# voxelmap

*Release 3.5*

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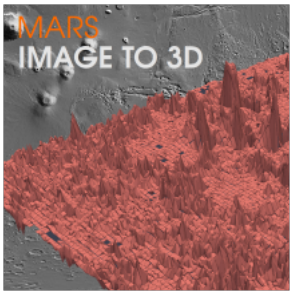
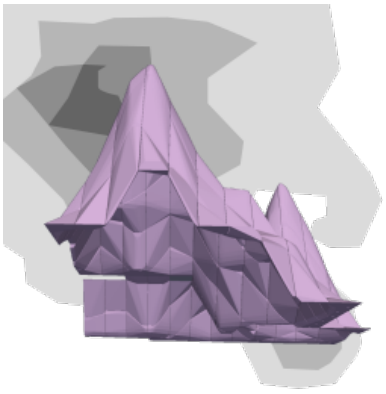
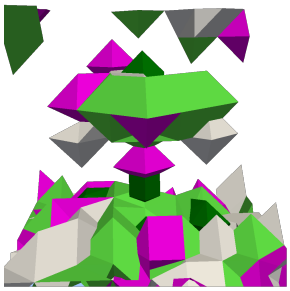
CHAPTER

# ONE

# LET'S MAKE 3-D MODELS WITH PYTHON!



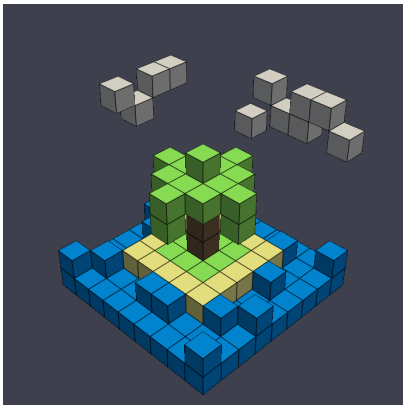
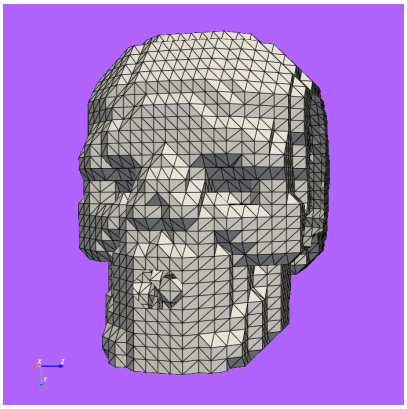
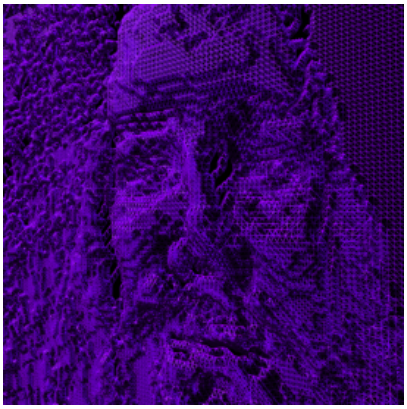



Ever wanted to make simple 3-D models from numpy arrays? Now you can do that with voxelmap ! **Voxelmap** is a Python library for making voxel and three-dimensional models from NumPy arrays. It was initially made to streamline 3-D voxel modeling by assigning each integer in an array to a voxel. Now, methods are being developed for mesh representations, such as ImageMesh (see: *ImageMesh : A Convex Hull based 3D Reconstruction Method*), voxel-to-mesh transformation and vice-versa.

Check out the *Usage* section for further information, including how to *Installation* the project. For some quick examples / templates, check out the next section.

## 1.1 Clickable examples

Click on the images below for their source code.

## 1.2 Colab Notebook

We also offer an interactive tutorial through a Colab notebook, click below:

**Note:** This project is under active development.

CHAPTER

TWO

# CONTENTS

## 2.1 Usage

### 2.1.1 Installation

It is recommended you use voxelmap through a virtual environment. You may follow the below simple protocol to create the virtual environment, run it, and install the package there:

```
$ virtualenv venv
$ source venv/bin/activate
(.venv) $ pip install voxelmap
```

To exit the virtual environment, simply type `deactivate`. To access it at any other time again, enter with the above `source` command.

### 2.1.2 Draw voxels from an integer array

**Voxelmap** was originally made to handle third-order integer arrays of the form `np.array((int,int,int))` as blueprints to 3-D voxel models.

While **"0"** integers are used to represent empty space, the non-zero integer values are used to define a distinct voxel type and thus, they are used as keys for such voxel type to be mapped to a specific color and `alpha` transparency. These keys are stored in a map (also known as "dictionary") internal to the `voxelmap.Model` class called `hashblocks`.

The voxel color and transparencies may be added or modified to the `hashblocks` map with the `hashblocksAdd` method.

```
import voxelmap as vxm
import numpy as np

#make a 3x3x3 integer array with random values between 0 and 9
array = np.random.randint(0, 10, (3, 3, 3))
print(array)

#incorporate array to Model structure
model = vxm.Model(array)

#add voxel colors and alpha-transparency for integer values 0 - 9 (needed for `custom`␣
↪coloring)
colors = ['#ffffff', 'black', '#ffffff', 'k',
```

(continues on next page)

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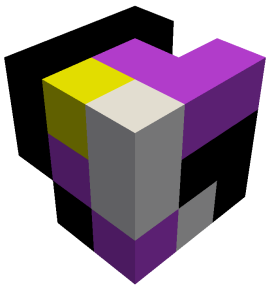
```
        'yellow', '#000000', 'white', 'k', '#c745f8']
for i in range(9):
   model.hashblocksAdd(i+1, colors[i])

#draw array as a voxel model with `custom` coloring scheme
model.draw('custom', background_color='#ffffff')
```

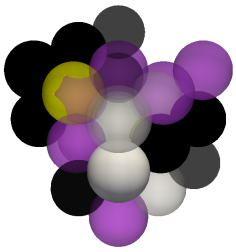
```
>>> [Out]
[[[3 8 5]
  [0 2 6]
  [2 2 7]]
 [[8 3 6]
  [7 2 0]
  [2 2 1]]
 [[9 2 4]
  [8 5 7]
  [8 9 8]]]
```



### With particles geometry and user-defined `alpha` transparencies

The new version of voxelmap now has a `geometry` kwarg for the `Model.draw()` method where the voxel geometry can be chosen between *voxels* and *particles* form. Below we change it to *particles* to represent the voxels above as spherical objects. In addition, we declare different transparencies of the different voxel-item types:

```
alphas = [0.8,1,0.5,1,0.75,0.5,1.0,0.8,0.6]
for i in range(9):
model.hashblocksAdd(i+1,colors[i],alphas[i])
model.draw('custom', geometry='particles', background_color='#ffffff')
```



### 2.1.3 Draw voxels from coordinate arrays

**Voxelmap** may also draw a voxel model from an array which defines the coordinates for each of the voxels to be drawn in x y and z space.

The internal variable `data.xyz` will thus take a third-order array where the rows are the number of voxels and the columns are the 3 coordinates for the x,y,z axis. Another internal input, `data.rgb`, can be used to define the colors for each of the voxels in the `data.xyz` object in `'xxxxxx'` hex format (i.e. `'ffffff'` for white).

The algorithm will also work for negative coordinates, as it is shown in the example below.

