes the value of "body_id" to 12
print(geom.opt)  # will print: {'body_id': 12}

geom.opt = ["body_id", None]  # deletes "body_id"
print(geom.opt)  # will print: {}
```

Please refer to the wiki for details on using this class member.

Getter Gets the dict

Setter Adds key and value pair to the dict

Deleter Deletes the contents of the dict

opt_get(*value*)

Safely query for the value from the *opt* property.

Parameters **value** (*str*) – a key in the *opt* property

Returns the corresponding value, if the key exists. `None`, otherwise.

order_u

Order for the u-direction.

Defined as `order = degree + 1`

Please refer to the wiki for details on using this class member.

Getter Gets order for the u-direction

Setter Sets order for the u-direction

Type int

order_v

Order for the v-direction.

Defined as `order = degree + 1`

Please refer to the wiki for details on using this class member.

Getter Gets surface order for the v-direction

Setter Sets surface order for the v-direction

Type int

pdimension
Parametric dimension.

Please refer to the wiki for details on using this class member.

Getter Gets the parametric dimension

Type int

range
Domain range.

Getter Gets the range

rational
Defines the rational and non-rational B-spline shapes.

Rational shapes use homogeneous coordinates which includes a weight alongside with the Cartesian coordinates. Rational B-splines are also named as NURBS (Non-uniform rational basis spline) and non-rational B-splines are sometimes named as NUBS (Non-uniform basis spline) or directly as B-splines.

Please refer to the wiki for details on using this class member.

Getter Returns True is the B-spline object is rational (NURBS)

Type bool

render (***kwargs*)
Renders the surface using the visualization component.

The visualization component must be set using `vis` property before calling this method.

Keyword Arguments:

- `cpcolor`: sets the color of the control points grid
- `evalcolor`: sets the color of the surface
- `trimcolor`: sets the color of the trim curves
- `filename`: saves the plot with the input name
- `plot`: controls plot window visibility. *Default: True*
- `animate`: activates animation (if supported). *Default: False*
- `extras`: adds line plots to the figure. *Default: None*
- `colormap`: sets the colormap of the surface

The `plot` argument is useful when you would like to work on the command line without any window context. If `plot` flag is False, this method saves the plot as an image file (.png file where possible) and disables plot window popping out. If you don't provide a file name, the name of the image file will be pulled from the configuration class.

`extras` argument can be used to add extra line plots to the figure. This argument expects a list of dicts in the format described below:

```
[
    dict(  # line plot 1
        points=[[1, 2, 3], [4, 5, 6]],  # list of points
        name="My line Plot 1",  # name displayed on the legend
        color="red",   # color of the line plot
        size=6.5  # size of the line plot
    ),
```

(continues on next page)

(continued from previous page)

```
    dict(  # line plot 2
        points=[[7, 8, 9], [10, 11, 12]],  # list of points
        name="My line Plot 2",  # name displayed on the legend
        color="navy",   # color of the line plot
        size=12.5  # size of the line plot
    )
]
```

Please note that `colormap` argument can only work with visualization classes that support colormaps. As an example, please see `VisMPL.VisSurfTriangle()` class documentation. This method expects a single colormap input.

Returns the figure object

reset(***kwargs*)

Resets control points and/or evaluated points.

Keyword Arguments:

- `evalpts`: if True, then resets evaluated points
- `ctrlpts` if True, then resets control points

sample_size

Sample size for both u- and v-directions.

Sample size defines the number of surface points to generate. It also sets the `delta` property.

The following figure illustrates the working principles of sample size property:

$$\underbrace{\left[u_{start}, \ldots, u_{end}\right]}_{n_{sample}}$$

Please refer to the wiki for details on using this class member.

Getter Gets sample size as a tuple of values corresponding to u- and v-directions

Setter Sets sample size for both u- and v-directions

Type int

sample_size_u

Sample size for the u-direction.

Sample size defines the number of surface points to generate. It also sets the `delta_u` property.

Please refer to the wiki for details on using this class member.

Getter Gets sample size for the u-direction

Setter Sets sample size for the u-direction

Type int

sample_size_v

Sample size for the v-direction.

Sample size defines the number of surface points to generate. It also sets the `delta_v` property.

Please refer to the wiki for details on using this class member.

Getter Gets sample size for the v-direction

Setter Sets sample size for the v-direction

Type int

set_ctrlpts (*ctrlpts*, **args*, ***kwargs*)

Sets the control points and checks if the data is consistent.

This method is designed to provide a consistent way to set control points whether they are weighted or not. It directly sets the control points member of the class, and therefore it doesn't return any values. The input will be an array of coordinates. If you are working in the 3-dimensional space, then your coordinates will be an array of 3 elements representing *(x, y, z)* coordinates.

Note: The v index varies first. That is, a row of v control points for the first u value is found first. Then, the row of v control points for the next u value.

Parameters

- **ctrlpts** (*list*) – input control points as a list of coordinates
- **args** (*tuple[int, int]*) – number of control points corresponding to each parametric dimension

tessellate (***kwargs*)

Tessellates the surface.

Keyword arguments are directly passed to the tessellation component.

tessellator

Tessellation component.

Please refer to the wiki for details on using this class member.

Getter Gets the tessellation component

Setter Sets the tessellation component

trims

Curves for trimming the surface.

Surface trims are 2-dimensional curves which are introduced on the parametric space of the surfaces. Trim curves can be a spline curve, an analytic curve or a 2-dimensional freeform shape. To visualize the trimmed surfaces, you need to use a tessellator that supports trimming. The following code snippet illustrates changing the default surface tessellator to the trimmed surface tessellator, `tessellate.TrimTessellate`.

```
from geomdl import tessellate

# Assuming that "surf" variable stores the surface instance
surf.tessellator = tessellate.TrimTessellate()
```

In addition, using *trims* initialization argument of the visualization classes, trim curves can be visualized together with their underlying surfaces. Please refer to the visualization configuration class initialization arguments for more details.

Please refer to the wiki for details on using this class member.

Getter Gets the array of trim curves

Setter Sets the array of trim curves

type

Geometry type

Please refer to the wiki for details on using this class member.

Getter Gets the geometry type

Type str

vertices
Vertices generated by the tessellation operation.

If the tessellation component is set to None, the result will be an empty list.

Getter Gets the vertices

vis
Visualization component.

Please refer to the wiki for details on using this class member.

Getter Gets the visualization component

Setter Sets the visualization component

Type vis.VisAbstract

weights
Weights.

Note: Only available for rational spline geometries. Getter return `None` otherwise.

Please refer to the wiki for details on using this class member.

Getter Gets the weights

Setter Sets the weights

Abstract Volume

class `geomdl.abstract.Volume(**kwargs)`
Bases: *geomdl.abstract.SplineGeometry*

Abstract base class for defining spline volumes.

Volume ABC is inherited from abc.ABCMeta class which is included in Python standard library by default. Due to differences between Python 2 and 3 on defining a metaclass, the compatibility module `six` is employed. Using `six` to set metaclass allows users to use the abstract classes in a correct way.

The abstract base classes in this module are implemented using a feature called Python Properties. This feature allows users to use some of the functions as if they are class fields. You can also consider properties as a pythonic way to set getters and setters. You will see "getter" and "setter" descriptions on the documentation of these properties.

The Volume ABC allows users to set the *FindSpan* function to be used in evaluations with `find_span_func` keyword as an input to the class constructor. NURBS-Python includes a binary and a linear search variation of the FindSpan function in the `helpers` module. You may also implement and use your own *FindSpan* function. Please see the `helpers` module for details.

Code segment below illustrates a possible implementation of Volume abstract base class:

```
from geomdl import abstract

class MyVolumeClass(abstract.Volume):
    def __init__(self, **kwargs):
```

(continues on next page)

(continued from previous page)

```
    super(MyVolumeClass, self).__init__(**kwargs)
    # Add your constructor code here

    def evaluate(self, **kwargs):
        # Implement this function
        pass

    def evaluate_single(self, uvw):
        # Implement this function
        pass

    def evaluate_list(self, uvw_list):
        # Implement this function
        pass
```

The properties and functions defined in the abstract base class will be automatically available in the subclasses.

Keyword Arguments:

- `id`: object ID (as integer)
- `precision`: number of decimal places to round to. *Default: 18*
- `normalize_kv`: if True, knot vector(s) will be normalized to [0,1] domain. *Default: True*
- `find_span_func`: default knot span finding algorithm. *Default:* `helpers.find_span_linear()`

add_trim (*trim*)

Adds a trim to the volume.

`trims` uses this method to add trims to the volume.

Parameters **trim** (`abstract.Surface`) – trimming surface

bbox

Bounding box.

Evaluates the bounding box and returns the minimum and maximum coordinates.

Please refer to the wiki for details on using this class member.

Getter Gets the bounding box

Type tuple

cpsize

Number of control points in all parametric directions.

Note: This is an expert property for getting and setting control point size(s) of the geometry.

Please refer to the wiki for details on using this class member.

Getter Gets the number of control points

Setter Sets the number of control points

Type list

ctrlpts

1-dimensional array of control points.

Please refer to the wiki for details on using this class member.

Getter Gets the control points

Setter Sets the control points

Type list

ctrlpts_size

Total number of control points.

Getter Gets the total number of control points

Type int

ctrlpts_size_u

Number of control points for the u-direction.

Please refer to the wiki for details on using this class member.

Getter Gets number of control points for the u-direction

Setter Sets number of control points for the u-direction

ctrlpts_size_v

Number of control points for the v-direction.

Please refer to the wiki for details on using this class member.

Getter Gets number of control points for the v-direction

Setter Sets number of control points for the v-direction

ctrlpts_size_w

Number of control points for the w-direction.

Please refer to the wiki for details on using this class member.

Getter Gets number of control points for the w-direction

Setter Sets number of control points for the w-direction

data

Returns a dict which contains the geometry data.

Please refer to the wiki for details on using this class member.

degree

Degree for u-, v- and w-directions

Getter Gets the degree

Setter Sets the degree

Type list

degree_u

Degree for the u-direction.

Please refer to the wiki for details on using this class member.

Getter Gets degree for the u-direction

Setter Sets degree for the u-direction

Type int

degree_v

Degree for the v-direction.

Please refer to the wiki for details on using this class member.

Getter Gets degree for the v-direction

Setter Sets degree for the v-direction

Type int

degree_w

Degree for the w-direction.

Please refer to the wiki for details on using this class member.

Getter Gets degree for the w-direction

Setter Sets degree for the w-direction

Type int

delta

Evaluation delta for u-, v- and w-directions.

Evaluation delta corresponds to the *step size* while `evaluate()` function iterates on the knot vector to generate surface points. Decreasing step size results in generation of more surface points. Therefore; smaller the delta value, smoother the surface.

Please note that `delta` and `sample_size` properties correspond to the same variable with different descriptions. Therefore, setting `delta` will also set `sample_size`.

The following figure illustrates the working principles of the delta property:

$$[u_0, u_{start} + \delta, (u_{start} + \delta) + \delta, \ldots, u_{end}]$$

Please refer to the wiki for details on using this class member.

Getter Gets evaluation delta as a tuple of values corresponding to u-, v- and w-directions

Setter Sets evaluation delta for u-, v- and w-directions

Type float

delta_u

Evaluation delta for the u-direction.

Evaluation delta corresponds to the *step size* while `evaluate()` function iterates on the knot vector to generate surface points. Decreasing step size results in generation of more surface points. Therefore; smaller the delta value, smoother the surface.

Please note that `delta_u` and `sample_size_u` properties correspond to the same variable with different descriptions. Therefore, setting `delta_u` will also set `sample_size_u`.

Please refer to the wiki for details on using this class member.

Getter Gets evaluation delta for the u-direction

Setter Sets evaluation delta for the u-direction

Type float

delta_v

Evaluation delta for the v-direction.

Evaluation delta corresponds to the *step size* while `evaluate()` function iterates on the knot vector to generate surface points. Decreasing step size results in generation of more surface points. Therefore; smaller the delta value, smoother the surface.

Please note that `delta_v` and `sample_size_v` properties correspond to the same variable with different descriptions. Therefore, setting `delta_v` will also set `sample_size_v`.

Please refer to the wiki for details on using this class member.

Getter Gets evaluation delta for the v-direction

Setter Sets evaluation delta for the v-direction

Type float

delta_w
Evaluation delta for the w-direction.

Evaluation delta corresponds to the *step size* while `evaluate()` function iterates on the knot vector to generate surface points. Decreasing step size results in generation of more surface points. Therefore; smaller the delta value, smoother the surface.

Please note that `delta_w` and `sample_size_w` properties correspond to the same variable with different descriptions. Therefore, setting `delta_w` will also set `sample_size_w`.

Please refer to the wiki for details on using this class member.

Getter Gets evaluation delta for the w-direction

Setter Sets evaluation delta for the w-direction

Type float

dimension
Spatial dimension.

Spatial dimension will be automatically estimated from the first element of the control points array.

Please refer to the wiki for details on using this class member.

Getter Gets the spatial dimension, e.g. 2D, 3D, etc.

Type int

domain
Domain.

Domain is determined using the knot vector(s).

Getter Gets the domain

evalpts
Evaluated points.

Please refer to the wiki for details on using this class member.

Getter Gets the coordinates of the evaluated points

Type list

evaluate(***kwargs*)
Evaluates the parametric volume.

Note: This is an abstract method and it must be implemented in the subclass.

evaluate_list (*param_list*)

Evaluates the parametric volume for an input range of (u, v, w) parameter pairs.

Note: This is an abstract method and it must be implemented in the subclass.

Parameters **param_list** – array of parameter pairs (u, v, w)

evaluate_single (*param*)

Evaluates the parametric surface at the given (u, v, w) parameter.

Note: This is an abstract method and it must be implemented in the subclass.

Parameters **param** – parameter pair (u, v, w)

evaluator

Evaluator instance.

Evaluators allow users to use different algorithms for B-Spline and NURBS evaluations. Please see the documentation on `Evaluator` classes.

Please refer to the wiki for details on using this class member.

Getter Gets the current Evaluator instance

Setter Sets the Evaluator instance

Type *evaluators.AbstractEvaluator*

id

Object ID (as an integer).

Please refer to the wiki for details on using this class member.

Getter Gets the object ID

Setter Sets the object ID

Type int

knotvector

Knot vector for u-, v- and w-directions

Getter Gets the knot vector

Setter Sets the knot vector

Type list

knotvector_u

Knot vector for the u-direction.

The knot vector will be normalized to [0, 1] domain if the class is initialized with `normalize_kv=True` argument.

Please refer to the wiki for details on using this class member.

Getter Gets knot vector for the u-direction

Setter Sets knot vector for the u-direction

Type list

knotvector_v

Knot vector for the v-direction.

The knot vector will be normalized to [0, 1] domain if the class is initialized with `normalize_kv=True` argument.

Please refer to the wiki for details on using this class member.

Getter Gets knot vector for the v-direction

Setter Sets knot vector for the v-direction

Type list

knotvector_w

Knot vector for the w-direction.

The knot vector will be normalized to [0, 1] domain if the class is initialized with `normalize_kv=True` argument.

Please refer to the wiki for details on using this class member.

Getter Gets knot vector for the w-direction

Setter Sets knot vector for the w-direction

Type list

name

Object name (as a string)

Please refer to the wiki for details on using this class member.

Getter Gets the object name

Setter Sets the object name

Type str

opt

Dictionary for storing custom data in the current geometry object.

`opt` is a wrapper to a dict in *key* => *value* format, where *key* is string, *value* is any Python object. You can use `opt` property to store custom data inside the geometry object. For instance:

```
geom.opt = ["face_id", 4]  # creates "face_id" key and sets its value to an integer
geom.opt = ["contents", "data values"]  # creates "face_id" key and sets its value to a string
print(geom.opt)  # will print: {'face_id': 4, 'contents': 'data values'}

del geom.opt  # deletes the contents of the hash map
print(geom.opt)  # will print: {}

geom.opt = ["body_id", 1]  # creates "body_id" key  and sets its value to 1
geom.opt = ["body_id", 12]  # changes the value of "body_id" to 12
print(geom.opt)  # will print: {'body_id': 12}

geom.opt = ["body_id", None]  # deletes "body_id"
print(geom.opt)  # will print: {}
```

Please refer to the wiki for details on using this class member.

Getter Gets the dict

Setter Adds key and value pair to the dict

Deleter Deletes the contents of the dict

opt_get (*value*)
Safely query for the value from the `opt` property.

Parameters **value** (`str`) – a key in the `opt` property

Returns the corresponding value, if the key exists. `None`, otherwise.

order_u
Order for the u-direction.

Defined as `order = degree + 1`

Please refer to the wiki for details on using this class member.

Getter Gets the surface order for u-direction

Setter Sets the surface order for u-direction

Type int

order_v
Order for the v-direction.

Defined as `order = degree + 1`

Please refer to the wiki for details on using this class member.

Getter Gets the surface order for v-direction

Setter Sets the surface order for v-direction

Type int

order_w
Order for the w-direction.

Defined as `order = degree + 1`

Please refer to the wiki for details on using this class member.

Getter Gets the surface order for v-direction

Setter Sets the surface order for v-direction

Type int

pdimension
Parametric dimension.

Please refer to the wiki for details on using this class member.

Getter Gets the parametric dimension

Type int

range
Domain range.

Getter Gets the range

rational
Defines the rational and non-rational B-spline shapes.

Rational shapes use homogeneous coordinates which includes a weight alongside with the Cartesian coordinates. Rational B-splines are also named as NURBS (Non-uniform rational basis spline) and non-rational B-splines are sometimes named as NUBS (Non-uniform basis spline) or directly as B-splines.

Please refer to the wiki for details on using this class member.

Getter Returns True is the B-spline object is rational (NURBS)

Type bool

render (***kwargs*)

Renders the volume using the visualization component.

The visualization component must be set using `vis` property before calling this method.

Keyword Arguments:

- `cpcolor`: sets the color of the control points
- `evalcolor`: sets the color of the volume
- `filename`: saves the plot with the input name
- `plot`: controls plot window visibility. *Default: True*
- `animate`: activates animation (if supported). *Default: False*
- `grid_size`: grid size for voxelization. *Default: (8, 8, 8)*
- `use_cubes`: use cube voxels instead of cuboid ones. *Default: False*
- `num_procs`: number of concurrent processes for voxelization. *Default: 1*

The `plot` argument is useful when you would like to work on the command line without any window context. If `plot` flag is False, this method saves the plot as an image file (.png file where possible) and disables plot window popping out. If you don't provide a file name, the name of the image file will be pulled from the configuration class.

`extras` argument can be used to add extra line plots to the figure. This argument expects a list of dicts in the format described below:

```
[
    dict(  # line plot 1
        points=[[1, 2, 3], [4, 5, 6]],  # list of points
        name="My line Plot 1",  # name displayed on the legend
        color="red",   # color of the line plot
        size=6.5  # size of the line plot
    ),
    dict(  # line plot 2
        points=[[7, 8, 9], [10, 11, 12]],  # list of points
        name="My line Plot 2",  # name displayed on the legend
        color="navy",   # color of the line plot
        size=12.5  # size of the line plot
    )
]
```

Returns the figure object

reset (***kwargs*)

Resets control points and/or evaluated points.

Keyword Arguments:

- `evalpts`: if True, then resets evaluated points

- `ctrlpts` if True, then resets control points

sample_size

Sample size for both u- and v-directions.

Sample size defines the number of surface points to generate. It also sets the `delta` property.

The following figure illustrates the working principles of sample size property:

$$\underbrace{\left[u_{start}, \ldots, u_{end}\right]}_{n_{sample}}$$

Please refer to the wiki for details on using this class member.

Getter Gets sample size as a tuple of values corresponding to u-, v- and w-directions

Setter Sets sample size value for both u-, v- and w-directions

Type int

sample_size_u

Sample size for the u-direction.

Sample size defines the number of evaluated points to generate. It also sets the `delta_u` property.

Please refer to the wiki for details on using this class member.

Getter Gets sample size for the u-direction

Setter Sets sample size for the u-direction

Type int

sample_size_v

Sample size for the v-direction.

Sample size defines the number of evaluated points to generate. It also sets the `delta_v` property.

Please refer to the wiki for details on using this class member.

Getter Gets sample size for the v-direction

Setter Sets sample size for the v-direction

Type int

sample_size_w

Sample size for the w-direction.

Sample size defines the number of evaluated points to generate. It also sets the `delta_w` property.

Please refer to the wiki for details on using this class member.

Getter Gets sample size for the w-direction

Setter Sets sample size for the w-direction

Type int

set_ctrlpts(*ctrlpts*, **args*, ***kwargs*)

Sets the control points and checks if the data is consistent.

This method is designed to provide a consistent way to set control points whether they are weighted or not. It directly sets the control points member of the class, and therefore it doesn't return any values. The input will be an array of coordinates. If you are working in the 3-dimensional space, then your coordinates will be an array of 3 elements representing *(x, y, z)* coordinates.

Parameters

- **ctrlpts** (*list*) – input control points as a list of coordinates
- **args** (*tuple[int, int, int]*) – number of control points corresponding to each parametric dimension

trims
Trimming surfaces.

Please refer to the wiki for details on using this class member.

Getter Gets the array of trim surfaces

Setter Sets the array of trim surfaces

type
Geometry type

Please refer to the wiki for details on using this class member.

Getter Gets the geometry type

Type str

vis
Visualization component.

Please refer to the wiki for details on using this class member.

Getter Gets the visualization component

Setter Sets the visualization component

Type vis.VisAbstract

weights
Weights.

Note: Only available for rational spline geometries. Getter return `None` otherwise.

Please refer to the wiki for details on using this class member.

Getter Gets the weights

Setter Sets the weights

Low Level API

The following classes provide the low level API for the geometry abstract base.

- *GeomdlBase*
- *Geometry*
- *SplineGeometry*

Geometry abstract base class can be used for implementation of any geometry object, whereas *SplineGeometry* abstract base class is designed specifically for spline geometries, including basis splines.

class geomdl.abstract.**GeomdlBase**(***kwargs*)
Bases: `object`

Abstract base class for defining geomdl objects.

This class provides the following properties:

- *type*
- *id*
- *name*
- *dimension*
- *opt*

Keyword Arguments:

- `id`: object ID (as integer)
- `precision`: number of decimal places to round to. *Default: 18*

dimension

Spatial dimension.

Please refer to the wiki for details on using this class member.

Getter Gets the spatial dimension, e.g. 2D, 3D, etc.

Type int

id

Object ID (as an integer).

Please refer to the wiki for details on using this class member.

Getter Gets the object ID

Setter Sets the object ID

Type int

name

Object name (as a string)

Please refer to the wiki for details on using this class member.

Getter Gets the object name

Setter Sets the object name

Type str

opt

Dictionary for storing custom data in the current geometry object.

`opt` is a wrapper to a dict in *key* => *value* format, where *key* is string, *value* is any Python object. You can use `opt` property to store custom data inside the geometry object. For instance:

```
geom.opt = ["face_id", 4]  # creates "face_id" key and sets its value to an␣
↪integer
geom.opt = ["contents", "data values"]  # creates "face_id" key and sets its␣
↪value to a string
print(geom.opt)  # will print: {'face_id': 4, 'contents': 'data values'}

del geom.opt  # deletes the contents of the hash map
print(geom.opt)  # will print: {}

geom.opt = ["body_id", 1]  # creates "body_id" key  and sets its value to 1
geom.opt = ["body_id", 12]  # changes the value of "body_id" to 12
print(geom.opt)  # will print: {'body_id': 12}
```

(continues on next page)

(continued from previous page)

```
geom.opt = ["body_id", None]  # deletes "body_id"
print(geom.opt)  # will print: {}
```

Please refer to the wiki for details on using this class member.

Getter Gets the dict

Setter Adds key and value pair to the dict

Deleter Deletes the contents of the dict

opt_get (*value*)

Safely query for the value from the *opt* property.

Parameters **value** (*str*) – a key in the *opt* property

Returns the corresponding value, if the key exists. None, otherwise.

type

Geometry type

Please refer to the wiki for details on using this class member.

Getter Gets the geometry type

Type str

class geomdl.abstract.**Geometry** (***kwargs*)

Bases: *geomdl.abstract.GeomdlBase*

Abstract base class for defining geometry objects.

This class provides the following properties:

- *type*
- *id*
- *name*
- *dimension*
- *evalpts*
- *opt*

Keyword Arguments:

- id: object ID (as integer)
- precision: number of decimal places to round to. *Default: 18*

dimension

Spatial dimension.

Please refer to the wiki for details on using this class member.

Getter Gets the spatial dimension, e.g. 2D, 3D, etc.

Type int

evalpts

Evaluated points.

Please refer to the wiki for details on using this class member.

Getter Gets the coordinates of the evaluated points

Type list

evaluate(***kwargs*)
Abstract method for the implementation of evaluation algorithm.

Note: This is an abstract method and it must be implemented in the subclass.

id
Object ID (as an integer).

Please refer to the wiki for details on using this class member.

Getter Gets the object ID

Setter Sets the object ID

Type int

name
Object name (as a string)

Please refer to the wiki for details on using this class member.

Getter Gets the object name

Setter Sets the object name

Type str

opt
Dictionary for storing custom data in the current geometry object.

`opt` is a wrapper to a dict in *key* => *value* format, where *key* is string, *value* is any Python object. You can use `opt` property to store custom data inside the geometry object. For instance:

```
geom.opt = ["face_id", 4]  # creates "face_id" key and sets its value to an␣
↪integer
geom.opt = ["contents", "data values"]  # creates "face_id" key and sets its␣
↪value to a string
print(geom.opt)  # will print: {'face_id': 4, 'contents': 'data values'}

del geom.opt  # deletes the contents of the hash map
print(geom.opt)  # will print: {}

geom.opt = ["body_id", 1]  # creates "body_id" key  and sets its value to 1
geom.opt = ["body_id", 12]  # changes the value of "body_id" to 12
print(geom.opt)  # will print: {'body_id': 12}

geom.opt = ["body_id", None]  # deletes "body_id"
print(geom.opt)  # will print: {}
```

Please refer to the wiki for details on using this class member.

Getter Gets the dict

Setter Adds key and value pair to the dict

Deleter Deletes the contents of the dict

opt_get(*value*)
Safely query for the value from the `opt` property.

Parameters **value** (`str`) – a key in the `opt` property

Returns the corresponding value, if the key exists. `None`, otherwise.

type
Geometry type

Please refer to the wiki for details on using this class member.

Getter Gets the geometry type

Type str

class geomdl.abstract.**SplineGeometry**(***kwargs*)
Bases: *geomdl.abstract.Geometry*

Abstract base class for defining spline geometry objects.

This class provides the following properties:

- *type* = spline
- *id*
- *name*
- *rational*
- *dimension*
- *pdimension*
- *degree*
- *knotvector*
- *ctrlpts*
- *ctrlpts_size*
- *weights* (for completeness with the rational spline implementations)
- *evalpts*
- *bbox*
- *evaluator*
- *vis*
- *opt*

Keyword Arguments:

- `id`: object ID (as integer)
- `precision`: number of decimal places to round to. *Default: 18*
- `normalize_kv`: if True, knot vector(s) will be normalized to [0,1] domain. *Default: True*
- `find_span_func`: default knot span finding algorithm. *Default:* *helpers.find_span_linear()*

bbox
Bounding box.

Evaluates the bounding box and returns the minimum and maximum coordinates.

Please refer to the wiki for details on using this class member.

Getter Gets the bounding box

Type tuple

cpsize
Number of control points in all parametric directions.

Note: This is an expert property for getting and setting control point size(s) of the geometry.

Please refer to the wiki for details on using this class member.

Getter Gets the number of control points

Setter Sets the number of control points

Type list

ctrlpts
Control points.

Please refer to the wiki for details on using this class member.

Getter Gets the control points

Setter Sets the control points

Type list

ctrlpts_size
Total number of control points.

Getter Gets the total number of control points

Type int

degree
Degree

Note: This is an expert property for getting and setting the degree(s) of the geometry.

Please refer to the wiki for details on using this class member.

Getter Gets the degree

Setter Sets the degree

Type list

dimension
Spatial dimension.

Spatial dimension will be automatically estimated from the first element of the control points array.

Please refer to the wiki for details on using this class member.

Getter Gets the spatial dimension, e.g. 2D, 3D, etc.

Type int

domain
Domain.

Domain is determined using the knot vector(s).

Getter Gets the domain

evalpts
Evaluated points.

Please refer to the wiki for details on using this class member.

Getter Gets the coordinates of the evaluated points

Type list

evaluate(***kwargs*)
Abstract method for the implementation of evaluation algorithm.

Note: This is an abstract method and it must be implemented in the subclass.

---

evaluator
Evaluator instance.

Evaluators allow users to use different algorithms for B-Spline and NURBS evaluations. Please see the documentation on `Evaluator` classes.

Please refer to the wiki for details on using this class member.

Getter Gets the current Evaluator instance

Setter Sets the Evaluator instance

Type *evaluators.AbstractEvaluator*

id
Object ID (as an integer).

Please refer to the wiki for details on using this class member.

Getter Gets the object ID

Setter Sets the object ID

Type int

knotvector
Knot vector

Note: This is an expert property for getting and setting the knot vector(s) of the geometry.

Please refer to the wiki for details on using this class member.

Getter Gets the knot vector

Setter Sets the knot vector

Type list

name
Object name (as a string)

Please refer to the wiki for details on using this class member.

Getter Gets the object name

Setter Sets the object name

Type str

opt

Dictionary for storing custom data in the current geometry object.

`opt` is a wrapper to a dict in *key* => *value* format, where *key* is string, *value* is any Python object. You can use `opt` property to store custom data inside the geometry object. For instance:

```
geom.opt = ["face_id", 4]  # creates "face_id" key and sets its value to an␣
↪integer
geom.opt = ["contents", "data values"]  # creates "face_id" key and sets its␣
↪value to a string
print(geom.opt)  # will print: {'face_id': 4, 'contents': 'data values'}

del geom.opt  # deletes the contents of the hash map
print(geom.opt)  # will print: {}

geom.opt = ["body_id", 1]  # creates "body_id" key  and sets its value to 1
geom.opt = ["body_id", 12]  # changes the value of "body_id" to 12
print(geom.opt)  # will print: {'body_id': 12}

geom.opt = ["body_id", None]  # deletes "body_id"
print(geom.opt)  # will print: {}
```

Please refer to the wiki for details on using this class member.

Getter Gets the dict

Setter Adds key and value pair to the dict

Deleter Deletes the contents of the dict

opt_get(*value*)

Safely query for the value from the *opt* property.

Parameters **value** (*str*) – a key in the *opt* property

Returns the corresponding value, if the key exists. `None`, otherwise.

pdimension

Parametric dimension.

Please refer to the wiki for details on using this class member.

Getter Gets the parametric dimension

Type int

range

Domain range.

Getter Gets the range

rational

Defines the rational and non-rational B-spline shapes.

Rational shapes use homogeneous coordinates which includes a weight alongside with the Cartesian coordinates. Rational B-splines are also named as NURBS (Non-uniform rational basis spline) and non-rational B-splines are sometimes named as NUBS (Non-uniform basis spline) or directly as B-splines.

Please refer to the wiki for details on using this class member.

Getter Returns True is the B-spline object is rational (NURBS)

Type bool

render (***kwargs*)

Abstract method for spline rendering and visualization.

Note: This is an abstract method and it must be implemented in the subclass.

set_ctrlpts (*ctrlpts*, **args*, ***kwargs*)

Sets control points and checks if the data is consistent.

This method is designed to provide a consistent way to set control points whether they are weighted or not. It directly sets the control points member of the class, and therefore it doesn't return any values. The input will be an array of coordinates. If you are working in the 3-dimensional space, then your coordinates will be an array of 3 elements representing *(x, y, z)* coordinates.

Keyword Arguments:

- `array_init`: initializes the control points array in the instance
- `array_check_for`: defines the types for input validation
- `callback`: defines the callback function for processing input points
- `dimension`: defines the spatial dimension of the input points

Parameters

- **ctrlpts** (*list*) – input control points as a list of coordinates
- **args** (*tuple*) – number of control points corresponding to each parametric dimension

type

Geometry type

Please refer to the wiki for details on using this class member.

Getter Gets the geometry type

Type str

vis

Visualization component.

Please refer to the wiki for details on using this class member.

Getter Gets the visualization component

Setter Sets the visualization component

Type vis.VisAbstract

weights

Weights.

Note: Only available for rational spline geometries. Getter return `None` otherwise.

Please refer to the wiki for details on using this class member.

Getter Gets the weights

Setter Sets the weights

17.3.2 Evaluators

Evaluators allow users to change the evaluation algorithms that are used to evaluate curves, surfaces and volumes, take derivatives and more. All geometry classes set an evaluator by default. Users may switch between the evaluation algorithms at runtime. It is also possible to implement different algorithms (e.g. T-splines) or extend existing ones.

How to Use

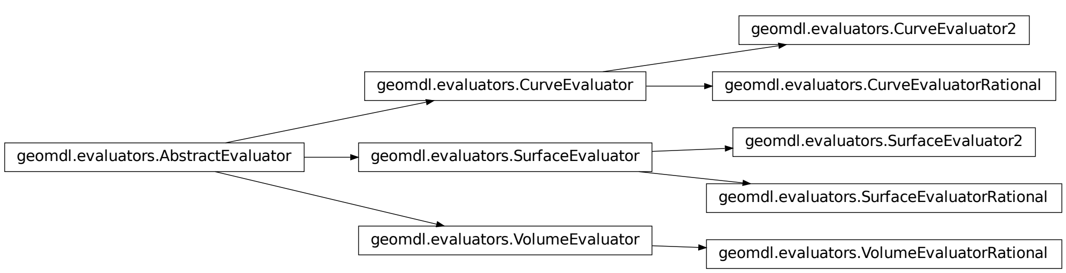
All geometry classes come with a default specialized `evaluator` class, the algorithms are generally different for rational and non-rational geometries. The evaluator class instance can be accessed and/or updated using `evaluator` property. For instance, the following code snippet changes the evaluator of a B-Spline curve.

```
from geomdl import BSpline
from geomdl import evaluators

crv = BSpline.Curve()
cevaltr = evaluators.CurveEvaluator2()
crv.evaluator = cevaltr

# Curve "evaluate" method will use CurveEvaluator2.evaluate() method
crv.evaluate()

# Get evaluated points
curve_points = crv.evalpts
```

Implementing Evaluators

All evaluators should be extended from *`evaluators.AbstractEvaluator`* abstract base class. This class provides a point evaluation and a derivative computation methods. Both methods take a *data* input which contains the geometry data as a *dict* object (refer to *`BSpline.Surface.data`* property as an example). The derivative computation method also takes additional arguments, such as the parametric position and the derivative order.

Inheritance Diagram



Abstract Base

class geomdl.evaluators.**AbstractEvaluator**(***kwargs*)

Bases: `object`

Abstract base class for implementations of fundamental spline algorithms, such as evaluate and derivative.

Abstract Methods:

- `evaluate` is used for computation of the complete spline shape
- `derivative_single` is used for computation of derivatives at a single parametric coordinate

Please note that this class requires the keyword argument `find_span_func` to be set to a valid find_span function implementation. Please see *helpers* module for details.

derivatives(*datadict*, *parpos*, *deriv_order=0*, ***kwargs*)

Abstract method for evaluation of the n-th order derivatives at the input parametric position.

Note: This is an abstract method and it must be implemented in the subclass.

Parameters

- **datadict** (*dict*) – data dictionary containing the necessary variables
- **parpos** (*list, tuple*) – parametric position where the derivatives will be computed
- **deriv_order** (*int*) – derivative order; to get the i-th derivative

evaluate(*datadict*, ***kwargs*)

Abstract method for evaluation of points on the spline geometry.

Note: This is an abstract method and it must be implemented in the subclass.

Parameters **datadict** (*dict*) – data dictionary containing the necessary variables

name

Evaluator name.

Getter Gets the name of the evaluator

Type str

Curve Evaluators

class geomdl.evaluators.**CurveEvaluator**(***kwargs*)

Bases: *geomdl.evaluators.AbstractEvaluator*

Sequential curve evaluation algorithms.

This evaluator implements the following algorithms from **The NURBS Book**:

- Algorithm A3.1: CurvePoint
- Algorithm A3.2: CurveDerivsAlg1

Please note that knot vector span finding function may be changed by setting `find_span_func` keyword argument during the initialization. By default, this function is set to *helpers.find_span_linear()*. Please see *Helpers Module Documentation* for more details.

derivatives (*datadict*, *parpos*, *deriv_order=0*, ***kwargs*)
Evaluates the n-th order derivatives at the input parametric position.

Parameters

- **datadict** (*dict*) – data dictionary containing the necessary variables
- **parpos** (*list, tuple*) – parametric position where the derivatives will be computed
- **deriv_order** (*int*) – derivative order; to get the i-th derivative

Returns evaluated derivatives

Return type list

evaluate (*datadict*, ***kwargs*)
Evaluates the curve.

Keyword Arguments:

- `start`: starting parametric position for evaluation
- `stop`: ending parametric position for evaluation

Parameters datadict (*dict*) – data dictionary containing the necessary variables

Returns evaluated points

Return type list

name
Evaluator name.

Getter Gets the name of the evaluator

Type str

class geomdl.evaluators.**CurveEvaluatorRational** (***kwargs*)
Bases: *geomdl.evaluators.CurveEvaluator*

Sequential rational curve evaluation algorithms.

This evaluator implements the following algorithms from **The NURBS Book**:

- Algorithm A3.1: CurvePoint
- Algorithm A4.2: RatCurveDerivs

Please note that knot vector span finding function may be changed by setting `find_span_func` keyword argument during the initialization. By default, this function is set to *helpers.find_span_linear()*. Please see *Helpers Module Documentation* for more details.

derivatives (*datadict*, *parpos*, *deriv_order=0*, ***kwargs*)
Evaluates the n-th order derivatives at the input parametric position.

Parameters

- **datadict** (*dict*) – data dictionary containing the necessary variables
- **parpos** (*list, tuple*) – parametric position where the derivatives will be computed
- **deriv_order** (*int*) – derivative order; to get the i-th derivative

Returns evaluated derivatives

Return type list

evaluate (*datadict*, ***kwargs*)
Evaluates the rational curve.

Keyword Arguments:

- `start`: starting parametric position for evaluation
- `stop`: ending parametric position for evaluation

Parameters **datadict** (*dict*) – data dictionary containing the necessary variables

Returns evaluated points

Return type list

name
Evaluator name.

Getter Gets the name of the evaluator

Type str

class geomdl.evaluators.**CurveEvaluator2** (***kwargs*)
Bases: *geomdl.evaluators.CurveEvaluator*

Sequential curve evaluation algorithms (alternative).

This evaluator implements the following algorithms from **The NURBS Book**:

- Algorithm A3.1: CurvePoint
- Algorithm A3.3: CurveDerivCpts
- Algorithm A3.4: CurveDerivsAlg2

Please note that knot vector span finding function may be changed by setting `find_span_func` keyword argument during the initialization. By default, this function is set to *helpers.find_span_linear()*. Please see *Helpers Module Documentation* for more details.

derivatives (*datadict*, *parpos*, *deriv_order=0*, ***kwargs*)
Evaluates the n-th order derivatives at the input parametric position.

Parameters

- **datadict** (*dict*) – data dictionary containing the necessary variables
- **parpos** (*list, tuple*) – parametric position where the derivatives will be computed
- **deriv_order** (*int*) – derivative order; to get the i-th derivative

Returns evaluated derivatives

Return type list

evaluate (*datadict*, ***kwargs*)
Evaluates the curve.

Keyword Arguments:

- `start`: starting parametric position for evaluation
- `stop`: ending parametric position for evaluation

Parameters **datadict** (*dict*) – data dictionary containing the necessary variables

Returns evaluated points

Return type list

name
Evaluator name.

Getter Gets the name of the evaluator

Type str

Surface Evaluators

class geomdl.evaluators.**SurfaceEvaluator**(***kwargs*)
Bases: *geomdl.evaluators.AbstractEvaluator*

Sequential surface evaluation algorithms.

This evaluator implements the following algorithms from **The NURBS Book**:

- Algorithm A3.5: SurfacePoint
- Algorithm A3.6: SurfaceDerivsAlg1

Please note that knot vector span finding function may be changed by setting `find_span_func` keyword argument during the initialization. By default, this function is set to *helpers.find_span_linear()*. Please see *Helpers Module Documentation* for more details.

derivatives(*datadict, parpos, deriv_order=0, **kwargs*)
Evaluates the n-th order derivatives at the input parametric position.

Parameters

- **datadict** (*dict*) – data dictionary containing the necessary variables
- **parpos** (*list, tuple*) – parametric position where the derivatives will be computed
- **deriv_order** (*int*) – derivative order; to get the i-th derivative

Returns evaluated derivatives

Return type list

evaluate(*datadict, **kwargs*)
Evaluates the surface.

Keyword Arguments:

- `start`: starting parametric position for evaluation
- `stop`: ending parametric position for evaluation

Parameters **datadict** (*dict*) – data dictionary containing the necessary variables

Returns evaluated points

Return type list

name
Evaluator name.

Getter Gets the name of the evaluator

Type str

class geomdl.evaluators.**SurfaceEvaluatorRational**(***kwargs*)

Bases: *geomdl.evaluators.SurfaceEvaluator*

Sequential rational surface evaluation algorithms.

This evaluator implements the following algorithms from **The NURBS Book**:

- Algorithm A4.3: SurfacePoint
- Algorithm A4.4: RatSurfaceDerivs

Please note that knot vector span finding function may be changed by setting `find_span_func` keyword argument during the initialization. By default, this function is set to *helpers.find_span_linear()*. Please see *Helpers Module Documentation* for more details.

derivatives(*datadict*, *parpos*, *deriv_order=0*, ***kwargs*)

Evaluates the n-th order derivatives at the input parametric position.

Parameters

- **datadict** (*dict*) – data dictionary containing the necessary variables
- **parpos** (*list, tuple*) – parametric position where the derivatives will be computed
- **deriv_order** (*int*) – derivative order; to get the i-th derivative

Returns evaluated derivatives

Return type list

evaluate(*datadict*, ***kwargs*)

Evaluates the rational surface.

Keyword Arguments:

- `start`: starting parametric position for evaluation
- `stop`: ending parametric position for evaluation

Parameters **datadict** (*dict*) – data dictionary containing the necessary variables

Returns evaluated points

Return type list

name

Evaluator name.

Getter Gets the name of the evaluator

Type str

class geomdl.evaluators.**SurfaceEvaluator2**(***kwargs*)

Bases: *geomdl.evaluators.SurfaceEvaluator*

Sequential surface evaluation algorithms (alternative).

This evaluator implements the following algorithms from **The NURBS Book**:

- Algorithm A3.5: SurfacePoint
- Algorithm A3.7: SurfaceDerivCpts
- Algorithm A3.8: SurfaceDerivsAlg2

Please note that knot vector span finding function may be changed by setting `find_span_func` keyword argument during the initialization. By default, this function is set to *helpers.find_span_linear()*. Please see *Helpers Module Documentation* for more details.

derivatives (*datadict*, *parpos*, *deriv_order=0*, ***kwargs*)
Evaluates the n-th order derivatives at the input parametric position.

Parameters

- **datadict** (*dict*) – data dictionary containing the necessary variables
- **parpos** (*list, tuple*) – parametric position where the derivatives will be computed
- **deriv_order** (*int*) – derivative order; to get the i-th derivative

Returns evaluated derivatives

Return type list

evaluate (*datadict*, ***kwargs*)
Evaluates the surface.

Keyword Arguments:

- `start`: starting parametric position for evaluation
- `stop`: ending parametric position for evaluation

Parameters datadict (*dict*) – data dictionary containing the necessary variables

Returns evaluated points

Return type list

name
Evaluator name.

Getter Gets the name of the evaluator

Type str

Volume Evaluators

class geomdl.evaluators.**VolumeEvaluator** (***kwargs*)
Bases: *geomdl.evaluators.AbstractEvaluator*

Sequential volume evaluation algorithms.

Please note that knot vector span finding function may be changed by setting `find_span_func` keyword argument during the initialization. By default, this function is set to *helpers.find_span_linear()*. Please see *Helpers Module Documentation* for more details.

derivatives (*datadict*, *parpos*, *deriv_order=0*, ***kwargs*)
Evaluates the n-th order derivatives at the input parametric position.

Parameters

- **datadict** (*dict*) – data dictionary containing the necessary variables
- **parpos** (*list, tuple*) – parametric position where the derivatives will be computed
- **deriv_order** (*int*) – derivative order; to get the i-th derivative

Returns evaluated derivatives

Return type list

evaluate(*datadict*, ***kwargs*)
Evaluates the volume.

Keyword Arguments:

- `start`: starting parametric position for evaluation
- `stop`: ending parametric position for evaluation

Parameters **datadict** (*dict*) – data dictionary containing the necessary variables

Returns evaluated points

Return type list

name
Evaluator name.

Getter Gets the name of the evaluator

Type str

class geomdl.evaluators.**VolumeEvaluatorRational**(***kwargs*)
Bases: *geomdl.evaluators.VolumeEvaluator*

Sequential rational volume evaluation algorithms.

Please note that knot vector span finding function may be changed by setting `find_span_func` keyword argument during the initialization. By default, this function is set to *helpers.find_span_linear()*. Please see *Helpers Module Documentation* for more details.

derivatives(*datadict*, *parpos*, *deriv_order=0*, ***kwargs*)
Evaluates the n-th order derivatives at the input parametric position.

Parameters

- **datadict** (*dict*) – data dictionary containing the necessary variables
- **parpos** (*list, tuple*) – parametric position where the derivatives will be computed
- **deriv_order** (*int*) – derivative order; to get the i-th derivative

Returns evaluated derivatives

Return type list

evaluate(*datadict*, ***kwargs*)
Evaluates the rational volume.

Keyword Arguments:

- `start`: starting parametric position for evaluation
- `stop`: ending parametric position for evaluation

Parameters **datadict** (*dict*) – data dictionary containing the necessary variables

Returns evaluated points

Return type list

name
Evaluator name.

Getter Gets the name of the evaluator

Type str

17.3.3 Utility Functions

These modules contain common utility and helper functions for B-Spline / NURBS curve and surface evaluation operations.

Utilities

The `utilities` module contains common utility functions for NURBS-Python library and its extensions.

`geomdl.utilities.`**`check_params`**(*params*)

Checks if the parameters are defined in the domain [0, 1].

Parameters **params** (*list, tuple*) – parameters (u, v, w)

Returns True if defined in the domain [0, 1]. False, otherwise.

Return type bool

`geomdl.utilities.`**`color_generator`**(*seed=None*)

Generates random colors for control and evaluated curve/surface points plots.

The `seed` argument is used to set the random seed by directly passing the value to `random.seed()` function. Please see the Python documentation for more details on the `random` module .

Inspired from https://stackoverflow.com/a/14019260

Parameters **seed** – Sets the random seed

Returns list of color strings in hex format

Return type list

`geomdl.utilities.`**`evaluate_bounding_box`**(*ctrlpts*)

Computes the minimum bounding box of the point set.

The (minimum) bounding box is the smallest enclosure in which all the input points lie.

Parameters **ctrlpts** (*list, tuple*) – points

Returns bounding box in the format [min, max]

Return type tuple

`geomdl.utilities.`**`make_quad`**(*points, size_u, size_v*)

Converts linear sequence of input points into a quad structure.

Parameters

- **points** (*list, tuple*) – list of points to be ordered
- **size_v** (*int*) – number of elements in a row
- **size_u** (*int*) – number of elements in a column

Returns re-ordered points

Return type list

geomdl.utilities.**make_quadtree**(*points*, *size_u*, *size_v*, ***kwargs*)

Generates a quadtree-like structure from surface control points.

This function generates a 2-dimensional list of control point coordinates. Considering the object-oriented representation of a quadtree data structure, first dimension of the generated list corresponds to a list of *QuadTree* classes. Second dimension of the generated list corresponds to a *QuadTree* data structure. The first element of the 2nd dimension is the mid-point of the bounding box and the remaining elements are corner points of the bounding box organized in counter-clockwise order.

To maintain stability for the data structure on the edges and corners, the function accepts `extrapolate` keyword argument. If it is *True*, then the function extrapolates the surface on the corners and edges to complete the quad-like structure for each control point. If it is *False*, no extrapolation will be applied. By default, `extrapolate` is set to *True*.

Please note that this function's intention is not generating a real quadtree structure but reorganizing the control points in a very similar fashion to make them available for various geometric operations.

Parameters

- **points** (*list, tuple*) – 1-dimensional array of surface control points
- **size_u** (*int*) – number of control points on the u-direction
- **size_v** (*int*) – number of control points on the v-direction

Returns control points organized in a quadtree-like structure

Return type tuple

geomdl.utilities.**make_zigzag**(*points*, *num_cols*)

Converts linear sequence of points into a zig-zag shape.

This function is designed to create input for the visualization software. It orders the points to draw a zig-zag shape which enables generating properly connected lines without any scanlines. Please see the below sketch on the functionality of the `num_cols` parameter:

```
     num cols
<-=============->
------->>-------|
|------<<-------|
|------>>-------|
-------<<-------|
```

Please note that this function does not detect the ordering of the input points to detect the input points have already been processed to generate a zig-zag shape.

Parameters

- **points** (*list*) – list of points to be ordered
- **num_cols** (*int*) – number of elements in a row which the zig-zag is generated

Returns re-ordered points

Return type list

Helpers

The `helpers` module contains common functions required for evaluating both surfaces and curves, such as basis function computations, knot vector span finding, etc.

`geomdl.helpers.`**`basis_function`**(*degree*, *knot_vector*, *span*, *knot*)

Computes the non-vanishing basis functions for a single parameter.

Implementation of Algorithm A2.2 from The NURBS Book by Piegl & Tiller. Uses recurrence to compute the basis functions, also known as Cox - de Boor recursion formula.

Parameters

- **degree** (*int*) – degree, p
- **knot_vector** (*list, tuple*) – knot vector, U
- **span** (*int*) – knot span, i
- **knot** (*float*) – knot or parameter, u

Returns basis functions

Return type list

`geomdl.helpers.`**`basis_function_all`**(*degree*, *knot_vector*, *span*, *knot*)

Computes all non-zero basis functions of all degrees from 0 up to the input degree for a single parameter.

A slightly modified version of Algorithm A2.2 from The NURBS Book by Piegl & Tiller. Wrapper for *helpers.basis_function()* to compute multiple basis functions. Uses recurrence to compute the basis functions, also known as Cox - de Boor recursion formula.

For instance; if `degree = 2`, then this function will compute the basis function values of degrees **0, 1** and **2** for the `knot` value at the input knot `span` of the `knot_vector`.

Parameters

- **degree** (*int*) – degree, p
- **knot_vector** (*list, tuple*) – knot vector, U
- **span** (*int*) – knot span, i
- **knot** (*float*) – knot or parameter, u

Returns basis functions

Return type list

`geomdl.helpers.`**`basis_function_ders`**(*degree*, *knot_vector*, *span*, *knot*, *order*)

Computes derivatives of the basis functions for a single parameter.

Implementation of Algorithm A2.3 from The NURBS Book by Piegl & Tiller.

Parameters

- **degree** (*int*) – degree, p
- **knot_vector** (*list, tuple*) – knot vector, U
- **span** (*int*) – knot span, i
- **knot** (*float*) – knot or parameter, u
- **order** (*int*) – order of the derivative

Returns derivatives of the basis functions

Return type list

`geomdl.helpers.`**`basis_function_ders_one`**(*degree*, *knot_vector*, *span*, *knot*, *order*)

Computes the derivative of one basis functions for a single parameter.

Implementation of Algorithm A2.5 from The NURBS Book by Piegl & Tiller.

Parameters

- **degree** (*int*) – degree, p
- **knot_vector** (*list, tuple*) – knot_vector, U
- **span** (*int*) – knot span, i
- **knot** (*float*) – knot or parameter, u
- **order** (*int*) – order of the derivative

Returns basis function derivatives

Return type list

`geomdl.helpers.`**`basis_function_one`**(*degree*, *knot_vector*, *span*, *knot*)

Computes the value of a basis function for a single parameter.

Implementation of Algorithm 2.4 from The NURBS Book by Piegl & Tiller.

Parameters

- **degree** (*int*) – degree, p
- **knot_vector** (*list, tuple*) – knot vector
- **span** (*int*) – knot span, i
- **knot** (*float*) – knot or parameter, u

Returns basis function, $N_{i,p}$

Return type float

`geomdl.helpers.`**`basis_functions`**(*degree*, *knot_vector*, *spans*, *knots*)

Computes the non-vanishing basis functions for a list of parameters.

Wrapper for `helpers.basis_function()` to process multiple span and knot values. Uses recurrence to compute the basis functions, also known as Cox - de Boor recursion formula.

Parameters

- **degree** (*int*) – degree, p
- **knot_vector** (*list, tuple*) – knot vector, U
- **spans** (*list, tuple*) – list of knot spans
- **knots** (*list, tuple*) – list of knots or parameters

Returns basis functions

Return type list

`geomdl.helpers.`**`basis_functions_ders`**(*degree*, *knot_vector*, *spans*, *knots*, *order*)

Computes derivatives of the basis functions for a list of parameters.

Wrapper for `helpers.basis_function_ders()` to process multiple span and knot values.

Parameters

- **degree** (*int*) – degree, p
- **knot_vector** (*list, tuple*) – knot vector, U
- **spans** (*list, tuple*) – list of knot spans
- **knots** (*list, tuple*) – list of knots or parameters

- **order** (*int*) – order of the derivative

Returns derivatives of the basis functions

Return type list

geomdl.helpers.**curve_deriv_cpts**(*dim*, *degree*, *kv*, *cpts*, *rs*, *deriv_order=0*)

Compute control points of curve derivatives.

Implementation of Algorithm A3.3 from The NURBS Book by Piegl & Tiller.

Parameters

- **dim** (*int*) – spatial dimension of the curve
- **degree** (*int*) – degree of the curve
- **kv** (*list, tuple*) – knot vector
- **cpts** (*list, tuple*) – control points
- **rs** – minimum (r1) and maximum (r2) knot spans that the curve derivative will be computed
- **deriv_order** (*int*) – derivative order, i.e. the i-th derivative

Returns control points of the derivative curve over the input knot span range

Return type list

geomdl.helpers.**degree_elevation**(*degree*, *ctrlpts*, ***kwargs*)

Computes the control points of the rational/non-rational spline after degree elevation.

Implementation of Eq. 5.36 of The NURBS Book by Piegl & Tiller, 2nd Edition, p.205

Keyword Arguments:

- `num`: number of degree elevations

Please note that degree elevation algorithm can only operate on Bezier shapes, i.e. curves, surfaces, volumes.

Parameters

- **degree** (*int*) – degree
- **ctrlpts** (*list, tuple*) – control points

Returns control points of the degree-elevated shape

Return type list

geomdl.helpers.**degree_reduction**(*degree*, *ctrlpts*, ***kwargs*)

Computes the control points of the rational/non-rational spline after degree reduction.

Implementation of Eqs. 5.41 and 5.42 of The NURBS Book by Piegl & Tiller, 2nd Edition, p.220

Please note that degree reduction algorithm can only operate on Bezier shapes, i.e. curves, surfaces, volumes and this implementation does NOT compute the maximum error tolerance as described via Eqs. 5.45 and 5.46 of The NURBS Book by Piegl & Tiller, 2nd Edition, p.221 to determine whether the shape is degree reducible or not.

Parameters

- **degree** (*int*) – degree
- **ctrlpts** (*list, tuple*) – control points

Returns control points of the degree-reduced shape

Return type list

`geomdl.helpers.`**`find_multiplicity`**(*knot*, *knot_vector*, ***kwargs*)

Finds knot multiplicity over the knot vector.

Keyword Arguments:

- `tol`: tolerance (delta) value for equality checking

Parameters

- **knot** (*float*) – knot or parameter, u
- **knot_vector** (*list, tuple*) – knot vector, U

Returns knot multiplicity, s

Return type int

`geomdl.helpers.`**`find_span_binsearch`**(*degree*, *knot_vector*, *num_ctrlpts*, *knot*, ***kwargs*)

Finds the span of the knot over the input knot vector using binary search.

Implementation of Algorithm A2.1 from The NURBS Book by Piegl & Tiller.

The NURBS Book states that the knot span index always starts from zero, i.e. for a knot vector [0, 0, 1, 1]; if FindSpan returns 1, then the knot is between the half-open interval [0, 1).

Parameters

- **degree** (*int*) – degree, p
- **knot_vector** (*list, tuple*) – knot vector, U
- **num_ctrlpts** (*int*) – number of control points, $n + 1$
- **knot** (*float*) – knot or parameter, u

Returns knot span

Return type int

`geomdl.helpers.`**`find_span_linear`**(*degree*, *knot_vector*, *num_ctrlpts*, *knot*, ***kwargs*)

Finds the span of a single knot over the knot vector using linear search.

Alternative implementation for the Algorithm A2.1 from The NURBS Book by Piegl & Tiller.

Parameters

- **degree** (*int*) – degree, p
- **knot_vector** (*list, tuple*) – knot vector, U
- **num_ctrlpts** (*int*) – number of control points, $n + 1$
- **knot** (*float*) – knot or parameter, u

Returns knot span

Return type int

`geomdl.helpers.`**`find_spans`**(*degree*, *knot_vector*, *num_ctrlpts*, *knots*, *func=<function find_span_linear>*)

Finds spans of a list of knots over the knot vector.

Parameters

- **degree** (*int*) – degree, p
- **knot_vector** (*list, tuple*) – knot vector, U
- **num_ctrlpts** (*int*) – number of control points, $n + 1$

- **knots** (*list, tuple*) – list of knots or parameters
- **func** – function for span finding, e.g. linear or binary search

Returns list of spans

Return type list

geomdl.helpers.**knot_insertion**(*degree*, *knotvector*, *ctrlpts*, *u*, ***kwargs*)
Computes the control points of the rational/non-rational spline after knot insertion.

Part of Algorithm A5.1 of The NURBS Book by Piegl & Tiller, 2nd Edition.

Keyword Arguments:

- `num`: number of knot insertions. *Default: 1*
- `s`: multiplicity of the knot. *Default: computed via :func:`.find_multiplicity`*
- `span`: knot span. *Default: computed via :func:`.find_span_linear`*

Parameters

- **degree** (*int*) – degree
- **knotvector** (*list, tuple*) – knot vector
- **ctrlpts** (*list*) – control points
- **u** (*float*) – knot to be inserted

Returns updated control points

Return type list

geomdl.helpers.**knot_insertion_alpha**
Computes α coefficient for knot insertion algorithm.

Parameters

- **u** (*float*) – knot
- **knotvector** (*tuple*) – knot vector
- **span** (*int*) – knot span
- **idx** (*int*) – index value (degree-dependent)
- **leg** (*int*) – i-th leg of the control points polygon

Returns coefficient value

Return type float

geomdl.helpers.**knot_insertion_kv**(*knotvector*, *u*, *span*, *r*)
Computes the knot vector of the rational/non-rational spline after knot insertion.

Part of Algorithm A5.1 of The NURBS Book by Piegl & Tiller, 2nd Edition.

Parameters

- **knotvector** (*list, tuple*) – knot vector
- **u** (*float*) – knot
- **span** (*int*) – knot span
- **r** (*int*) – number of knot insertions

Returns updated knot vector

Return type list

`geomdl.helpers.`**`knot_refinement`**(*degree*, *knotvector*, *ctrlpts*, ***kwargs*)

Computes the knot vector and the control points of the rational/non-rational spline after knot refinement.

Implementation of Algorithm A5.4 of The NURBS Book by Piegl & Tiller, 2nd Edition.

The algorithm automatically find the knots to be refined, i.e. the middle knots in the knot vector, and their multiplicities, i.e. number of same knots in the knot vector. This is the basis of knot refinement algorithm. This operation can be overridden by providing a list of knots via `knot_list` argument. In addition, users can provide a list of additional knots to be inserted in the knot vector via `add_knot_list` argument.

Moreover, a numerical `density` argument can be used to automate extra knot insertions. If `density` is bigger than 1, then the algorithm finds the middle knots in each internal knot span to increase the number of knots to be refined.

Example: Let the degree is 2 and the knot vector to be refined is `[0, 2, 4]` with the superfluous knots from the start and end are removed. Knot vectors with the changing `density (d)` value will be:

- `d = 1`, knot vector `[0, 1, 1, 2, 2, 3, 3, 4]`
- `d = 2`, knot vector `[0, 0.5, 0.5, 1, 1, 1.5, 1.5, 2, 2, 2.5, 2.5, 3, 3, 3.5, 3.5, 4]`

Keyword Arguments:

- `knot_list`: knot list to be refined. *Default: list of internal knots*
- `add_knot_list`: additional list of knots to be refined. *Default: []*
- `density`: Density of the knots. *Default: 1*

Parameters

- **`degree`** (*`int`*) – degree
- **`knotvector`** (*`list, tuple`*) – knot vector
- **`ctrlpts`** – control points

Returns updated control points and knot vector

Return type tuple

`geomdl.helpers.`**`knot_removal`**(*degree*, *knotvector*, *ctrlpts*, *u*, ***kwargs*)

Computes the control points of the rational/non-rational spline after knot removal.

Implementation based on Algorithm A5.8 and Equation 5.28 of The NURBS Book by Piegl & Tiller

Keyword Arguments:

- `num`: number of knot removals

Parameters

- **`degree`** (*`int`*) – degree
- **`knotvector`** (*`list, tuple`*) – knot vector
