Virtual Worlds User Guide

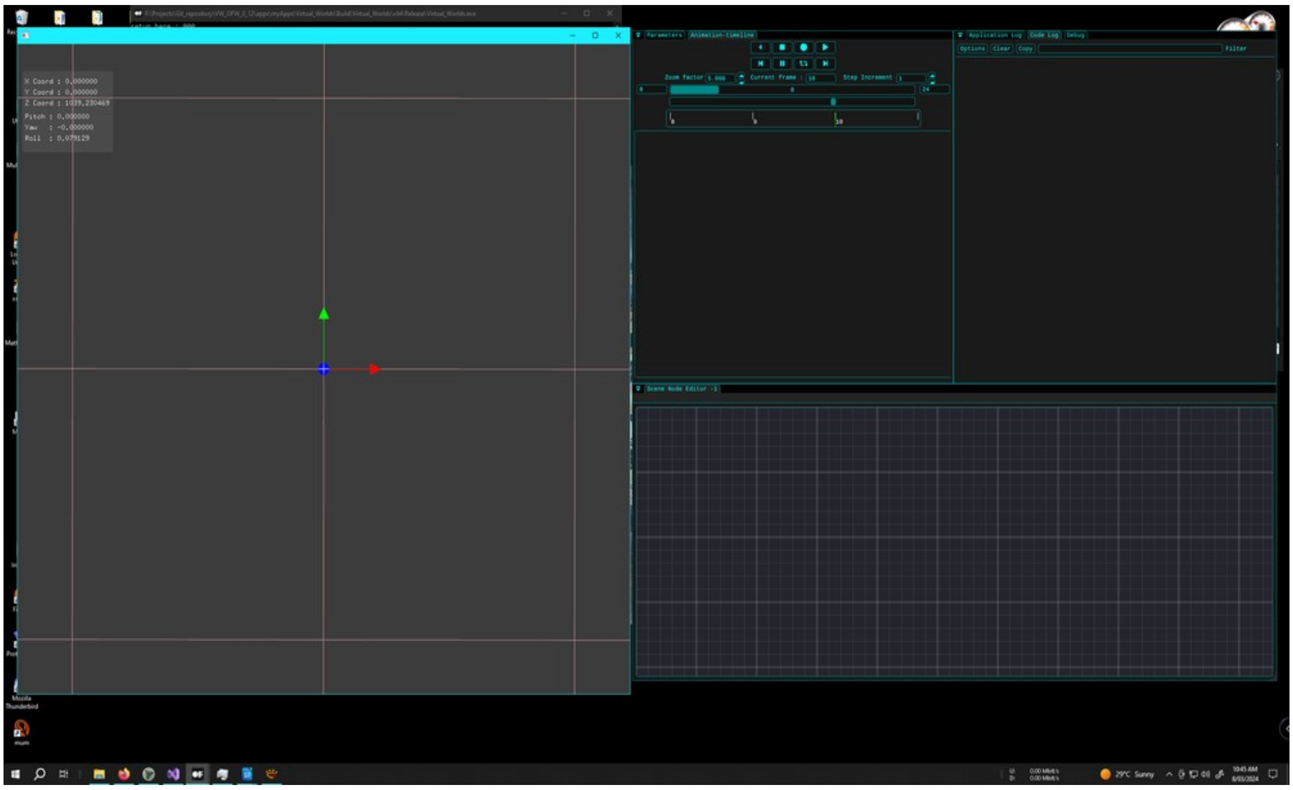
Introduction :

The Virtual Worlds application as it is implemented as of March 2024 is not in intended to be a fully functional production ready application at this time. It is, at this time, intended to be a functioning application to act as a base for further development and demonstrate the idea of using a different form of 3D voxel geometry and coordinate system that departs from the conventional cubic voxels that are used widely in many areas of computer computation and simulation.

In 3D space, for any one cubic voxel, the distance between its center and that of every neighbour around it is not the same. However, a 3D space that does have a structure where the center of any location in that space is of equal distance to all its neighbours is that of a hexagonal close packed spheres of equal radius, where the geometric shape of a Trapezo-rhombic dodecahedral can be arranged in such a manner that it forms a space filling geometry that can be utilised as a voxel.