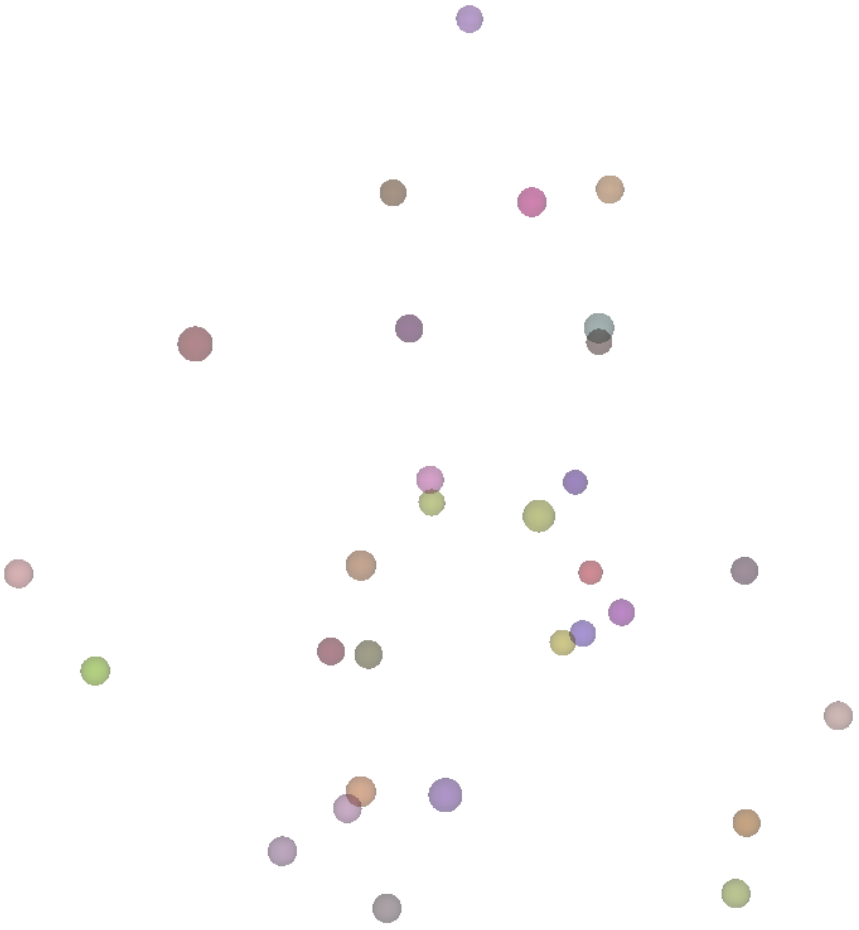
```
import voxelmap as vxm
import numpy as np

cubes = vxm.Model()
num_voxels = 30
cubes.XYZ = np.random.randint(-1,1,(num_voxels,3))+np.random.random((num_voxels,3))
    # random x,y,z locs for 10 voxels
cubes.RGB = [ hex(np.random.randint(0.5e7,1.5e7))[2:] for i in range(num_voxels) ]   #
define random colors for the 10 voxels
cubes.sparsity = 5
                                                    # spaces out coordinates
cubes.load(coords=True)
cubes.hashblocks

for i in cubes.hashblocks:
   cubes.hashblocks[i][1] = 0.30     # update all voxel alphas (transparency) to 0.3

# print(cubes.XYZ)                                  # print the xyz coordinate data
cubes.draw('custom',geometry='particles', background_color='#ffffff',window_size=[416,
416])                              # draw the model from that data
```

```
>>> [Out]
Color list built from file!
Model().hashblocks =
 {1: ['#4db692', 1], 2: ['#564bfb', 1], 3: ['#5915c1', 1], 4: ['#6283df', 1], 5: ['
#6e5722', 1], 6: ['#6eebc3', 1], 7: ['#70cffa', 1], 8: ['#787ea7', 1], 9: ['#813c5b',
1], 10: ['#8906d7', 1], 11: ['#8a871d', 1], 12: ['#8ba24f', 1], 13: ['#930979', 1],
14: ['#932fde', 1], 15: ['#964c67', 1], 16: ['#9bafea', 1], 17: ['#9c248b', 1], 18: ['
#9e5fff', 1], 19: ['#a2183b', 1], 20: ['#a248a6', 1], 21: ['#a63265', 1], 22: ['#a6c6a1
', 1], 23: ['#aa381b', 1], 24: ['#ae9c6a', 1], 25: ['#b58c2c', 1], 26: ['#c114a1', 1],
27: ['#c618df', 1], 28: ['#d15d6e', 1], 29: ['#da6f7d', 1], 30: ['#e36ff6', 1]}
```

### Increase sparsity

The *sparsity* variable will extend the distance from all voxels at the expense of increased memory.

```
cubes.sparsity = 12                                                    # spaces out␣
↪coordinates
cubes.load(coords=True)
for i in cubes.hashblocks:
   cubes.hashblocks[i][1] = 0.30     # update all voxel alphas (transparency) to 0.3

cubes.draw('custom', geometry='particles', background_color='#ffffff',window_size=[1000,␣
↪1000])                            # draw the model from that data
```



### 2.1.4 Get files for below examples

Click on the links below to save the files in the same directory you are running these examples:

LAND IMAGE (.png)

DOG MODEL (.txt)

ISLAND MODEL (.txt)

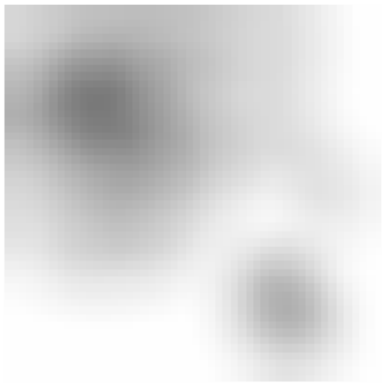
### 2.1.5 3-D Mapping of an Image

Here we map the synthetic topography image land.png we just downloaded to 3-D using the `map3d` method from the `voxelmap.Image` class.

```
#import packages
import cv2
import matplotlib.pyplot as plt

plt.imshow(cv2.imread('land.png'))      # display fake land topography .png file as plot
plt.axis('off')
plt.show()

#import packages
import numpy as np
from matplotlib import cm

img = vxm.Image('land.png')             # incorporate fake land topography .png file to␣
↪voxelmap.Image class
print(img.array.shape)
```

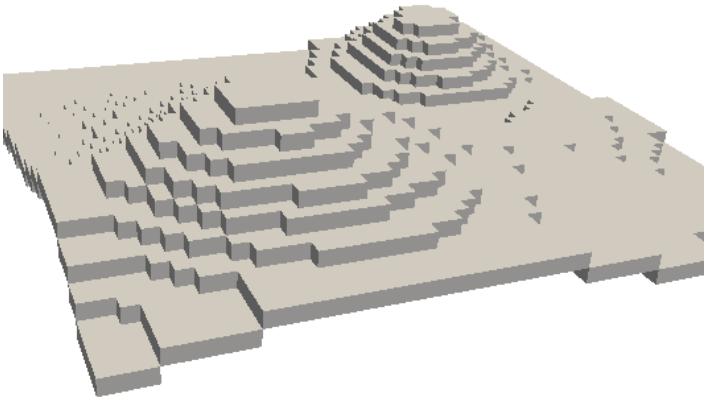
The image is then resized for the voxel draw with the matplotlib method i.e. `Model().draw_mpl`. This is done with `cv2.resize`, resizing the image from 1060x1060 to 50x50. After resizing, we convolve the image to obtain a less sharp color shift between the different gray regions with the `cv2.blur` method:

```
img.array = cv2.resize(img.array, (50,50), interpolation = cv2.INTER_AREA)
print(img.array.shape)

img.array = cv2.blur(img.array,(10,10))    # blur the image for realiztic topography␣
↪levels
plt.imshow(img.array)      # display fake land topography .png file as plot
plt.axis('off')
plt.show()
```