- **`ctrlpts`** (*`list`*) – control points
- **`u`** (*`float`*) – knot to be removed

Returns updated control points

Return type list

geomdl.helpers.**knot_removal_alpha_i**

Computes α_i coefficient for knot removal algorithm.

Please refer to Eq. 5.29 of The NURBS Book by Piegl & Tiller, 2nd Edition, p.184 for details.

Parameters

- **u** (*float*) – knot
- **degree** (*int*) – degree
- **knotvector** (*tuple*) – knot vector
- **num** (*int*) – knot removal index
- **idx** (*int*) – iterator index

Returns coefficient value

Return type float

geomdl.helpers.**knot_removal_alpha_j**

Computes α_j coefficient for knot removal algorithm.

Please refer to Eq. 5.29 of The NURBS Book by Piegl & Tiller, 2nd Edition, p.184 for details.

Parameters

- **u** (*float*) – knot
- **degree** (*int*) – degree
- **knotvector** (*tuple*) – knot vector
- **num** (*int*) – knot removal index
- **idx** (*int*) – iterator index

Returns coefficient value

Return type float

geomdl.helpers.**knot_removal_kv**(*knotvector*, *span*, *r*)

Computes the knot vector of the rational/non-rational spline after knot removal.

Part of Algorithm A5.8 of The NURBS Book by Piegl & Tiller, 2nd Edition.

Parameters

- **knotvector** (*list, tuple*) – knot vector
- **span** (*int*) – knot span
- **r** (*int*) – number of knot removals

Returns updated knot vector

Return type list

geomdl.helpers.**surface_deriv_cpts**(*dim*, *degree*, *kv*, *cpts*, *cpsize*, *rs*, *ss*, *deriv_order=0*)

Compute control points of surface derivatives.

Implementation of Algorithm A3.7 from The NURBS Book by Piegl & Tiller.

Parameters

- **dim** (*int*) – spatial dimension of the surface

- **degree** (*list, tuple*) – degrees
- **kv** (*list, tuple*) – knot vectors
- **cpts** (*list, tuple*) – control points
- **cpsize** (*list, tuple*) – number of control points in all parametric directions
- **rs** (*list, tuple*) – minimum (r1) and maximum (r2) knot spans for the u-direction
- **ss** (*list, tuple*) – minimum (s1) and maximum (s2) knot spans for the v-direction
- **deriv_order** (*int*) – derivative order, i.e. the i-th derivative

Returns control points of the derivative surface over the input knot span ranges

Return type list

Linear Algebra

The `linalg` module contains some basic functions for point, vector and matrix operations.

Although most of the functions are designed for internal usage, the users can still use some of the functions for their advantage, especially the point and vector manipulation and generation functions. Functions related to point manipulation have `point_` prefix and the ones related to vectors have `vector_` prefix.

`geomdl.linalg.`**`backward_substitution`**(*matrix_u*, *matrix_y*)

Backward substitution method for the solution of linear systems.

Solves the equation $Ux = y$ using backward substitution method where U is a upper triangular matrix and y is a column matrix.

Parameters

- **matrix_u** (*list, tuple*) – U, upper triangular matrix
- **matrix_y** (*list, tuple*) – y, column matrix

Returns x, column matrix

Return type list

`geomdl.linalg.`**`binomial_coefficient`**

Computes the binomial coefficient (denoted by *k choose i*).

Please see the following website for details: http://mathworld.wolfram.com/BinomialCoefficient.html

Parameters

- **k** (*int*) – size of the set of distinct elements
- **i** (*int*) – size of the subsets

Returns combination of *k* and *i*

Return type float

`geomdl.linalg.`**`convex_hull`**(*points*)

Returns points on convex hull in counterclockwise order according to Graham's scan algorithm.

Reference: https://gist.github.com/arthur-e/5cf52962341310f438e96c1f3c3398b8

Note: This implementation only works in 2-dimensional space.

Parameters **points** (*list, tuple*) – list of 2-dimensional points

Returns convex hull of the input points

Return type list

`geomdl.linalg.`**`forward_substitution`**(*matrix_l*, *matrix_b*)

Forward substitution method for the solution of linear systems.

Solves the equation $Ly = b$ using forward substitution method where L is a lower triangular matrix and b is a column matrix.

Parameters

- **matrix_l** (*list, tuple*) – L, lower triangular matrix
- **matrix_b** (*list, tuple*) – b, column matrix

Returns y, column matrix

Return type list

`geomdl.linalg.`**`frange`**(*start*, *stop*, *step=1.0*)

Implementation of Python's `range()` function which works with floats.

Reference to this implementation: https://stackoverflow.com/a/36091634

Parameters

- **start** (*float*) – start value
- **stop** (*float*) – end value
- **step** (*float*) – increment

Returns float

Return type generator

`geomdl.linalg.`**`is_left`**(*point0*, *point1*, *point2*)

Tests if a point is Left|On|Right of an infinite line.

Ported from the C++ version: on http://geomalgorithms.com/a03-_inclusion.html

Note: This implementation only works in 2-dimensional space.

Parameters

- **point0** – Point P0
- **point1** – Point P1
- **point2** – Point P2

Returns >0 for P2 left of the line through P0 and P1 =0 for P2 on the line <0 for P2 right of the line

`geomdl.linalg.`**`linspace`**(*start*, *stop*, *num*, *decimals=18*)

Returns a list of evenly spaced numbers over a specified interval.

Inspired from Numpy's linspace function: https://github.com/numpy/numpy/blob/master/numpy/core/function_base.py

Parameters

- **start** (*float*) – starting value

- **stop** (*float*) – end value
- **num** (*int*) – number of samples to generate
- **decimals** (*int*) – number of significands

Returns a list of equally spaced numbers

Return type list

geomdl.linalg.**lu_decomposition**(*matrix_a*)

LU-Factorization method using Doolittle's Method for solution of linear systems.

Decomposes the matrix A such that $A = LU$.

The input matrix is represented by a list or a tuple. The input matrix is **2-dimensional**, i.e. list of lists of integers and/or floats.

Parameters **matrix_a** (*list, tuple*) – Input matrix (must be a square matrix)

Returns a tuple containing matrices L and U

Return type tuple

geomdl.linalg.**lu_factor**(*matrix_a*, *b*)

Computes the solution to a system of linear equations with partial pivoting.

This function solves $Ax = b$ using LUP decomposition. A is a $N \times N$ matrix, b is $N \times M$ matrix of M column vectors. Each column of x is a solution for corresponding column of b.

Parameters

- **matrix_a** – matrix A
- **b** (*list*) – matrix of M column vectors

Returns x, the solution matrix

Return type list

geomdl.linalg.**lu_solve**(*matrix_a*, *b*)

Computes the solution to a system of linear equations.

This function solves $Ax = b$ using LU decomposition. A is a $N \times N$ matrix, b is $N \times M$ matrix of M column vectors. Each column of x is a solution for corresponding column of b.

Parameters

- **matrix_a** – matrix A
- **b** (*list*) – matrix of M column vectors

Returns x, the solution matrix

Return type list

geomdl.linalg.**matrix_determinant**(*m*)

Computes the determinant of the square matrix M via LUP decomposition.

Parameters **m** (*list, tuple*) – input matrix

Returns determinant of the matrix

Return type float

geomdl.linalg.**matrix_identity**

Generates a $N \times N$ identity matrix.

Parameters **n** (*int*) – size of the matrix

Returns identity matrix

Return type list

`geomdl.linalg.`**`matrix_inverse`**`(`*m*`)`

Computes the inverse of the matrix via LUP decomposition.

Parameters m (*list, tuple*) – input matrix

Returns inverse of the matrix

Return type list

`geomdl.linalg.`**`matrix_multiply`**`(`*mat1*, *mat2*`)`

Matrix multiplication (iterative algorithm).

The running time of the iterative matrix multiplication algorithm is $O(n^3)$.

Parameters

- **mat1** (*list, tuple*) – 1st matrix with dimensions $(n \times p)$
- **mat2** (*list, tuple*) – 2nd matrix with dimensions $(p \times m)$

Returns resultant matrix with dimensions $(n \times m)$

Return type list

`geomdl.linalg.`**`matrix_pivot`**`(`*m*, *sign=False*`)`

Computes the pivot matrix for M, a square matrix.

This function computes

- the permutation matrix, P
- the product of M and P, $M \times P$
- determinant of P, $det(P)$ if `sign = True`

Parameters

- **m** (*list, tuple*) – input matrix
- **sign** (*bool*) – flag to return the determinant of the permutation matrix, P

Returns a tuple containing the matrix product of M x P, P and det(P)

Return type tuple

`geomdl.linalg.`**`matrix_scalar`**`(`*m*, *sc*`)`

Matrix multiplication by a scalar value (iterative algorithm).

The running time of the iterative matrix multiplication algorithm is $O(n^2)$.

Parameters

- **m** (*list, tuple*) – input matrix
- **sc** (*int, float*) – scalar value

Returns resultant matrix

Return type list

`geomdl.linalg.`**`matrix_transpose`**`(`*m*`)`

Transposes the input matrix.

The input matrix m is a 2-dimensional array.

Parameters **m** (*list, tuple*) – input matrix with dimensions $(n \times m)$

Returns transpose matrix with dimensions $(m \times n)$

Return type list

geomdl.linalg.**point_distance**(*pt1*, *pt2*)

Computes distance between two points.

Parameters

- **pt1** (*list, tuple*) – point 1
- **pt2** (*list, tuple*) – point 2

Returns distance between input points

Return type float

geomdl.linalg.**point_mid**(*pt1*, *pt2*)

Computes the midpoint of the input points.

Parameters

- **pt1** (*list, tuple*) – point 1
- **pt2** (*list, tuple*) – point 2

Returns midpoint

Return type list

geomdl.linalg.**point_translate**(*point_in*, *vector_in*)

Translates the input points using the input vector.

Parameters

- **point_in** (*list, tuple*) – input point
- **vector_in** (*list, tuple*) – input vector

Returns translated point

Return type list

geomdl.linalg.**triangle_center**(*tri*, *uv=False*)

Computes the center of mass of the input triangle.

Parameters

- **tri** (elements.Triangle) – triangle object
- **uv** (*bool*) – if True, then finds parametric position of the center of mass

Returns center of mass of the triangle

Return type tuple

geomdl.linalg.**triangle_normal**(*tri*)

Computes the (approximate) normal vector of the input triangle.

Parameters **tri** (elements.Triangle) – triangle object

Returns normal vector of the triangle

Return type tuple

`geomdl.linalg.`**`vector_angle_between`**(*vector1*, *vector2*, ***kwargs*)

Computes the angle between the two input vectors.

If the keyword argument `degrees` is set to *True*, then the angle will be in degrees. Otherwise, it will be in radians. By default, `degrees` is set to *True*.

Parameters

- **vector1** (*list, tuple*) – vector
- **vector2** (*list, tuple*) – vector

Returns angle between the vectors

Return type float

`geomdl.linalg.`**`vector_cross`**(*vector1*, *vector2*)

Computes the cross-product of the input vectors.

Parameters

- **vector1** (*list, tuple*) – input vector 1
- **vector2** (*list, tuple*) – input vector 2

Returns result of the cross product

Return type tuple

`geomdl.linalg.`**`vector_dot`**(*vector1*, *vector2*)

Computes the dot-product of the input vectors.

Parameters

- **vector1** (*list, tuple*) – input vector 1
- **vector2** (*list, tuple*) – input vector 2

Returns result of the dot product

Return type float

`geomdl.linalg.`**`vector_generate`**(*start_pt*, *end_pt*, *normalize=False*)

Generates a vector from 2 input points.

Parameters

- **start_pt** (*list, tuple*) – start point of the vector
- **end_pt** (*list, tuple*) – end point of the vector
- **normalize** (*bool*) – if True, the generated vector is normalized

Returns a vector from start_pt to end_pt

Return type list

`geomdl.linalg.`**`vector_is_zero`**(*vector_in*, *tol=1e-07*)

Checks if the input vector is a zero vector.

Parameters

- **vector_in** (*list, tuple*) – input vector
- **tol** (*float*) – tolerance value

Returns True if the input vector is zero, False otherwise

Return type bool

geomdl.linalg.**vector_magnitude**(*vector_in*)

Computes the magnitude of the input vector.

Parameters **vector_in** (*list, tuple*) – input vector

Returns magnitude of the vector

Return type float

geomdl.linalg.**vector_mean**(**args*)

Computes the mean (average) of a list of vectors.

The function computes the arithmetic mean of a list of vectors, which are also organized as a list of integers or floating point numbers.