It is of the view that a HCP sphere structure is superior than a cubic structure for use in procedural generation of geometric shapes, to simulate 3D environments and for cellular automata. Virtual Worlds had the initial ambition to be an application that generates procedural landscapes of a fractal nature utilising voxels and point clouds, hence the name. That ambition may not come to pass, but as a more practical purpose, and wanting to give and share something that could not be found elsewhere in my searches, is a demonstration of how a HCP Trapezo-rhombic dodecahedral voxel model can be implemented.

01.0 Application Overview



X Coord : 0.000000
Y Coord : 0.000000
Z Coord : 1039.230469
Pitch : 0.000000
Yaw : -0.000000
Roll : 0.079129

Fig 01.0.1

The Virtual Worlds application executable and all required files is located in the File Directory Build/Virtual_Worlds/x64/Release of the Virtual_Worlds project. All these files need to be copied to any other directory path if the user wishes to run it elsewhere.

By starting up the application, the application main user interface similar to the image given in **Fig 01.0.1** should appear.

On the left is the view port in which the 3D objects of the scene will be rendered.

On the right is the main application user interface. This user interface panels are dockable and may appear different in the arrangement of the panels according to user preference. The ImGui system that forms the basis of the GUI may interfere with the communication of widgets or user interaction between them. If any problems encountered, just redock to overcome.

The user interface composes of the following panels

Node Editor panel : Is where all of the entity objects in the scene and functions or operations on them are created, deleted, imported, or saved, and are represented as a graphical node or rectangle box. This node editor is much similar many other node editors in its function to selects, display, link, and manage nodes.

Parameters Panel : Is where the parameter and variables data is displayed on the current selected scene entity object that is designated in the node editor panel, and settings for the view port display, camera and scene lights. The user, through the widgets displayed in this panel can make changes to the parameters and variables displayed in this panel , and/or perform tasks or actions that generate or modify graphical or other data to be displayed in the view port.

View port : Is where the view of the objects that are made visible in the scene are displayed, and where the user can interact with the viewer camera to move about the scene. A central cross hairs, camera information and navigational overlay are displayed with an initial x-y axis reference grid.

Timeline Panel : Is a control panel where the user can perform animations of the objects in the scene based upon the timeline tracks for specific scene and node elements that have been assigned to them.

Application Logger : Is where any messages that the application issues to inform the user of any application status are displayed.

Shader Logger : Is where any opengl shader compilation error messages that are generated while compiling shader code are displayed.

01.1 The Node Editor

The node editor is generally the first point on startup of where the user will go. Is where all of the entity objects in the scene and functions or operations on them are created, deleted, imported, or saved, and where the management of scene objects is performed.

The Node editor is ImGUI based in its operation and thus faces many of the limitations and restrictions that ImGUI invokes.

To get started, clicking the right mouse button and releasing it will display a floating menu. Within this floating menu should be options to create a 3D data object, a group node and some other options.

Like most node editors, if nodes and their associated ports and links are displayed within the node editor, the user can left click on a node to move it, or a node port to create a link between nodes. As with most node editors, inputs are on the left side of the node, and outputs on the right.

By left clicking on a node to select it, the parameters panel will display a parameter widget with all the settings, data and functionality appropriate to the node selected. The user can then go to the parameter panel and perform any changes and/or tasks presented. Also after selecting a node, if the user right clicks on the node and releases it while it is selected, a floating menu specific to that node will appear for the user to interact with.

If the user moves the mouse cursor over a link and left clicks it select it, and the presses the right mouse button and releases it, a floating menu relevant to that link appears for the user to take action.

If the user moves the mouse cursor over a node pin (port) and left clicks it select it, and the presses the right mouse button and releases it, a floating menu relevant to that pin appears for the user to take action.

A special node called a group node can be created to open a child node editor of the current node editor. This group node editor is used to manage a scene of large nodes in a more manageable form. This group node node editor will behave just like the prim root node editor in every way except it will have two special nodes that are used to import and export link data to and from this group node. This is so a group node can act as if it is a single node.

If the user creates a group node, after selecting it, if the user makes a right double click, the node editor for that group node will be made visible for the user to use. Other wise a single right click will bring up a floating menu as with any node.