After this treatment, the resized and blurred image is mapped to a 3-D voxel model using the *ImageMap* method from the *Image* class:

```
mapped_img = img.ImageMap(12)              # mapped to 3d with a depth of 12 voxels
print(mapped_img.shape)
model = vxm.Model(mapped_img)
model.array = np.flip(np.transpose(model.array))

model.alphacm = 0.5
model.draw('none',background_color='#ffffff')
```



### 2.1.6 ImageMesh : 3-D Mesh Mapping from Image

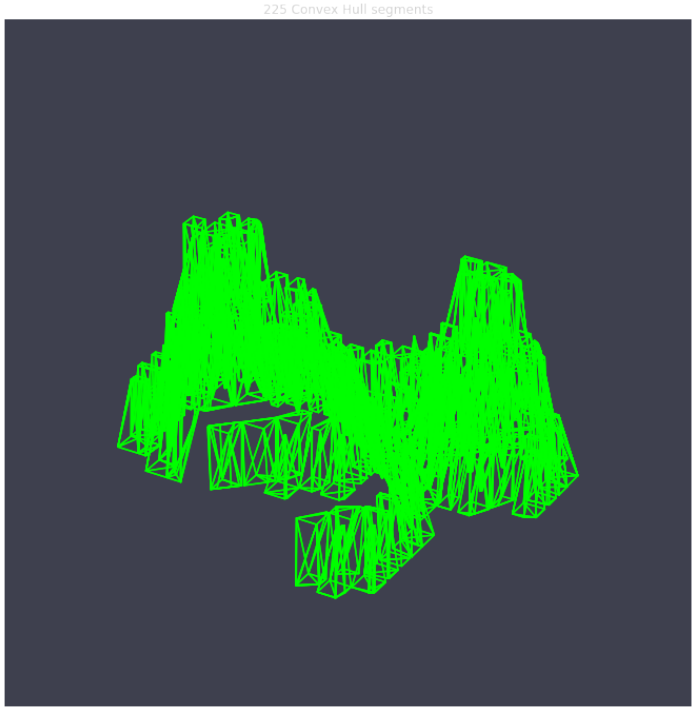
This method creates a low-poly mesh model from an Image using an algorithm developed by Andrew Garcia where 3-D convex hull is performed on separate "cuts" or sectors from the image (see: *ImageMesh : A Convex Hull based 3D Reconstruction Method*).

This can decrease the size of the 3-D model and the runtime to generate it significantly, making the runtime proportional to the number of sectors rather than the number of pixels. Sectors are quantified with the L_sectors kwarg, which is the length scale for the number of sectors in the grid.

We can see that the mesh model can be calculated and drawn with matplotlib `plot=mpl` option even from a large image

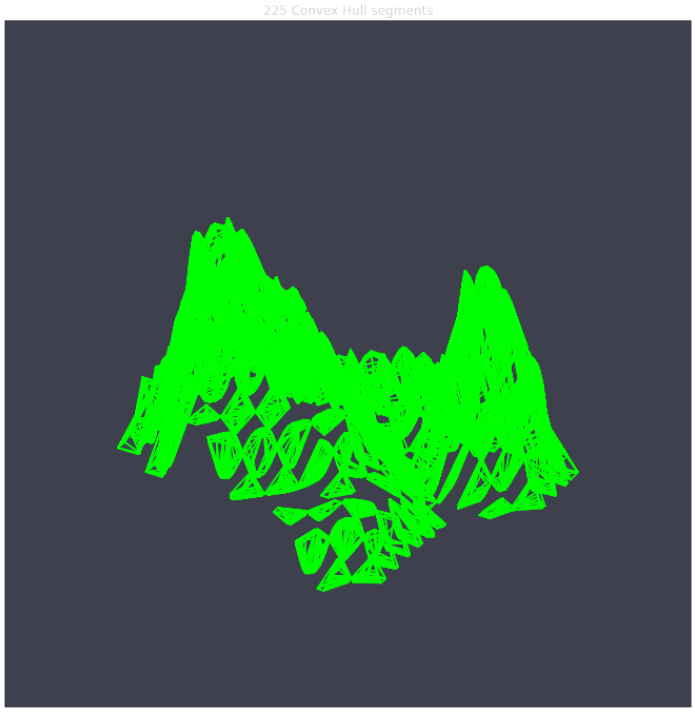
of 1060x1060 without resizing:

```
import voxelmap as vxm
import cv2

img = vxm.Image('land.png')   # incorporate fake land topography .png file

print(img.array.shape)

img.ImageMesh(out_file='model.obj', L_sectors = 15, trace_min=5, rel_depth = 20,␣
↪figsize=(15,12), plot='mpl')
```



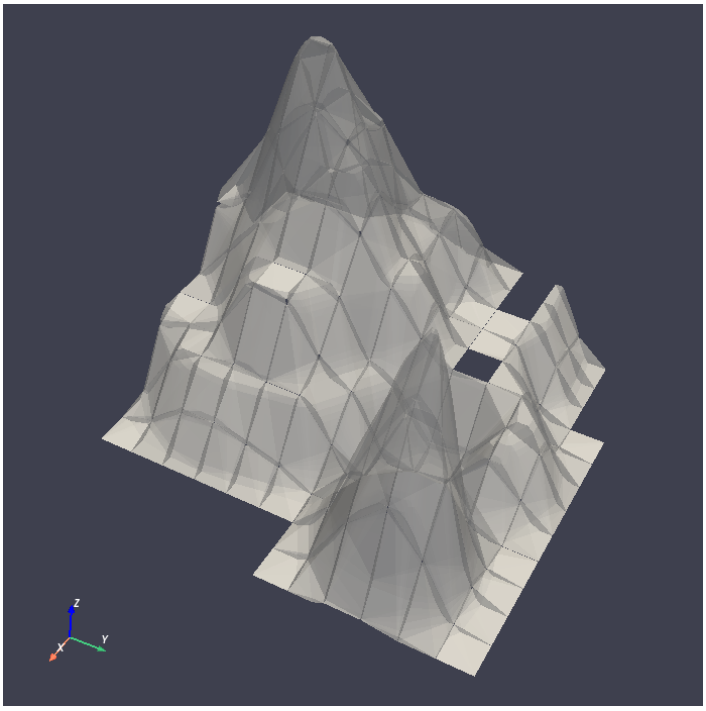

This `ImageMesh` transformation is also tested with a blurred version of the image with `cv2.blur`. A more smooth low-poly 3-D mesh is generated with this additional treatment. The topography seems more realistic:

```
img.array = cv2.blur(img.array,(60,60))    # blur the image for realiztic topography␣
↪levels
img.ImageMesh(out_file='model.obj', L_sectors = 15, trace_min=5, rel_depth = 20,␣
↪figsize=(15,12), plot='mpl')
```