```
# Create a list of vectors as an example
vector_list = [[1, 2, 3], [4, 5, 6], [7, 8, 9]]

# Compute mean vector
mean_vector = vector_mean(*vector_list)

# Alternative usage example (same as above):
mean_vector = vector_mean([1, 2, 3], [4, 5, 6], [7, 8, 9])
```

Parameters **args** (*list, tuple*) – list of vectors

Returns mean vector

Return type list

geomdl.linalg.**vector_multiply**(*vector_in, scalar*)

Multiplies the vector with a scalar value.

This operation is also called *vector scaling*.

Parameters

- **vector_in** (*list, tuple*) – vector
- **scalar** (*int, float*) – scalar value

Returns updated vector

Return type tuple

geomdl.linalg.**vector_normalize**(*vector_in, decimals=18*)

Generates a unit vector from the input.

Parameters

- **vector_in** (*list, tuple*) – vector to be normalized
- **decimals** (*int*) – number of significands

Returns the normalized vector (i.e. the unit vector)

Return type list

geomdl.linalg.**vector_sum**(*vector1, vector2, coeff=1.0*)

Sums the vectors.

This function computes the result of the vector operation $\overline{v}_1 + c * \overline{v}_2$, where $\overline{v}_1$ is `vector1`, $\overline{v}_2$ is `vector2` and c is `coeff`.

Parameters

- **vector1** (*list, tuple*) – vector 1
- **vector2** (*list, tuple*) – vector 2
- **coeff** (*float*) – multiplier for vector 2

Returns updated vector

Return type list

geomdl.linalg.**wn_poly**(*point, vertices*)

Winding number test for a point in a polygon.

Ported from the C++ version: http://geomalgorithms.com/a03-_inclusion.html

Note: This implementation only works in 2-dimensional space.

Parameters

- **point** (*list, tuple*) – point to be tested
- **vertices** (*list, tuple*) – vertex points of a polygon vertices[n+1] with vertices[n] = vertices[0]

Returns True if the point is inside the input polygon, False otherwise

Return type bool

17.3.4 Voxelization

New in version 5.0.

voxelize module provides functions for voxelizing NURBS volumes. *voxelize()* also supports multi-threaded operations via multiporcessing module.

Function Reference

geomdl.voxelize.**voxelize**(*obj, **kwargs*)

Generates binary voxel representation of the surfaces and volumes.

Keyword Arguments:

- grid_size: size of the voxel grid. *Default: (8, 8, 8)*
- padding: voxel padding for in-outs finding. *Default: 10e-8*
- use_cubes: use cube voxels instead of cuboid ones. *Default: False*
- num_procs: number of concurrent processes for voxelization. *Default: 1*

Parameters obj (abstract.Surface *or* abstract.Volume) – input surface(s) or volume(s)

Returns voxel grid and filled information

Return type tuple

`geomdl.voxelize.`**`save_voxel_grid`**`(`*voxel_grid*, *file_name*`)`

Saves binary voxel grid as a binary file.

The binary file is structured in little-endian unsigned int format.

Parameters

- **`voxel_grid`** (*`list, tuple`*) – binary voxel grid
- **`file_name`** (*`str`*) – file name to save

17.3.5 Geometric Entities

The geometric entities are used for advanced algorithms, such as tessellation. The `AbstractEntity` class provides the abstract base for all geometric and topological entities.

This module provides the following geometric and topological entities:

- *`Vertex`*
- *`Triangle`*
- *`Quad`*
- *`Face`*
- *`Body`*

Class Reference

`class` `geomdl.elements.`**`Vertex`**`(`**args*, ***kwargs*`)`

Bases: `geomdl.elements.AbstractEntity`

3-dimensional Vertex entity with spatial and parametric position.

`data`

(x,y,z) components of the vertex.

Getter Gets the 3-dimensional components

Setter Sets the 3-dimensional components

`id`

Object ID (as an integer).

Please refer to the wiki for details on using this class member.

Getter Gets the object ID

Setter Sets the object ID

Type int

`inside`

Inside-outside flag

Getter Gets the flag

Setter Sets the flag

Type bool

name

Object name (as a string)

Please refer to the wiki for details on using this class member.

Getter Gets the object name

Setter Sets the object name

Type str

opt

Dictionary for storing custom data in the current geometry object.

`opt` is a wrapper to a dict in *key* => *value* format, where *key* is string, *value* is any Python object. You can use `opt` property to store custom data inside the geometry object. For instance:

```
geom.opt = ["face_id", 4]  # creates "face_id" key and sets its value to an␣
↪integer
geom.opt = ["contents", "data values"]  # creates "face_id" key and sets its␣
↪value to a string
print(geom.opt)  # will print: {'face_id': 4, 'contents': 'data values'}

del geom.opt  # deletes the contents of the hash map
print(geom.opt)  # will print: {}

geom.opt = ["body_id", 1]  # creates "body_id" key  and sets its value to 1
geom.opt = ["body_id", 12]  # changes the value of "body_id" to 12
print(geom.opt)  # will print: {'body_id': 12}

geom.opt = ["body_id", None]  # deletes "body_id"
print(geom.opt)  # will print: {}
```

Getter Gets the dict

Setter Adds key and value pair to the dict

Deleter Deletes the contents of the dict

opt_get (*value*)

Safely query for the value from the *opt* property.

Parameters **value** (*str*) – a key in the *opt* property

Returns the corresponding value, if the key exists. `None`, otherwise.

u

Parametric u-component of the vertex

Getter Gets the u-component of the vertex

Setter Sets the u-component of the vertex

Type float

uv

Parametric (u,v) pair of the vertex

Getter Gets the uv-component of the vertex

Setter Sets the uv-component of the vertex

Type list, tuple

v

Parametric v-component of the vertex

Getter Gets the v-component of the vertex

Setter Sets the v-component of the vertex

Type float

x

x-component of the vertex

Getter Gets the x-component of the vertex

Setter Sets the x-component of the vertex

Type float

y

y-component of the vertex

Getter Gets the y-component of the vertex

Setter Sets the y-component of the vertex

Type float

z

z-component of the vertex

Getter Gets the z-component of the vertex

Setter Sets the z-component of the vertex

Type float

class `geomdl.elements.`**`Triangle`**(**args*, ***kwargs*)

Bases: `geomdl.elements.AbstractEntity`

Triangle entity which represents a triangle composed of vertices.

A Triangle entity stores the vertices in its data structure. `data` returns the vertex IDs and `vertices` return the `Vertex` instances that compose the triangular structure.

add_vertex(**args*)

Adds vertices to the Triangle object.

This method takes a single or a list of vertices as its function arguments.

data

Vertices composing the triangular structure.

Getter Gets the vertex indices (as int values)

Setter Sets the vertices (as Vertex objects)

edges

Edges of the triangle

Getter Gets the list of vertices that generates the edges of the triangle

Type list

id

Object ID (as an integer).

Please refer to the wiki for details on using this class member.

Getter Gets the object ID

Setter Sets the object ID

Type int

inside

Inside-outside flag

Getter Gets the flag

Setter Sets the flag

Type bool

name

Object name (as a string)

Please refer to the wiki for details on using this class member.

Getter Gets the object name

Setter Sets the object name

Type str

opt

Dictionary for storing custom data in the current geometry object.

`opt` is a wrapper to a dict in *key* => *value* format, where *key* is string, *value* is any Python object. You can use `opt` property to store custom data inside the geometry object. For instance:

```
geom.opt = ["face_id", 4]  # creates "face_id" key and sets its value to an␣
↪integer
geom.opt = ["contents", "data values"]  # creates "face_id" key and sets its␣
↪value to a string
print(geom.opt)  # will print: {'face_id': 4, 'contents': 'data values'}

del geom.opt  # deletes the contents of the hash map
print(geom.opt)  # will print: {}

geom.opt = ["body_id", 1]  # creates "body_id" key  and sets its value to 1
geom.opt = ["body_id", 12]  # changes the value of "body_id" to 12
print(geom.opt)  # will print: {'body_id': 12}

geom.opt = ["body_id", None]  # deletes "body_id"
print(geom.opt)  # will print: {}
```

Getter Gets the dict

Setter Adds key and value pair to the dict

Deleter Deletes the contents of the dict

opt_get (*value*)

Safely query for the value from the `opt` property.

Parameters **value** (*str*) – a key in the `opt` property

Returns the corresponding value, if the key exists. `None`, otherwise.

vertex_ids

Vertex indices

Note: Please use *data* instead of this property.

Getter Gets the vertex indices

Type list

vertices
Vertices of the triangle

Getter Gets the list of vertices

Type tuple

vertices_closed
Vertices which generates a closed triangle

Adds the first vertex as a last element of the return value (good for plotting)

Getter Gets the list of vertices

Type list

class geomdl.elements.**Quad**(**args*, ***kwargs*)
Bases: geomdl.elements.AbstractEntity

Quad entity which represents a quadrilateral structure composed of vertices.

A Quad entity stores the vertices in its data structure. *data* returns the vertex IDs and *vertices* return the *Vertex* instances that compose the quadrilateral structure.

add_vertex(**args*)
Adds vertices to the Quad object.

This method takes a single or a list of vertices as its function arguments.

data
Vertices composing the quadrilateral structure.

Getter Gets the vertex indices (as int values)

Setter Sets the vertices (as Vertex objects)

id
Object ID (as an integer).

Please refer to the wiki for details on using this class member.

Getter Gets the object ID

Setter Sets the object ID

Type int

name
Object name (as a string)

Please refer to the wiki for details on using this class member.

Getter Gets the object name

Setter Sets the object name

Type str

opt

Dictionary for storing custom data in the current geometry object.

opt is a wrapper to a dict in *key* => *value* format, where *key* is string, *value* is any Python object. You can use opt property to store custom data inside the geometry object. For instance:

```
geom.opt = ["face_id", 4]  # creates "face_id" key and sets its value to an␣
↪integer
geom.opt = ["contents", "data values"]  # creates "face_id" key and sets its␣
↪value to a string
print(geom.opt)  # will print: {'face_id': 4, 'contents': 'data values'}

del geom.opt  # deletes the contents of the hash map
print(geom.opt)  # will print: {}

geom.opt = ["body_id", 1]  # creates "body_id" key  and sets its value to 1
geom.opt = ["body_id", 12]  # changes the value of "body_id" to 12
print(geom.opt)  # will print: {'body_id': 12}

geom.opt = ["body_id", None]  # deletes "body_id"
print(geom.opt)  # will print: {}
```

Getter Gets the dict

Setter Adds key and value pair to the dict

Deleter Deletes the contents of the dict

opt_get (*value*)

Safely query for the value from the *opt* property.

Parameters **value** (*str*) – a key in the *opt* property

Returns the corresponding value, if the key exists. None, otherwise.

vertices

Vertices composing the quadrilateral structure.

Getter Gets the vertices

class geomdl.elements.**Face** (**args*, ***kwargs*)

Bases: geomdl.elements.AbstractEntity

Representation of Face entity which is composed of triangles or quads.

add_triangle (**args*)

Adds triangles to the Face object.

This method takes a single or a list of triangles as its function arguments.

id

Object ID (as an integer).

Please refer to the wiki for details on using this class member.

Getter Gets the object ID

Setter Sets the object ID

Type int

name

Object name (as a string)

Please refer to the wiki for details on using this class member.

Getter Gets the object name

Setter Sets the object name

Type str

opt

Dictionary for storing custom data in the current geometry object.

`opt` is a wrapper to a dict in *key* => *value* format, where *key* is string, *value* is any Python object. You can use `opt` property to store custom data inside the geometry object. For instance:

```
geom.opt = ["face_id", 4]  # creates "face_id" key and sets its value to an␣
↪integer
geom.opt = ["contents", "data values"]  # creates "face_id" key and sets its␣
↪value to a string
print(geom.opt)  # will print: {'face_id': 4, 'contents': 'data values'}

del geom.opt  # deletes the contents of the hash map
print(geom.opt)  # will print: {}

geom.opt = ["body_id", 1]  # creates "body_id" key  and sets its value to 1
geom.opt = ["body_id", 12]  # changes the value of "body_id" to 12
print(geom.opt)  # will print: {'body_id': 12}

geom.opt = ["body_id", None]  # deletes "body_id"
print(geom.opt)  # will print: {}
```

Getter Gets the dict

Setter Adds key and value pair to the dict

Deleter Deletes the contents of the dict

opt_get(*value*)

Safely query for the value from the *opt* property.

Parameters value (*str*) – a key in the *opt* property

Returns the corresponding value, if the key exists. `None`, otherwise.

triangles

Triangles of the face

Getter Gets the list of triangles

Type tuple

class geomdl.elements.**Body**(**args*, ***kwargs*)

Bases: `geomdl.elements.AbstractEntity`

Representation of Body entity which is composed of faces.

add_face(**args*)

Adds faces to the Body object.

This method takes a single or a list of faces as its function arguments.

faces

Faces of the body

Getter Gets the list of faces

Type tuple

id

Object ID (as an integer).

Please refer to the wiki for details on using this class member.

Getter Gets the object ID

Setter Sets the object ID

Type int

name

Object name (as a string)

Please refer to the wiki for details on using this class member.

Getter Gets the object name

Setter Sets the object name

Type str

opt

Dictionary for storing custom data in the current geometry object.

`opt` is a wrapper to a dict in *key* => *value* format, where *key* is string, *value* is any Python object. You can use `opt` property to store custom data inside the geometry object. For instance:

```
geom.opt = ["face_id", 4]  # creates "face_id" key and sets its value to an␣
↪integer
geom.opt = ["contents", "data values"]  # creates "face_id" key and sets its␣
↪value to a string
print(geom.opt)  # will print: {'face_id': 4, 'contents': 'data values'}

del geom.opt  # deletes the contents of the hash map
print(geom.opt)  # will print: {}

geom.opt = ["body_id", 1]  # creates "body_id" key  and sets its value to 1
geom.opt = ["body_id", 12]  # changes the value of "body_id" to 12
print(geom.opt)  # will print: {'body_id': 12}

geom.opt = ["body_id", None]  # deletes "body_id"
print(geom.opt)  # will print: {}
```

Getter Gets the dict

Setter Adds key and value pair to the dict

Deleter Deletes the contents of the dict

opt_get (*value*)

Safely query for the value from the *opt* property.

Parameters value (*str*) – a key in the *opt* property

Returns the corresponding value, if the key exists. `None`, otherwise.

17.3.6 Ray Module

`ray` module provides utilities for ray operations. A ray (half-line) is defined by two distinct points represented by *Ray* class. This module also provides a function to compute intersection of 2 rays.

Function and Class Reference

class geomdl.ray.**Ray**(*point1*, *point2*)

Representation of a n-dimensional ray generated from 2 points.

A ray is defined by $r(t) = p_1 + t \times \vec{d}$ where :math't' is the parameter value, $\vec{d} = p_2 - p_1$ is the vector component of the ray, p_1 is the origin point and p_2 is the second point which is required to define a line segment

Parameters

- **point1** (*list, tuple*) – 1st point of the line segment
- **point2** (*list, tuple*) – 2nd point of the line segment

d

Vector component of the ray (d)

Please refer to the wiki for details on using this class member.

Getter Gets the vector component of the ray

dimension

Spatial dimension of the ray

Please refer to the wiki for details on using this class member.

Getter Gets the dimension of the ray

eval(*t=0*)

Finds the point on the line segment defined by the input parameter.

$t = 0$ returns the origin (1st) point, defined by the input argument `point1` and $t = 1$ returns the end (2nd) point, defined by the input argument `point2`.

Parameters t (*float*) – parameter

Returns point at the parameter value

Return type tuple

p

Origin point of the ray (p)

Please refer to the wiki for details on using this class member.

Getter Gets the origin point of the ray

points

Start and end points of the line segment that the ray was generated

Please refer to the wiki for details on using this class member.

Getter Gets the points

class geomdl.ray.**RayIntersection**

The status of the ray intersection operation `geomdl.ray.`**`intersect`**`(`*ray1*, *ray2*, ***kwargs*`)`

Finds intersection of 2 rays.

This functions finds the parameter values for the 1st and 2nd input rays and returns a tuple of `(parameter for ray1, parameter for ray2, intersection status)`. `status` value is a enum type which reports the case which the intersection operation encounters.

The intersection operation can encounter 3 different cases:

- Intersecting: This is the anticipated solution. Returns `(t1, t2, RayIntersection.INTERSECT)`
- Colinear: The rays can be parallel or coincident. Returns `(t1, t2, RayIntersection.COLINEAR)`
- Skew: The rays are neither parallel nor intersecting. Returns `(t1, t2, RayIntersection.SKEW)`

For the colinear case, `t1` and `t2` are the parameter values that give the starting point of the ray2 and ray1, respectively. Therefore;

```
ray1.eval(t1) == ray2.p
ray2.eval(t2) == ray1.p
```

Please note that this operation is only implemented for 2- and 3-dimensional rays.

Parameters

- **`ray1`** – 1st ray
- **`ray2`** – 2nd ray

Returns a tuple of the parameter (t) for ray1 and ray2, and status of the intersection

Return type tuple

CHAPTER 18

Visualization Modules

NURBS-Python provides an abstract base for visualization modules. It is a part of the *Core Library* and it can be used to implement various visualization backends.

NURBS-Python comes with the following visualization modules:

18.1 Visualization Base

The visualization component in the NURBS-Python package provides an easy way to visualise the surfaces and the 2D/3D curves generated using the library. The following are the list of abstract classes for the visualization system and its configuration.

18.1.1 Class Reference

Abstract base class for visualization

Defines an abstract base for NURBS-Python (geomdl) visualization modules.

param config configuration class

type config VisConfigAbstract

`geomdl.vis.VisAbstract.`**`ctrlpts_offset`**

Defines an offset value for the control points grid plots

Only makes sense to use with surfaces with dense control points grid.

Getter Gets the offset value

Setter Sets the offset value

Type float

`geomdl.vis.VisAbstract.`**`mconf`**

Configuration directives for the visualization module (internal).

This property controls the internal configuration of the visualization module. It is for advanced use and testing only.

The visualization module is mainly designed to plot the control points (*ctrlpts*) and the surface points (*evalpts*). These are called as *plot types*. However, there is more than one way to plot the control points and the surface points. For instance, a control points plot can be a scatter plot or a quad mesh, and a surface points plot can be a scatter plot or a tessellated surface plot.

This function allows you to change the type of the plot, e.g. from scatter plot to tessellated surface plot. On the other than, some visualization modules also defines some specialized classes for this purpose as it might not be possible to change the type of the plot at the runtime due to visualization library internal API differences (i.e. different backends for 2- and 3-dimensional plots).

By default, the following plot types and values are available:

Curve:

- For control points (*ctrlpts*): points
- For evaluated points (*evalpts*): points

Surface:

- For control points (*ctrlpts*): points, quads
- For evaluated points (*evalpts*): points, quads, triangles

Volume:

- For control points (*ctrlpts*): points
- For evaluated points (*evalpts*): points, voxels

Getter Gets the visualization module configuration

Setter Sets the visualization module configuration

`geomdl.vis.VisAbstract.`**`vconf`**

User configuration class for visualization

Getter Gets the user configuration class

Type vis.VisConfigAbstract

Abstract base class for user configuration of the visualization module

Defines an abstract base for NURBS-Python (geomdl) visualization configuration.

18.2 Matplotlib Implementation

This module provides Matplotlib visualization implementation for NURBS-Python.

Note: Please make sure that you have installed `matplotlib` package before using this visualization module.

18.2.1 Class Reference

class `geomdl.visualization.VisMPL.`**`VisConfig`**`(**kwargs)`

Bases: `geomdl.vis.VisConfigAbstract`

Configuration class for Matplotlib visualization module.

This class is only required when you would like to change the visual defaults of the plots and the figure, such as hiding control points plot or legend.

The `VisMPL` module has the following configuration variables:

- `ctrlpts` (bool): Control points polygon/grid visibility. *Default: True*
- `evalpts` (bool): Curve/surface points visibility. *Default: True*
- `bbox` (bool): Bounding box visibility. *Default: False*
- `legend` (bool): Figure legend visibility. *Default: True*
- `axes` (bool): Axes and figure grid visibility. *Default: True*
- `labels` (bool): Axis labels visibility. *Default: True*
- `trims` (bool): Trim curves visibility. *Default: True*
- `axes_equal` (bool): Enables or disables equal aspect ratio for the axes. *Default: True*
- `figure_size` (list): Size of the figure in (x, y). *Default: [10, 8]*
- `figure_dpi` (int): Resolution of the figure in DPI. *Default: 96*
- `trim_size` (int): Size of the trim curves. *Default: 20*
- `alpha` (float): Opacity of the evaluated points. *Default: 1.0*

There is also a `debug` configuration variable which currently adds quiver plots to 2-dimensional curves to show their directions.

The following example illustrates the usage of the configuration class.

```
# Create a curve (or a surface) instance
curve = NURBS.Curve()

# Skipping degree, knot vector and control points assignments

# Create a visualization configuration instance with no legend, no axes and set␣
↪the resolution to 120 dpi
vis_config = VisMPL.VisConfig(legend=False, axes=False, figure_dpi=120)