To deselect every thing, move the mouse cursor to a location within the node editor where no node editor entity lies beneath it and click the left mouse button.

02.0 Generating a HCP voxel object

HCP voxel objects are generated using a text file with an OpenGL compute shader program. So before doing anything else, the user needs to create or have an opengl compute shader program source code text file to use. Virtual worlds already has some examples available for use in the examples directory of where the Virtual_Worlds executable is located. To find out how to create a Virtual Worlds compute shader code, see the documentation on how to do this in the section writing a compute shader program.

To generate a HCP voxel object, move the mouse cursor to within the node editor described in section 01.1 and right mouse click over an empty region where one wishes to place a node to represent a HCP voxel object and release it.

A floating menu should appear with the option Main Menu. Move the mouse cursor over this option to display a sub menu. One of these options should be Create Node …. Move the mouse cursor over this menu option and another sub menu should appear with a menu option HCP Voxel …. Move the mouse cursor over this menu option and yet another last sub menu will appear with one option being create HCP Voxel node.(fig 02.0.1). Left click with the mouse on this option, and where the mouse cursor was placed in the node editor should be a HCP Voxel node similar to fig 02.0.2

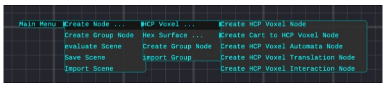


Fig 02.0.1

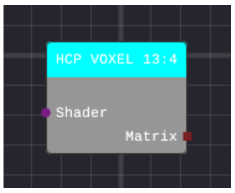


Fig 02.0.2

Move the mouse over this newly created node, select it using the left mouse button. In the parameters panel, select the tab with the label object. Within this object tab widget, more tab widgets should appear. Select the tab with the label Generation. A widget as in fig 02.0.3 should be displayed. The parameters in this widget required to generate the HCP voxel data. From top to bottom

Expression button : to select the virtual worlds OpenGL compute shader program file that generates the HCP voxel data.

Definition of the x-y-z volume limits of that the HCP voxel volume generation is to be confined to.

Compute invocation is a number that is relevant to the OpenGL compute shader process where the number indicates the number of threads running in parallel is used in the calculation. Generally from documentation, the higher numbers are used if have a large number of calculations to be performed.

Execute button : Generate the HCP voxel data. Only press when everything is ready.

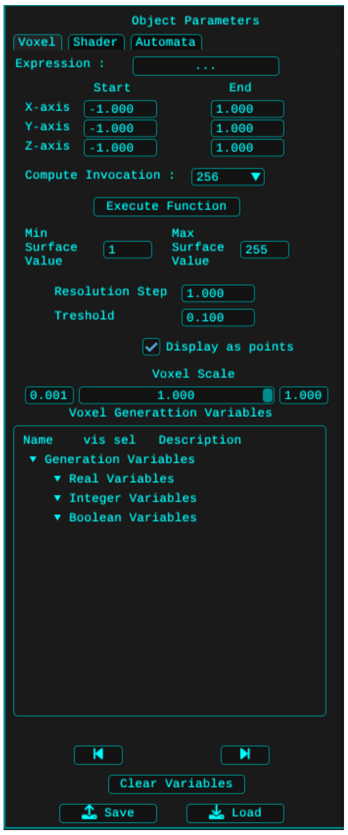
Min/Max surface values : These are the minimum and maximum permissible values that the voxels can posses to be designated as a valid voxel to be stored in computer memory and displayed on screen. At the time of this documentation, this should be left as the defaults as any other value may not work Something for a future update.

Resolution step : Basically, this is the spacing between each HCP voxel.

Threshold : Generation of HCP voxels is of the form voxel value = F(x,y,z) and the threshold is the minimum absolute value that this voxel value can have to be considered as a valid voxel to be stored in computer memory.

Display as points : Change the display of the generated data from points to voxels. This display is determined by the shader program and parameters that are defined in the the shader tab widget which is discussed below.

Voxel Scale : Widget to scale the HCP widget size when nwhen it is selected to not display the data as points.


Object Parameters

Voxel | Shader | Automata

Expression : ...