For a more customizable OpenGL rendering, `img.MeshView()` may be used on the above image:

```
import voxelmap as vxm
import numpy as np
import cv2 as cv

img = vxm.Image('land.png')           # incorporate fake land topography .png file
img.array = cv.blur(img.array,(100,100))    # blur the image for realistic topography␣
↪levels

img.make()                                  # resized to 1.0x original size i.e. not␣
↪resized (default)

img.ImageMesh('land.obj',  12, 14, 1, False, figsize=(10,10))

img.MeshView( alpha=0.7,background_color='#3e404e',color='white',viewport=(700, 700))
```

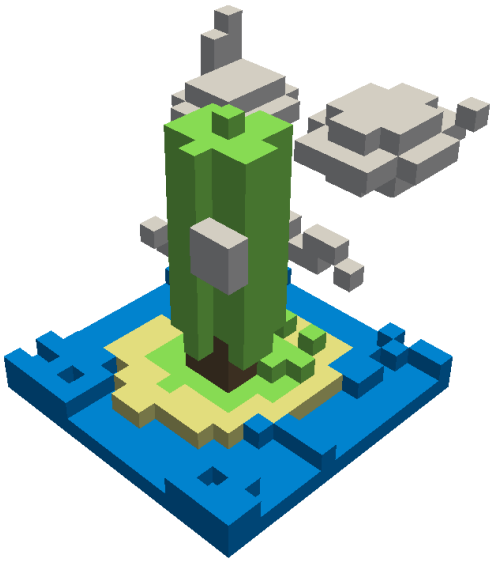


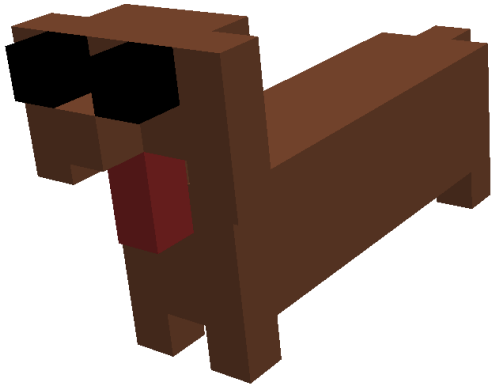
### 2.1.7 MarchingMesh : Turning Voxel Models to 3-D Mesh Representations

The `.txt` files you downloaded were exported from Goxel projects. Goxel is an open-source and cross-platform voxel editor which facilitates the graphical creation of voxel models. More information by clicking the icon link below.


We first load those `.txt` files with the below voxelmap methods:

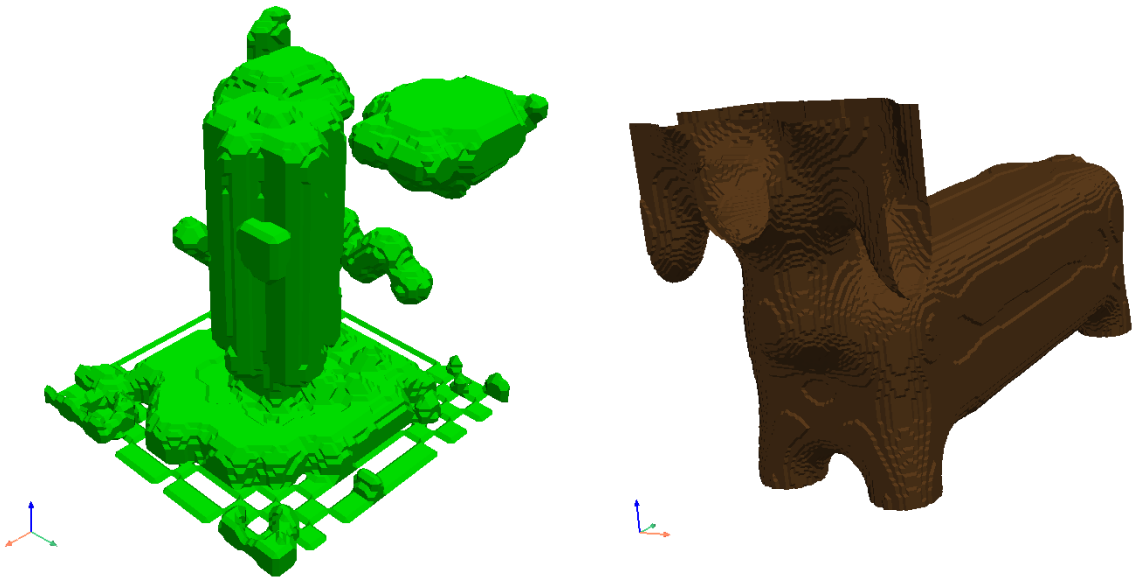
```
import voxelmap as vxm
import numpy as np

'''process argisle.txt from Goxel'''
theIsland = vxm.Model()
theIsland.load('argisle.txt')
theIsland.array = np.transpose(theIsland.array,(2,1,0))    #rotate island
theIsland.draw('custom',background_color='white')

'''process dog.txt from Goxel'''
Dog = vxm.Model()
Dog.load('dog.txt')
Dog.array = np.transpose(Dog.array,(2,1,0))     #rotate dog
Dog.draw('custom',background_color='white')
```





The voxel models can be transformed to 3D mesh representations with voxelmap's `Model().MarchingMesh` method, which uses *Marching Cubes* from the `scikit-image` Python library.

```
'''MarchingMesh on island model'''
theIsland.array = vxm.resize_array(theIsland.array,(5,5,5)) #make array larger before␣
↪mesh transformation
theIsland.MarchingMesh()
theIsland.MeshView(color='lime',wireframe=False,background_color='white',alpha=1,
↪viewport=[700,700])

'''MarchingMesh on dog model'''
Dog.array = vxm.resize_array(Dog.array,(20,20,20)) #make array larger before mesh␣
↪transformation
Dog.MarchingMesh()
Dog.MeshView(color='brown',wireframe=False,background_color='white',alpha=1,
↪viewport=[700,700])
```



Notice the `self.array` arrays were resized in both objects with the global `voxelmap.resize_array` method. This was done to avoid the formation of voids that you still see on the dog mesh above. The `MarchingMesh` method has a current limitation on small voxel models with low detail. It is not perfect, but this is an open-source package and it can always be developed further by the maintainer and/or other collaborators.

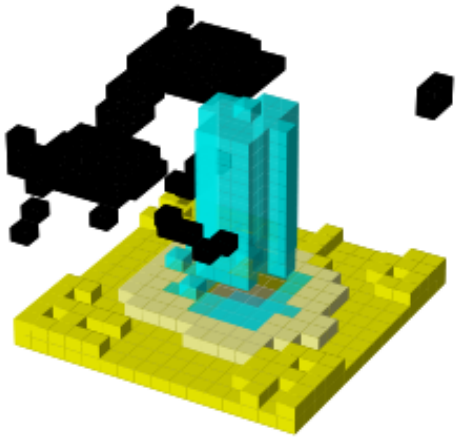
### 2.1.8 3-D Voxel Model Reprocessing

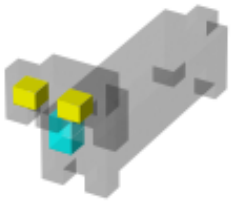
Here we do some reprocessing of the above *voxel* models. Note that here we use the `draw_mpl` method, which is `voxelmap`'s legacy method for voxel modeling and not its state-of-the-art. For faster and higher quality graphics with more kwargs / drawing options, use `voxelmap`'s `draw` method instead.