# Create a visualization method instance using the configuration above
vis_obj = VisMPL.VisCurve2D(vis_config)

# Set the visualization method of the curve object
curve.vis = vis_obj

# Plot the curve
curve.render()
```

Please refer to the **Examples Repository** for more details.

is_notebook()

Detects if Jupyter notebook GUI toolkit is active

return: True if the module is running inside a Jupyter notebook rtype: bool

static save_figure_as(*fig*, *filename*)

Saves the figure as a file.

Parameters

- **fig** – a Matplotlib figure instance
- **filename** – file name to save

static set_axes_equal(*ax*)
Sets equal aspect ratio across the three axes of a 3D plot.

Contributed by Xuefeng Zhao.

Parameters ax – a Matplotlib axis, e.g., as output from plt.gca().

class geomdl.visualization.VisMPL.**VisCurve2D**(*config=<geomdl.visualization.VisMPL.VisConfig object>, **kwargs*)
Bases: *geomdl.vis.VisAbstract*

Matplotlib visualization module for 2D curves

add(*ptsarr, plot_type, name=", color=", idx=0*)
Adds points sets to the visualization instance for plotting.

Parameters

- **ptsarr** (*list, tuple*) – control or evaluated points
- **plot_type** (*str*) – type of the plot, e.g. ctrlpts, evalpts, bbox, etc.
- **name** (*str*) – name of the plot displayed on the legend
- **color** (*int*) – plot color
- **color** – plot index

animate(***kwargs*)
Generates animated plots (if supported).

If the implemented visualization module supports animations, this function will create an animated figure. Otherwise, it will call *render()* method by default.

clear()
Clears the points, colors and names lists.

ctrlpts_offset
Defines an offset value for the control points grid plots

Only makes sense to use with surfaces with dense control points grid.

Getter Gets the offset value

Setter Sets the offset value

Type float

render(***kwargs*)
Plots the 2D curve and the control points polygon.

size(*plot_type*)
Returns the number of plots defined by the plot type.

Parameters plot_type (*str*) – plot type

Returns number of plots defined by the plot type

Return type int

vconf
User configuration class for visualization

Getter Gets the user configuration class

Type vis.VisConfigAbstract

class geomdl.visualization.VisMPL.**VisCurve3D**(*config=<geomdl.visualization.VisMPL.VisConfig object>*, ***kwargs*)

Bases: `geomdl.vis.VisAbstract`

Matplotlib visualization module for 3D curves.

add(*ptsarr*, *plot_type*, *name=''*, *color=''*, *idx=0*)
Adds points sets to the visualization instance for plotting.

Parameters

- **ptsarr** (*list, tuple*) – control or evaluated points
- **plot_type** (*str*) – type of the plot, e.g. ctrlpts, evalpts, bbox, etc.
- **name** (*str*) – name of the plot displayed on the legend
- **color** (*int*) – plot color
- **color** – plot index

animate(***kwargs*)
Generates animated plots (if supported).

If the implemented visualization module supports animations, this function will create an animated figure. Otherwise, it will call `render()` method by default.

clear()
Clears the points, colors and names lists.

ctrlpts_offset
Defines an offset value for the control points grid plots

Only makes sense to use with surfaces with dense control points grid.

Getter Gets the offset value

Setter Sets the offset value

Type float

render(***kwargs*)
Plots the 3D curve and the control points polygon.

size(*plot_type*)
Returns the number of plots defined by the plot type.

Parameters **plot_type** (*str*) – plot type

Returns number of plots defined by the plot type

Return type int

vconf
User configuration class for visualization

Getter Gets the user configuration class

Type vis.VisConfigAbstract

class geomdl.visualization.VisMPL.**VisSurfScatter**(*config=<geomdl.visualization.VisMPL.VisConfig object>*, ***kwargs*)

Bases: `geomdl.vis.VisAbstract`

Matplotlib visualization module for surfaces.

Wireframe plot for the control points and scatter plot for the surface points.

add(*ptsarr*, *plot_type*, *name=''*, *color=''*, *idx=0*)
Adds points sets to the visualization instance for plotting.

Parameters

- **ptsarr** (*list, tuple*) – control or evaluated points
- **plot_type** (*str*) – type of the plot, e.g. ctrlpts, evalpts, bbox, etc.
- **name** (*str*) – name of the plot displayed on the legend
- **color** (*int*) – plot color
- **color** – plot index

animate(***kwargs*)
Generates animated plots (if supported).

If the implemented visualization module supports animations, this function will create an animated figure. Otherwise, it will call `render()` method by default.

clear()
Clears the points, colors and names lists.

ctrlpts_offset
Defines an offset value for the control points grid plots

Only makes sense to use with surfaces with dense control points grid.

Getter Gets the offset value

Setter Sets the offset value

Type float

render(***kwargs*)
Plots the surface and the control points grid.

size(*plot_type*)
Returns the number of plots defined by the plot type.

Parameters **plot_type** (*str*) – plot type

Returns number of plots defined by the plot type

Return type int

vconf
User configuration class for visualization

Getter Gets the user configuration class

Type vis.VisConfigAbstract

class geomdl.visualization.VisMPL.**VisSurfWireframe**(*config=<geomdl.visualization.VisMPL.VisConfig object>*, ***kwargs*)
Bases: `geomdl.vis.VisAbstract`

Matplotlib visualization module for surfaces.

Scatter plot for the control points and wireframe plot for the surface points.

add(*ptsarr*, *plot_type*, *name=''*, *color=''*, *idx=0*)
Adds points sets to the visualization instance for plotting.

Parameters

- **ptsarr** (*list, tuple*) – control or evaluated points
- **plot_type** (*str*) – type of the plot, e.g. ctrlpts, evalpts, bbox, etc.
- **name** (*str*) – name of the plot displayed on the legend
- **color** (*int*) – plot color
- **color** – plot index

animate (***kwargs*)
Generates animated plots (if supported).

If the implemented visualization module supports animations, this function will create an animated figure. Otherwise, it will call `render()` method by default.

clear ()
Clears the points, colors and names lists.

ctrlpts_offset
Defines an offset value for the control points grid plots

Only makes sense to use with surfaces with dense control points grid.

Getter Gets the offset value

Setter Sets the offset value

Type float

render (***kwargs*)
Plots the surface and the control points grid.

size (*plot_type*)
Returns the number of plots defined by the plot type.

Parameters **plot_type** (*str*) – plot type

Returns number of plots defined by the plot type

Return type int

vconf
User configuration class for visualization

Getter Gets the user configuration class

Type vis.VisConfigAbstract

class geomdl.visualization.VisMPL.**VisSurface** (*config=<geomdl.visualization.VisMPL.VisConfig object>, **kwargs*)
Bases: `geomdl.vis.VisAbstract`

Matplotlib visualization module for surfaces.

Wireframe plot for the control points and triangulated plot (using `plot_trisurf`) for the surface points. The surface is triangulated externally using `utilities.make_triangle_mesh()` function.

add (*ptsarr, plot_type, name=”, color=”, idx=0*)
Adds points sets to the visualization instance for plotting.

Parameters

- **ptsarr** (*list, tuple*) – control or evaluated points
- **plot_type** (*str*) – type of the plot, e.g. ctrlpts, evalpts, bbox, etc.
- **name** (*str*) – name of the plot displayed on the legend

- **color** (*int*) – plot color
- **color** – plot index

animate(***kwargs*)

Animates the surface.

This function only animates the triangulated surface. There will be no other elements, such as control points grid or bounding box.

Keyword arguments:

- `colormap`: applies colormap to the surface

Colormaps are a visualization feature of Matplotlib. They can be used for several types of surface plots via the following import statement: `from matplotlib import cm`

The following link displays the list of Matplolib colormaps and some examples on colormaps: https://matplotlib.org/tutorials/colors/colormaps.html

clear()

Clears the points, colors and names lists.

ctrlpts_offset

Defines an offset value for the control points grid plots

Only makes sense to use with surfaces with dense control points grid.

Getter Gets the offset value

Setter Sets the offset value

Type float

render(***kwargs*)

Plots the surface and the control points grid.

Keyword arguments:

- `colormap`: applies colormap to the surface

Colormaps are a visualization feature of Matplotlib. They can be used for several types of surface plots via the following import statement: `from matplotlib import cm`

The following link displays the list of Matplolib colormaps and some examples on colormaps: https://matplotlib.org/tutorials/colors/colormaps.html

size(*plot_type*)

Returns the number of plots defined by the plot type.

Parameters **plot_type** (*str*) – plot type

Returns number of plots defined by the plot type

Return type int

vconf

User configuration class for visualization

Getter Gets the user configuration class

Type vis.VisConfigAbstract

class geomdl.visualization.VisMPL.**VisVolume**(*config=<geomdl.visualization.VisMPL.VisConfig object>, **kwargs*)

Bases: *geomdl.vis.VisAbstract*

Matplotlib visualization module for volumes.

add(*ptsarr*, *plot_type*, *name=''*, *color=''*, *idx=0*)
Adds points sets to the visualization instance for plotting.

Parameters

- **ptsarr** (*list, tuple*) – control or evaluated points
- **plot_type** (*str*) – type of the plot, e.g. ctrlpts, evalpts, bbox, etc.
- **name** (*str*) – name of the plot displayed on the legend
- **color** (*int*) – plot color
- **color** – plot index

animate(***kwargs*)
Generates animated plots (if supported).

If the implemented visualization module supports animations, this function will create an animated figure. Otherwise, it will call *render()* method by default.

clear()
Clears the points, colors and names lists.

ctrlpts_offset
Defines an offset value for the control points grid plots

Only makes sense to use with surfaces with dense control points grid.

Getter Gets the offset value

Setter Sets the offset value

Type float

render(***kwargs*)
Plots the volume and the control points.

size(*plot_type*)
Returns the number of plots defined by the plot type.

Parameters **plot_type** (*str*) – plot type

Returns number of plots defined by the plot type

Return type int

vconf
User configuration class for visualization

Getter Gets the user configuration class

Type vis.VisConfigAbstract

class geomdl.visualization.VisMPL.**VisVoxel**(*config=<geomdl.visualization.VisMPL.VisConfig object>*, ***kwargs*)
Bases: *geomdl.vis.VisAbstract*

Matplotlib visualization module for voxel representation of the volumes.

add(*ptsarr*, *plot_type*, *name=''*, *color=''*, *idx=0*)
Adds points sets to the visualization instance for plotting.

Parameters

- **ptsarr** (*list, tuple*) – control or evaluated points
- **plot_type** (*str*) – type of the plot, e.g. ctrlpts, evalpts, bbox, etc.

- **name** (*str*) – name of the plot displayed on the legend
- **color** (*int*) – plot color
- **color** – plot index

animate(***kwargs*)
Generates animated plots (if supported).

If the implemented visualization module supports animations, this function will create an animated figure. Otherwise, it will call render() method by default.

clear()
Clears the points, colors and names lists.

ctrlpts_offset
Defines an offset value for the control points grid plots

Only makes sense to use with surfaces with dense control points grid.

Getter Gets the offset value

Setter Sets the offset value

Type float

render(***kwargs*)
Displays the voxels and the control points.

size(*plot_type*)
Returns the number of plots defined by the plot type.

Parameters **plot_type** (*str*) – plot type

Returns number of plots defined by the plot type

Return type int

vconf
User configuration class for visualization

Getter Gets the user configuration class

Type vis.VisConfigAbstract

18.3 Plotly Implementation

This module provides Plotly visualization implementation for NURBS-Python.

Note: Please make sure that you have installed plotly package before using this visualization module.

18.3.1 Class Reference

18.4 VTK Implementation

New in version 5.0.

This module provides VTK visualization implementation for NURBS-Python.

Note: Please make sure that you have installed `vtk` package before using this visualization module.

18.4.1 Class Reference

class `geomdl.visualization.VisVTK.`**`VisConfig`**(***kwargs*)

Bases: *`geomdl.vis.VisConfigAbstract`*

Configuration class for VTK visualization module.

This class is only required when you would like to change the visual defaults of the plots and the figure.

The `VisVTK` module has the following configuration variables:

- `ctrlpts` (bool): Control points polygon/grid visibility. *Default: True*
- `evalpts` (bool): Curve/surface points visibility. *Default: True*
- `trims` (bool): Trim curve visibility. *Default: True*
- `trim_size` (int): Size of the trim curves. *Default: 4*
- `figure_size` (list): Size of the figure in (x, y). *Default: (800, 600)*
- `line_width` (int): Thickness of the lines on the figure. *Default: 1.0*

`keypress_callback`(*obj*, *ev*)

VTK callback for keypress events.

Keypress events:

- `e`: exit the application
- `p`: pick object (hover the mouse and then press to pick)
- `f`: fly to point (click somewhere in the window and press to fly)
- `r`: reset the camera
- `s` and `w`: switch between solid and wireframe modes
- `b`: change background color
- `m`: change color of the picked object
- `d`: print debug information (of picked object, point, etc.)
- `h`: change object visibility
- `n`: reset object visibility
- `arrow keys`: pan the model

Please refer to vtkInteractorStyle class reference for more details.

Parameters

- **obj** (*vtkRenderWindowInteractor*) – render window interactor
- **ev** (*str*) – event name

`geomdl.visualization.VisVTK.`**`VisCurve2D`**

alias of *`geomdl.visualization.VisVTK.VisCurve3D`*

class geomdl.visualization.VisVTK.**VisCurve3D**(*config=<geomdl.visualization.VisVTK.VisConfig object>*, ***kwargs*)

Bases: *geomdl.vis.VisAbstract*

VTK visualization module for curves.

add(*ptsarr*, *plot_type*, *name=''*, *color=''*, *idx=0*)

Adds points sets to the visualization instance for plotting.

Parameters

- **ptsarr** (*list, tuple*) – control or evaluated points
- **plot_type** (*str*) – type of the plot, e.g. ctrlpts, evalpts, bbox, etc.
- **name** (*str*) – name of the plot displayed on the legend
- **color** (*int*) – plot color
- **color** – plot index

animate(***kwargs*)

Generates animated plots (if supported).

If the implemented visualization module supports animations, this function will create an animated figure. Otherwise, it will call *render()* method by default.

clear()

Clears the points, colors and names lists.

ctrlpts_offset

Defines an offset value for the control points grid plots

Only makes sense to use with surfaces with dense control points grid.

Getter Gets the offset value

Setter Sets the offset value

Type float

render(***kwargs*)

Plots the curve and the control points polygon.

size(*plot_type*)

Returns the number of plots defined by the plot type.

Parameters **plot_type** (*str*) – plot type

Returns number of plots defined by the plot type

Return type int

vconf

User configuration class for visualization

Getter Gets the user configuration class

Type vis.VisConfigAbstract

class geomdl.visualization.VisVTK.**VisSurface**(*config=<geomdl.visualization.VisVTK.VisConfig object>*, ***kwargs*)

Bases: *geomdl.vis.VisAbstract*

VTK visualization module for surfaces.

add(*ptsarr*, *plot_type*, *name=''*, *color=''*, *idx=0*)

Adds points sets to the visualization instance for plotting.

Parameters

- **ptsarr** (*list, tuple*) – control or evaluated points
- **plot_type** (*str*) – type of the plot, e.g. ctrlpts, evalpts, bbox, etc.
- **name** (*str*) – name of the plot displayed on the legend
- **color** (*int*) – plot color
- **color** – plot index

animate (***kwargs*)
Generates animated plots (if supported).

If the implemented visualization module supports animations, this function will create an animated figure. Otherwise, it will call `render()` method by default.

clear ()
Clears the points, colors and names lists.

ctrlpts_offset
Defines an offset value for the control points grid plots

Only makes sense to use with surfaces with dense control points grid.

Getter Gets the offset value

Setter Sets the offset value

Type float

render (***kwargs*)
Plots the surface and the control points grid.

size (*plot_type*)
Returns the number of plots defined by the plot type.

Parameters **plot_type** (*str*) – plot type

Returns number of plots defined by the plot type

Return type int

vconf
User configuration class for visualization

Getter Gets the user configuration class

Type vis.VisConfigAbstract

class geomdl.visualization.VisVTK.**VisVolume** (*config=<geomdl.visualization.VisVTK.VisConfig object>, **kwargs*)
Bases: `geomdl.vis.VisAbstract`

VTK visualization module for volumes.

add (*ptsarr, plot_type, name=", color=", idx=0*)
Adds points sets to the visualization instance for plotting.

Parameters

- **ptsarr** (*list, tuple*) – control or evaluated points
- **plot_type** (*str*) – type of the plot, e.g. ctrlpts, evalpts, bbox, etc.
- **name** (*str*) – name of the plot displayed on the legend
- **color** (*int*) – plot color

- **color** – plot index

animate(***kwargs*)
Generates animated plots (if supported).

If the implemented visualization module supports animations, this function will create an animated figure. Otherwise, it will call `render()` method by default.

clear()
Clears the points, colors and names lists.

ctrlpts_offset
Defines an offset value for the control points grid plots

Only makes sense to use with surfaces with dense control points grid.

Getter Gets the offset value

Setter Sets the offset value

Type float

render(***kwargs*)
Plots the volume and the control points.

size(*plot_type*)
Returns the number of plots defined by the plot type.

Parameters **plot_type** (`str`) – plot type

Returns number of plots defined by the plot type

Return type int

vconf
User configuration class for visualization

Getter Gets the user configuration class

Type vis.VisConfigAbstract

class geomdl.visualization.VisVTK.**VisVoxel**(*config=<geomdl.visualization.VisVTK.VisConfig object>*, ***kwargs*)
Bases: `geomdl.vis.VisAbstract`

VTK visualization module for voxel representation of the volumes.

add(*ptsarr*, *plot_type*, *name=''*, *color=''*, *idx=0*)
Adds points sets to the visualization instance for plotting.

Parameters

- **ptsarr** (`list, tuple`) – control or evaluated points
- **plot_type** (`str`) – type of the plot, e.g. ctrlpts, evalpts, bbox, etc.
- **name** (`str`) – name of the plot displayed on the legend
- **color** (`int`) – plot color
- **color** – plot index

animate(***kwargs*)
Generates animated plots (if supported).

If the implemented visualization module supports animations, this function will create an animated figure. Otherwise, it will call `render()` method by default.

clear()
Clears the points, colors and names lists.

ctrlpts_offset
Defines an offset value for the control points grid plots

Only makes sense to use with surfaces with dense control points grid.

Getter Gets the offset value

Setter Sets the offset value

Type float

render(***kwargs*)
Plots the volume and the control points.

size(*plot_type*)
Returns the number of plots defined by the plot type.

Parameters **plot_type** (*str*) – plot type

Returns number of plots defined by the plot type

Return type int

vconf
User configuration class for visualization

Getter Gets the user configuration class

Type vis.VisConfigAbstract

geomdl.visualization.VisVTK.**random**() → x in the interval [0, 1).

The users are not limited with these visualization backends. For instance, control points and evaluated points can be in various formats. Please refer to the *Exchange module documentation* for details.

CHAPTER 19

Command-line Application

You can use NURBS-Python (geomdl) with the command-line application geomdl-cli. The command-line application is designed for automation and input files are highly customizable using Jinja2 templates.

`geomdl-cli` is highly extensible via via the configuration file. It is very easy to generate custom commands as well as variables to change behavior of the existing commands or independently use for the custom commands. Since it runs inside the user's Python environment, it is possible to create commands that use the existing Python libraries and even integrate NURBS-Python (geomdl) with these libraries.

19.1 Installation

The easiest method to install is via `pip`. It will install all the required modules.

```
$ pip install --user geomdl.cli
```

Please refer to geomdl-cli documentation for more installation options.

19.2 Documentation

`geomdl-cli` has a very detailed online documentation which describes the usage and customization options of the command-line application.

19.3 References

- **PyPI**: https://pypi.org/project/geomdl.cli
- **Documentation**: https://geomdl-cli.readthedocs.io
- **Development**: https://github.com/orbingol/geomdl-cli

CHAPTER 20

Shapes Module

The shapes module provides simple functions to generate commonly used analytic and spline geometries using NURBS-Python (geomdl).

Prior to NURBS-Python (geomdl) v5.0.0, the shapes module was automatically installed with the main package. Currently, it is maintained as a separate package.

20.1 Installation

The easiest method to install is via pip.

```
$ pip install --user geomdl.shapes
```

Please refer to geomdl-shapes documentation for more installation options.

20.2 Documentation

You can find the class and function references in the geomdl-shapes documentation.

20.3 References

- **PyPI**: https://pypi.org/project/geomdl.shapes
- **Documentation**: https://geomdl-shapes.readthedocs.io
- **Development**: https://github.com/orbingol/geomdl-shapes

CHAPTER 21

Rhino Importer/Exporter

The **Rhino importer/exporter**, `rw3dm` uses OpenNURBS to read and write .3dm files.

`rw3dm` comes with the following list of programs:

- `on2json` converts OpenNURBS .3dm files to geomdl JSON format
- `json2on` converts geomdl JSON format to OpenNURBS .3dm files

21.1 Use Cases

- Import geometry data from .3dm files and use it with *exchange.import_json()*
- Export geometry data with *exchange.export_json()* and convert to a .3dm file
- Convert OpenNURBS file format to OBJ, STL, OFF and other formats supported by geomdl

21.2 Installation

Please refer to the rw3dm repository for installation options. The binary files can be downloaded under Releases section of the GitHub repository.

21.3 Using with geomdl

The following code snippet illustrates importing the surface data converted from .3dm file:

```
from geomdl import exchange
from geomdl import multi
from geomdl.visualization import VisMPL as vis

```

(continues on next page)

(continued from previous page)

```
# Import converted data
data = exchange.import_json("converted_rhino.json")

# Add the imported data to a surface container
surf_cont = multi.SurfaceContainer(data)
surf_cont.sample_size = 30

# Visualize
surf_cont.vis = vis.VisSurface(ctrlpts=False, trims=False)
surf_cont.render()
```

21.4 References

- **Development**: https://github.com/orbingol/rw3dm
- **Downloads**: https://github.com/orbingol/rw3dm/releases

CHAPTER 22

ACIS Importer

The **ACIS importer**, `rwsat` uses 3D ACIS Modeler to convert .sat files to geomdl JSON format.

`rwsat` comes with the following list of programs:

- `sat2json` converts ACIS .sat files to geomdl JSON format
- `satgen` generates sample geometries

22.1 Use Cases

- Import geometry data from .sat files and use it with *`exchange.import_json()`*
- Convert ACIS file format to OBJ, STL, OFF and other formats supported by geomdl

22.2 Installation

Please refer to the rwsat repository for installation options. Due to ACIS licensing, no binary files are distributed within the repository.

22.3 Using with geomdl

The following code snippet illustrates importing the surface data converted from .sat file:

```
from geomdl import exchange
from geomdl import multi
from geomdl.visualization import VisMPL as vis

# Import converted data
data = exchange.import_json("converted_acis.json")
```

(continues on next page)

(continued from previous page)

```

# Add the imported data to a surface container
surf_cont = multi.SurfaceContainer(data)
surf_cont.sample_size = 30

# Visualize
surf_cont.vis = vis.VisSurface(ctrlpts=False, trims=False)
surf_cont.render()
```

22.4 References

- **Development**: https://github.com/orbingol/rwsat
- **Documentation**: https://github.com/orbingol/rwsat

Python Module Index

c

e

g

h

i

k

l

o

r

s

t

u

v

Index

A

B

C

D

E

F

G

H

I

K

L

M

N

O

P

Q

R

S

T

U

V

W

X

Y

Z