	Start	End
X-axis	-1.000	1.000
Y-axis	-1.000	1.000
Z-axis	-1.000	1.000

Compute Invocation : 256

Min Surface Value 1 | Max Surface Value 255

Resolution Step 1.000

Treshold 0.100

✓ Display as points

Voxel Scale 0.001 | 1.000 | 1.000

Voxel Generattion Variables

Name vis sel Description
- Generation Variables
  - Real Variables
  - Integer Variables
  - Boolean Variables

Fig 02.0.3

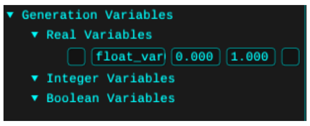
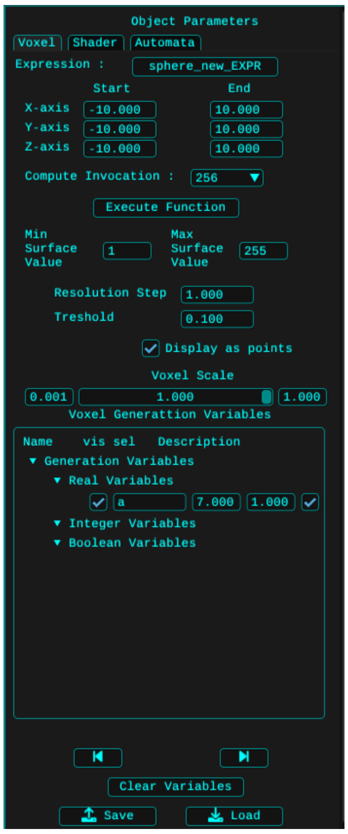

- Generation Variables
  - Real Variables
    - float_var | 0.000 | 1.000
  - Integer Variables
  - Boolean Variables

Fig 02.0.4


Object Parameters

Voxel | Shader | Automata

Expression : sphere_new_EXPR

	Start	End
X-axis	-10.000	10.000
Y-axis	-10.000	10.000
Z-axis	-10.000	10.000

Compute Invocation : 256

Min Surface Value 1 | Max Surface Value 255

Resolution Step 1.000

Treshold 0.100

✓ Display as points

Voxel Scale 0.001 | 1.000 | 1.000

Voxel Generattion Variables

Name vis sel Description
- Generation Variables
  - Real Variables
    - ✓ a | 7.000 | 1.000 ✓
  - Integer Variables
  - Boolean Variables

Fig 02.0.4

Voxel Generation Variables : A set of widgets that enable the user to manage and view the set of variables that are used to generate the volume of voxels within the volume as defined in the parameters above this widget. Any variables defined here must have an equivalent uniform shader variable that is defined in the compute shader program code that is used to generate the voxel volume or there will be a shader compilation error and no voxel volume generated.

Left and Right control buttons : These Buttons perform a decrement and increment of one or more of the variables defined in the voxel generations widget to be changed by a given step value, and then regenerate the voxel volume and display it on screen.

Clear variables button : Clears all the voxel generation variables

Save : Opens a dialog window to save the voxel parameters defined in this widget to a formatted text file of suffix .vgp (Voxel generation parameters)

Load : Opens a dialog window for the user to select a voxel generation parameters (.vgp) formatted text file to be imported into the application, and the values displayed in this widget ready to be used.

The details of creating a voxel generating compute shader program to be selected for use here is in the section Create Voxel Compute Shader Program. For the present as this is an overview of generating a voxel volume and displaying it, it is only required for the user to select an existing example.

Step vg01 : Select the Expression Button at the top of this widget to bring up the file load dialogue.

Step vg02 :Navigate to the Examples/Generation/HCP_Voxels/ directory that the Virtual Worlds application resides in and select the file name sphere_new_EXPR.txt.

The button name should now be changed to sphere_new_EXPR. If not repeat steps vg01 and vg02 above.

Step vg03 : To define the volume that the HCP voxels will be generated over, change all of the start x,y,z, values to -10, and the end values to 10

Step vg04 : Go to the voxel generation variables section and with the mouse cursor, navigate to and hover over the Real Variables tree node widget to highlight it. Press the right mouse button to bring up the only available floating menu option "add variable" and select it to create a new real (ie floating) variable.

The variable widget that is displayed (fig 02.0.4) is the same for all float and integer shader variables. From left to right.

Checkbox to indicate if the variable is defined and to be used in the shader program.