#### Re-color with custom colors

#### using the `hashblocksAdd()` method

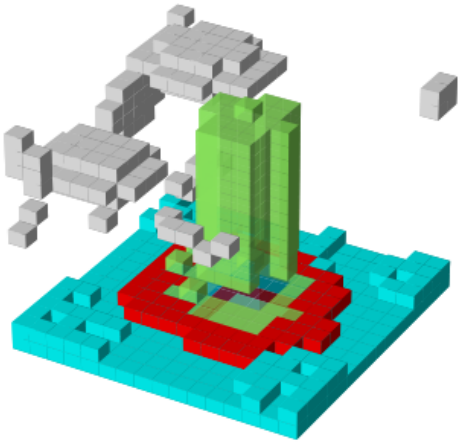
```
theIsland.hashblocksAdd(1,'yellow',1)
theIsland.hashblocksAdd(2,'#333333',0.2)
theIsland.hashblocksAdd(3,'cyan',0.75)
theIsland.hashblocksAdd(4,'#000000')

theIsland.draw_mpl('custom',figsize=(5,5))

Dog.hashblocks = theIsland.hashblocks
print('black dog, yellow eyes, cyan tongue')
Dog.draw_mpl('custom',figsize=(5,5))
```





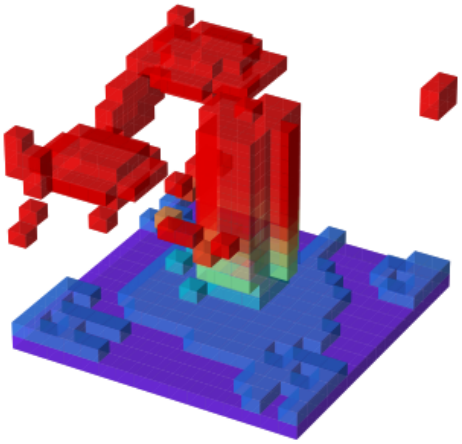
### defining them directly in the hashblocks dictionary

```
theIsland.hashblocks = {
      1: ['cyan', 1],
      2: ['#0197fd', 0.25],
      3: ['#98fc66', 0.78],
      4: ['#eeeeee', 1],
      5: ['red', 1]}

theIsland.draw_mpl('custom',figsize=(7,7))
```



### Re-color with the rainbow colormap

```
from matplotlib import cm

'draw with nuclear fill and rainbow colormap'
theIsland.colormap = cm.rainbow
theIsland.alphacm = 0.7

print('rainbow island')
theIsland.draw_mpl('linear',figsize=(7,7))
```



### Save and Load Methods for voxelmap Model objects

#### Save the ghost dog model

If you'd like to save an array with customized color assignments, you may do so now with the `Model().save()` method. This method saves the array data as a DOK hashmap and integrates this DOK hashmap with the Model.hashblocks color information in a higher-order JSON file format:

```
#re-define colors for a ghost dog
Dog.hashblocks = {
      1: ['cyan', 1],
      2: ['#0197fd', 0.25],
      3: ['#98fc66', 0.78],
      4: ['#eeeeee', 1]}

#save
Dog.save('ghostdog.json')
```

#### Load ghost dog model

The `Model().load()` method processes the array and color information to a blank Model object. To load this data into a "blank slate" and re-draw it, type the following:

```
# defines a blank model
blank = vxm.Model()
print(blank.array)
print(blank.hashblocks)

blank.load('ghostdog.json')

print(blank.array[0].shape)
print(blank.hashblocks)
blank.draw_mpl('custom',figsize=(7,7))
```

## 2.2 API Reference

### 2.2.1 Global Methods

As the methods are several, below are only listed the most pertinent global methods of `voxelmap`, in order of the lowest level to highest level of applications to 3-D modeling operations.and classified in sub-sections:

#### Load and Save

**class** voxelmap.**load_array**(*filename*)

Loads a pickled numpy array with *filename* name

**class** voxelmap.**save_array**(*array*, *filename*)

Saves an *array* array with *filename* name using the pickle module

**class** voxelmap.**tojson**(*filename*, *array*, *hashblocks={}*)

Save 3-D array and *hashblocks* color mapping as JSON file

**class** voxelmap.**load_from_json**(*filename*)

Load JSON file to object

#### Array Manipulation

**class** voxelmap.**resize_array**(*array*, *mult=(2, 2, 2)*)

Resizes a three-dimensional array by the three dim factors specified by *mult* tuple. Converts to sparse array of 0s and 1s

##### Parameters

**array**
[np.array(int,int,int)] array to resize

**mult: tuple(float,float,float)**
depth length width factors to resize array with. e.g 2,2,2 resizes array to double its size in all dims

**class** voxelmap.**roughen**(*array*, *kernel_level=1*)

Makes a 3d array model rougher by a special convolution operation. Uses *voxelmap.random_kernel_convolve*.

##### Parameters

**array**
[np.array(int,int,int)] array to *roughen up*

**kernel_level: int**
length scale (size) of random kernels used. The smallest scale (=1) gives the roughest transformation.

**class** voxelmap.**random_kernel_convolve**(*array*, *kernel*, *random_bounds=(-10, 10)*)

Applies a three-dimensional convolution with a randomly-mutating *kernel* on a 3-D *array* which changes for every array site when random_bounds are set to tuple. If random_bounds are set to False, convolution occurs in constant mode for the specified kernel.

### Parameters

**array**
[np.array(int,int,int)] array to convolve

**kernel: np.array(int,int,int)**
kernel to use for convolution. If random_bounds are set to tuple, only the kernel's shape is used to specify the random_kernels

**random_bounds**
[tuple(int,int) OR bool] see above explanation.

## Mapping

**class** voxelmap.**MarchingMesh**(*array*, *out_file='model.obj'*, *level=0*, *spacing=(1.0, 1.0, 1.0)*, *gradient_direction='descent'*, *step_size=1*, *allow_degenerate=True*, *method='lewiner'*, *mask=None*, *plot=False*, *figsize=(4.8, 4.8)*)

Marching cubes on sparse 3-D integer *voxelmap* arrays (GLOBAL)

### Parameters

**array: np.array((int/float,int/float,int/float))**
3-D array for which to run the marching cubes algorithm

**out_file**
[str] name and/or path for Wavefront .obj file output. This is the common format for OpenGL 3-D model files (default: model.obj)

**level**
[float, optional] Contour value to search for isosurfaces in *volume*. If not given or None, the average of the min and max of vol is used.

**spacing**
[length-3 tuple of floats, optional] Voxel spacing in spatial dimensions corresponding to numpy array indexing dimensions (M, N, P) as in *volume*.

**gradient_direction**
[string, optional] Controls if the mesh was generated from an isosurface with gradient descent toward objects of interest (the default), or the opposite, considering the *left-hand* rule. The two options are: – 'descent' : Object was greater than exterior – 'ascent' : Exterior was greater than object

**step_size**
[int, optional] Step size in voxels. Default 1. Larger steps yield faster but coarser results. The result will always be topologically correct though.

**allow_degenerate**
[bool, optional] Whether to allow degenerate (i.e. zero-area) triangles in the end-result. Default True. If False, degenerate triangles are removed, at the cost of making the algorithm slower.

**method: str, optional**
One of 'lewiner', 'lorensen' or '_lorensen'. Specify which of Lewiner et al. or Lorensen et al. method will be used. The '_lorensen' flag correspond to an old implementation that will be deprecated in version 0.19.

**mask**
[(M, N, P) array, optional] Boolean array. The marching cube algorithm will be computed only on True elements. This will save computational time when interfaces are located within certain region of the volume

M, N, P-e.g. the top half of the cube-and also allow to compute finite surfaces-i.e. open surfaces that do not end at the border of the cube.

**plot: bool**
plots a preliminary 3-D triangulated image if True

class voxelmap.**MeshView**(*objfile='model.obj'*, *wireframe=False*, *color='pink'*, *alpha=0.5*, *background_color='#333333'*, *viewport=[1024, 768]*)

Triangulated mesh view with PyVista (GLOBAL)

#### Parameters

**objfile: string**
.obj file to process with MeshView [in GLOBAL function only]

**wireframe: bool**
Represent mesh as wireframe instead of solid polyhedron if True (default: False).

**color**
[string / hexadecimal] mesh color. default: 'pink'

**alpha**
[float] opacity transparency range: 0 - 1.0. Default: 0.5

**background_color**
[string / hexadecimal] color of background. default: 'pink'

**viewport**
[(int,int)] viewport / screen (width, height) for display window (default: 80% your screen's width & height)

### 2.2.2 Local Methods to Model class

class voxelmap.**Model**(*array=[]*)

**MarchingMesh**(*level=0*, *spacing=(1.0, 1.0, 1.0)*, *gradient_direction='descent'*, *step_size=1*, *allow_degenerate=True*, *method='lewiner'*, *mask=None*, *plot=False*, *figsize=(4.8, 4.8)*)

Marching cubes on 3D mapped image

#### Parameters

**voxel_depth**
[int] depth of 3-D mapped image on number of voxels

**level**
[float, optional] Contour value to search for isosurfaces in *volume*. If not given or None, the average of the min and max of vol is used.

**spacing**
[length-3 tuple of floats, optional] Voxel spacing in spatial dimensions corresponding to numpy array indexing dimensions (M, N, P) as in *volume*.

**gradient_direction**
[string, optional] Controls if the mesh was generated from an isosurface with gradient descent toward objects of interest (the default), or the opposite, considering the *left-hand* rule. The two options are: – 'descent' : Object was greater than exterior – 'ascent' : Exterior was greater than object

**step_size**
[int, optional] Step size in voxels. Default 1. Larger steps yield faster but coarser results. The result will always be topologically correct though.

**allow_degenerate**
[bool, optional] Whether to allow degenerate (i.e. zero-area) triangles in the end-result. Default True. If False, degenerate triangles are removed, at the cost of making the algorithm slower.

**method: str, optional**
One of 'lewiner', 'lorensen' or '_lorensen'. Specify which of Lewiner et al. or Lorensen et al. method will be used. The '_lorensen' flag correspond to an old implementation that will be deprecated in version 0.19.

**mask**
[(M, N, P) array, optional] Boolean array. The marching cube algorithm will be computed only on True elements. This will save computational time when interfaces are located within certain region of the volume M, N, P-e.g. the top half of the cube-and also allow to compute finite surfaces-i.e. open surfaces that do not end at the border of the cube.

**plot: bool**
plots a preliminary 3-D triangulated image if True

`MeshView`(*wireframe=False*, *color='pink'*, *alpha=0.5*, *background_color='#333333'*, *viewport=[1024, 768]*)

Triangulated mesh view with PyVista

### Parameters

**objfile: string**
.obj file to process with MeshView [in GLOBAL function only]

**wireframe: bool**
Represent mesh as wireframe instead of solid polyhedron if True (default: False).

**color**
[string / hexadecimal] mesh color. default: 'pink'

**alpha**
[float] opacity transparency range: 0 - 1.0. Default: 0.5

**background_color**
[string / hexadecimal] color of background. default: 'pink'

**viewport**
[(int,int)] viewport / screen (width, height) for display window (default: 80% your screen's width & height)

`build`()

Builds voxel model structure from python numpy array

`draw`(*coloring='none'*, *geometry='voxels'*, *scalars=''*, *background_color='#cccccc'*, *wireframe=False*, *window_size=[1024, 768]*, *voxel_spacing=(1, 1, 1)*)

Draws voxel model after building it with the provided *array* with PyVista library

### Parameters

**coloring: string**

**voxel coloring scheme**

- 'custom' –> colors voxel model based on the provided keys to its array integers, defined in the *hashblocks* variable from the *Model* class
- 'custom: #8599A6' –> color all voxel types with the #8599A6 hex color (bluish dark gray) and an alpha transparency of 1.0 (default)
- 'custom: red, alpha: 0.24' –> color all voxel types red and with an alpha transparency of 0.24
- 'none' –> no coloring
- 'cool' cool colormap
- 'fire' fire colormap
- and so on…

**geometry: string**
voxel geometry. Choose voxels to have a box geometry with geometry='voxels' or spherical one with geometry='particles'

**scalars**
[list] list of scalars for cmap coloring scheme

**background_color**
[string / hex] background color of pyvista plot

**window_size**
[(float,float)] defines plot window dimensions. Defaults to [1024, 768], unless set differently in the relevant theme's window_size property [pyvista.Plotter]

**voxel_spacing**
[(float,float,float)] changes voxel spacing by defining length scales of x y and z directions (default:(1,1,1)).

`draw_mpl`(*coloring='custom'*, *edgecolors=None*, *figsize=(6.4, 4.8)*, *axis3don=False*)

Draws voxel model after building it with the provided *array* (Matplotlib version. For faster graphics, try the `draw()` method (uses PyVista)).

### Parameters

**coloring: string**

**voxel coloring scheme**

- 'custom' –> colors voxel model based on the provided keys to its array integers, defined in the *hashblocks* variable from the *Model* class
- 'custom: #8599A6' –> color all voxel types with the #8599A6 hex color (bluish dark gray) and an alpha transparency of 1.0 (default)
- 'custom: red, alpha: 0.24' –> color all voxel types red and with an alpha transparency of 0.2
- 'nuclear' colors model radially, from center to exterior
- 'linear' colors voxel model vertically, top to bottom.

**edgecolors: string/hex**
edge color of voxels (default: None)

**figsize**
[(float,float)] defines plot window dimensions. From matplotlib.pyplot.figure(figsize) kwarg.

**axis3don: bool**
defines presence of 3D axis in voxel model plot (Default: False)

`hashblocksAdd`(*key*, *color*, *alpha=1*)

Make your own 3-D colormap option. Adds to hashblocks dictionary.

### Parameters

**key**
[int ] array value to color as voxel

**color**
[str] color of voxel with corresponding *key* index (either in hexanumerical # format or default python color string)

**alpha**
[float, optional] transparency index (0 -> transparent; 1 -> opaque; default = 1.0)

`load`(*filename='voxeldata.json'*, *coords=False*)

Load to Model object.

### Parameters

**filename: string (.json or .txt extensions (see above))**
name of file to be loaded (e.g 'voxeldata.json')

**coords: bool**
loads and processes self.XYZ, self.RGB, and self.sparsity = 10.0 (see Model class desc above) to Model if True. This boolean overrides filename loader option.