Select and left mouse click to enable this variable to be used in the voxel generation compute shader.

Name of the variable that is defined in the voxel generation compute shader code.

Select the text input widget and change the name to a.

The initial or set value that this variable is defined to be assigned to.

Select the floating number input widget and type in the value 7.0

The next floating point input widget is the incremental step value to change the variable by as a step action if the increment or decrement button is selected.

The default is 1.0 and this can be left as it is.

The last checkbox widget is to indicate to the application if the step variable is to be used or not when performing incremental or decremental steps operations.

Select and set this widget to enable the step variable to be used.

The voxel generation panel should now look like that of Fig 02.0.4.

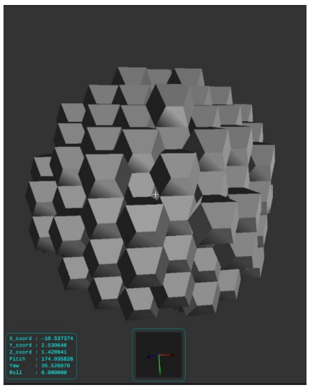
The generation of a simple HCP voxel sphere can be performed.

Step vg05 : Press the button labelled “Execute Function”

This will generate a HCP voxel point cloud of data, and in the viewer panel to the right of this voxel generation widget will be displayed some points that represent the centers of a the HCP Trapezo-rhombic dodecahedral shaped Voxels. These points are the centers of the equally spaced 3D hexagonal close packed spheres of radius.

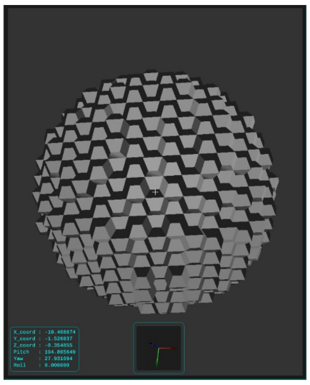
To see the HCP Trapezo-rhombic dodecahedral shaped Voxels, navigate the mouse to the checkbox labelled “Display as points” and uncheck it. A black or dark shape should now appear in the viewer panel.

This is a rather low resolution generation of a sphere and may look rather blocky or not spherical enough. To get a higher resolution and a more spherical shaped generated voxel volume, go to the resolution step number input widget and enter 0.5, and then press the execute function. A new generation of the voxel volume will be performed and replace the previous generation. What now appears in the viewer panel should look similar to Fig 4b.



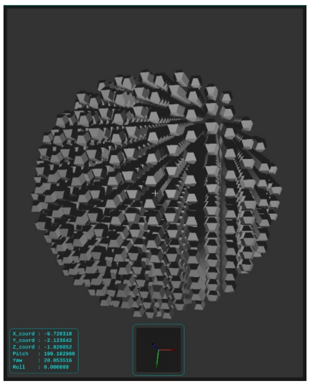
```
X_coord : -10.537374
Y_coord : 2.530648
Z_coord : 1.428941
Pitch   : 174.035828
Yaw     : 36.526070
Roll    : 0.000000
```

Fig 4a



```
X_coord : -10.466674
Y_coord : -1.520837
Z_coord : -0.354855
Pitch   : 194.805649
Yaw     : 27.931694
Roll    : 0.000000
```

Fig 4b



```
X_coord : -9.728318
Y_coord : -2.123642
Z_coord : -1.820852
Pitch   : 199.102966
Yaw     : 20.053516
Roll    : 0.000000
```

Fig 4c

From here the user can then experiment with the generation variable that has been defined in step vg04. As defined, the variable a is actually the radius of this sphere. If one were to change the value of the variable a from 7.0 to some other value, and then press the Execute Function button, a new HCP voxel sphere would be created of that radius.

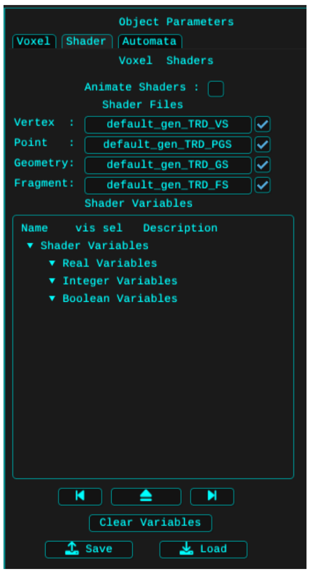
The other option to explore changing the variable is to change its value by stepping incrementally up or down by selecting the left and right control buttons. If the user were to press either of these, the value of the variable a would change by the step value defined as explained above. At this point, it is left to the user to explore performing this task to see how it works. Beware that if the leftmost checkbox is not in enable mode the generation will fail and a compute shader error message will be displayed in the bottom right code log.