`save`(*filename='voxeldata.json'*)

Save sparse array + color assignments Model data as a dictionary of keys (DOK) JSON file

### Parameters

**filename: string**
name of file (e.g. 'voxeldata.json') Data types: .json -> voxel data represented as (DOK) JSON file .txt -> voxel data represented x,y,z,rgb matrix in .txt file (see Goxel .txt imports)

### 2.2.3 Local Methods to Image class

class voxelmap.**Image**(*file=''*)

**ImageMap**(*depth=5*)

Map image to 3-D array

#### Parameters

**depth**
[int] depth in number of voxels (default = 5 voxels)

**ImageMesh**(*out_file='model.obj'*, *L_sectors=4*, *rel_depth=0.5*, *trace_min=5*, *plot=True*, *figsize=(4.8, 4.8)*, *verbose=False*)

3-D triangulation of 2-D images with a Convex Hull algorithm (Andrew Garcia, 2022)

#### Parameters

**out_file**
[str] name and/or path for Wavefront .obj file output. This is the common format for OpenGL 3-D model files (default: model.obj)

**L_sectors: int**
length scale of Convex Hull segments in sector grid, e.g. L_sectors = 4 makes a triangulation of 4 x 4 Convex Hull segments

**rel_depth: float**
relative depth of 3-D model with respect to the image's intensity magnitudes (default: 0.50)

**trace_min: int**
minimum number of points in different z-levels to triangulate per sector (default: 5)

**plot: bool / str**
plots a preliminary 3-D triangulated image if True [with PyVista (& with matplotlib if plot = 'img')

**MarchingMesh**(*voxel_depth=12*, *level=0*, *spacing=(1.0, 1.0, 1.0)*, *gradient_direction='descent'*, *step_size=1*, *allow_degenerate=True*, *method='lewiner'*, *mask=None*, *plot=False*, *figsize=(4.8, 4.8)*)

Marching cubes on 3D-mapped image

#### Parameters

**voxel_depth**
[int] depth of 3-D mapped image on number of voxels

**level**
[float, optional] Contour value to search for isosurfaces in *volume*. If not given or None, the average of the min and max of vol is used.

**spacing**
[length-3 tuple of floats, optional] Voxel spacing in spatial dimensions corresponding to numpy array indexing dimensions (M, N, P) as in *volume*.

**gradient_direction**
[string, optional] Controls if the mesh was generated from an isosurface with gradient descent toward objects of interest (the default), or the opposite, considering the *left-hand* rule. The two options are: * descent : Object was greater than exterior * ascent : Exterior was greater than object

**step_size**
[int, optional] Step size in voxels. Default 1. Larger steps yield faster but coarser results. The result will always be topologically correct though.

**allow_degenerate**
[bool, optional] Whether to allow degenerate (i.e. zero-area) triangles in the end-result. Default True. If False, degenerate triangles are removed, at the cost of making the algorithm slower.

**method: str, optional**
One of 'lewiner', 'lorensen' or '_lorensen'. Specify which of Lewiner et al. or Lorensen et al. method will be used. The '_lorensen' flag correspond to an old implementation that will be deprecated in version 0.19.

**mask**
[(M, N, P) array, optional] Boolean array. The marching cube algorithm will be computed only on True elements. This will save computational time when interfaces are located within certain region of the volume M, N, P-e.g. the top half of the cube-and also allow to compute finite surfaces-i.e. open surfaces that do not end at the border of the cube.

**plot: bool**
plots a preliminary 3-D triangulated image if True

`MeshView`(*wireframe=False*, *color='pink'*, *alpha=0.5*, *background_color='#333333'*, *viewport=[1024, 768]*)

MeshView: triangulated mesh view with PyVista

### Parameters

**objfile: string**
.obj file to process with MeshView [in GLOBAL function only]

**wireframe: bool**
Represent mesh as wireframe instead of solid polyhedron if True (default: False).

**color**
[string / hexadecimal] mesh color. default: 'pink'

**alpha**
[float] opacity transparency range: 0 - 1.0. Default: 0.5

**background_color**
[string / hexadecimal] color of background. default: 'pink'

**viewport**
[(int,int)] viewport / screen (width, height) for display window (default: 80% your screen's width & height)

`make`()

Turn image into intensity matrix i.e. matrix with pixel intensities

`resize`(*res=1.0*, *res_interp=3*)

Resize the intensity matrix of the provided image.

### Parameters

**res**
: [float, optional] relative resizing percentage as *x* times the original (default 1.0 [1.0x original dimensions])

**res_interp: object, optional**
: cv2 interpolation function for resizing (default cv2.INTER_AREA)

---

*voxelmap*

---

## voxelmap

CHAPTER

THREE

# WHITEPAPERS

## 3.1 ImageMesh : A Convex Hull based 3D Reconstruction Method

**Andrew R. Garcia**

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### 3.1.1 Abstract:

ImageMesh is a method available in versions $\geq$ 2.0 of the voxelmap Python library that generates 3D models from images using Convex Hull in 3-D to enclose external points obtained from a series of partitioned point clouds. These point clouds are generated by assigning the relative pixel intensities from the partitioned images as the depth dimension to the points. In this paper, we describe the limitations of the original ImageMesh method and the quick solution we have implemented to address them. Additionally, we introduce MeshView, a Python visualization tool developed in tandem with ImageMesh that provides a convenient way to visualize the 3D models generated by ImageMesh. Finally, we discuss the GPU memory space complexity of both methods.

### 3.1.2 Introduction:

ImageMesh is a 3D reconstruction method. It utilizes Convex Hull in 3-D to enclose external points obtained from a series of partitioned point clouds, which are generated by assigning the relative pixel intensities from the partitioned images as the depth dimension to the point clouds. ImageMesh generates 3-D model .obj files from images by drawing the smallest collection of triangular polygons that satisfies this rule in three-dimensional space. In simpler terms, it's like placing a fabric over a 3-D object. However, it is important to note that a single convex hull operation may fail to draw a structure with holes or bumps, which are essentially 2-D local extrema.

To address this limitation, we have implemented a quick solution that involves partitioning the input image into multiple segments and placing 3-D convex hull "sheets" on each segment to perform triangulation.

Fig. 1: An image of a crochet donut

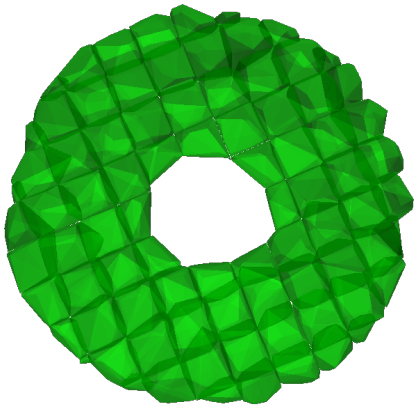
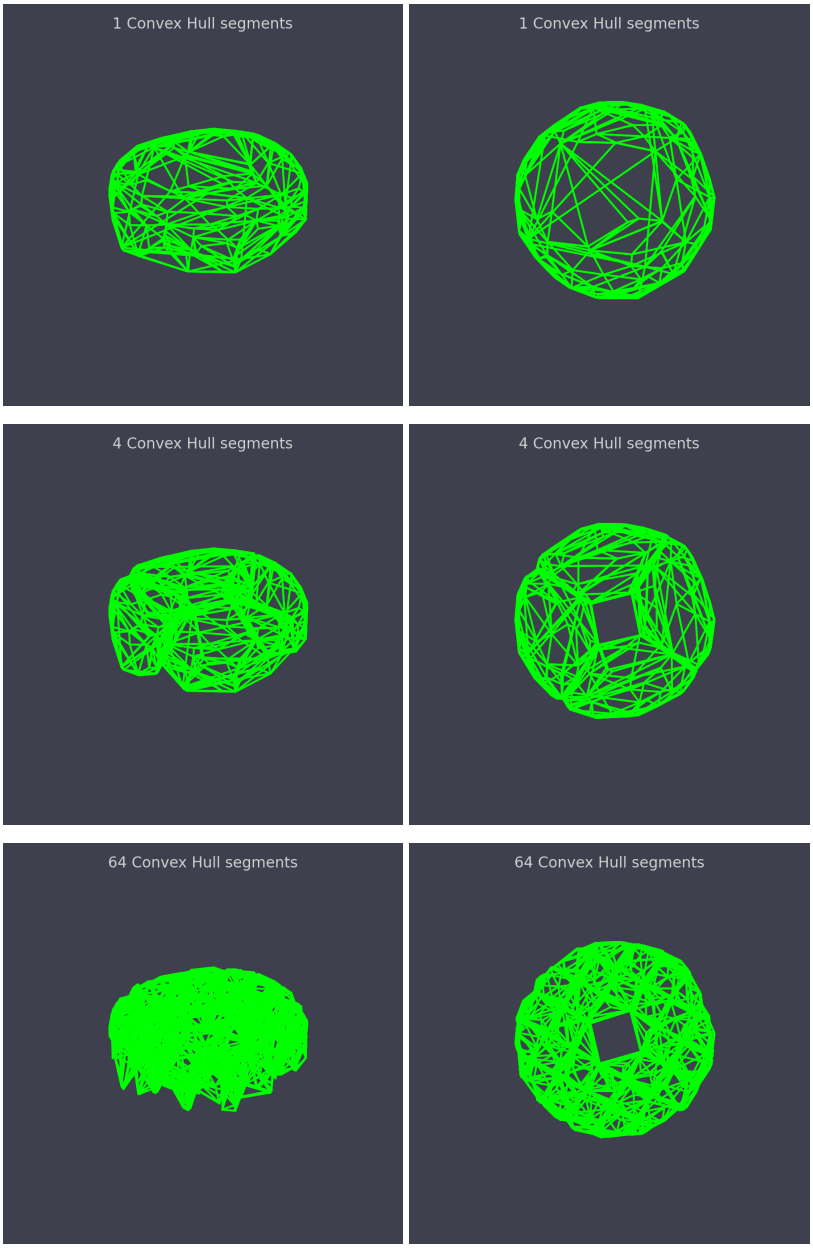


Fig. 2: 3-D reconstruction of donut image with ImageMesh




Complementing ImageMesh is MeshView, a Python visualization tool developed in tandem to provide a convenient way to visualize the 3D models generated by ImageMesh. MeshView is capable of loading the .obj files generated by ImageMesh and rendering them in a PyVista VTK window, allowing for interactive 3D visualization of the models

### 3.1.3 GPU Memory Space Complexity:

In this section, we will discuss the GPU memory space complexity of the two methods used in ImageMesh. The voxel-per-pixel method used in earlier versions of ImageMesh involves rendering a cube from every "n" input point, with each cube comprising 12 triangles in computer graphics. As a result, the GPU space complexity of this method is $\mathcal{O}(12n)$

To improve on this method, the new Convex Hull method uses the input points as vertices to form triangles that make up a polyhedron in 3-D space. Additionally, this method partitions the image into "s" sectors to increase resolution. The space complexity of the new method approximates to $\mathcal{O}(n\sqrt{s}/3)$ , which is significantly lower than the voxel-per-pixel method.

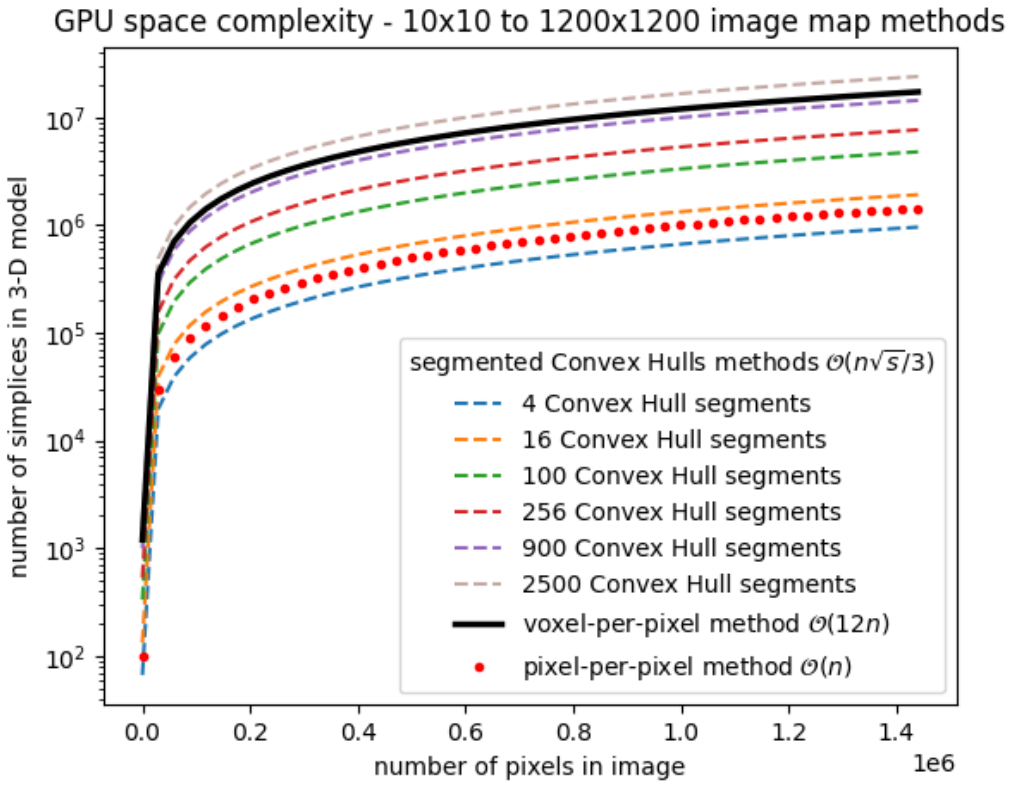



Fig. 3: Space complexity for graphics represented by the number of simplices made for the 3-D model from an image with "x" number of pixels.

In simpler terms, the new method reduces the amount of GPU memory required to generate 3D models from images, making it more efficient and scalable for large datasets. This reduction in GPU memory space complexity is a significant advantage of the Convex Hull method over the voxel-per-pixel method.

### 3.1.4 Conclusion:

ImageMesh, coupled with MeshView, provides a powerful and efficient 3D reconstruction method. By implementing the Convex Hull-based method with partitioning, we have addressed the limitation of a single convex hull operation and increased the resolution of the reconstructed 3D models. With the reduction in GPU space complexity, the new method has become more practical for real-world applications.

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