The integer variable is the same in functionality as the real variable except that it is for integer generation compute shader variables. The boolean compute shader variable is for boolean variables and cannot have step functionality. Note : If any variable is added, deleted or any change is made to any of the variables activity, or name, then the Execution Function button will need to be pressed so as to recompile the compute shader program and generate the voxel volume data.

If the user would like to see the voxels resized to reveal the voxels on the interior of the sphere, by selecting and moving the voxel scale slider, the voxels will be resized. (fig 4c) This does not regenerate any voxels.

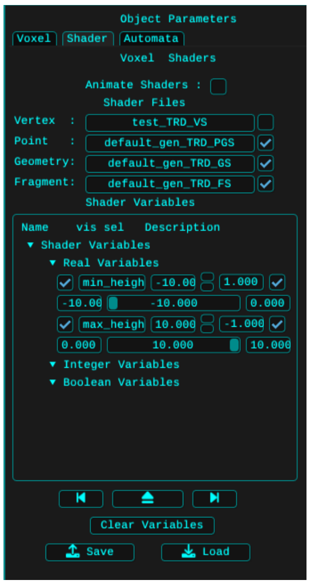
Without going into the detail of how to code a voxel generating compute shader program, this is basically all that is needed to be able to generate a HCP voxel volume of point data and view it on screen.

If the user so wishes, by pressing the save button, the user can select a directory and file name to save the defined parameters here for later use.



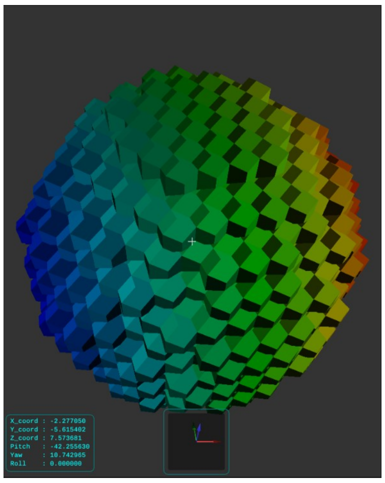
```
Object Parameters
Voxel | Shader | Automata
Voxel  Shaders
Animate Shaders : ☐
Shader Files
Vertex   :  default_gen_TRD_VS   ✓
Point    :  default_gen_TRD_PGS  ✓
Geometry:   default_gen_TRD_GS   ✓
Fragment:   default_gen_TRD_FS   ✓
Shader Variables
Name   vis sel   Description
▾ Shader Variables
   ▾ Real Variables
   ▾ Integer Variables
   ▾ Boolean Variables
Clear Variables
Save   Load
```

Fig 5a



```
Object Parameters
Voxel | Shader | Automata
Voxel  Shaders
Animate Shaders : ☐
Shader Files
Vertex   :  test_TRD_VS          ☐
Point    :  default_gen_TRD_PGS  ✓
Geometry:   default_gen_TRD_GS   ✓
Fragment:   default_gen_TRD_FS   ✓
Shader Variables
Name   vis sel   Description
▾ Shader Variables
   ▾ Real Variables
      ✓ min_heigh  -10.00    1.000  ✓
      -10.00    -10.000      0.000
      ✓ max_heigh  10.000   -1.000  ✓
      0.000      10.000     10.000
   ▾ Integer Variables
   ▾ Boolean Variables
Clear Variables
Save   Load
```

Fig 5b



```
X_coord : -2.277050
Y_coord : -5.615402
Z_coord : 7.573681
Pitch   : -42.255630
Yaw     : 10.742965
Roll    : 0.000000
```

Fig 5c

02.1 Visualising HCP voxel object

Any HCP Voxel generated object being displayed on screen utilises an OpenGL shader program. The points and HCP Trapezo-rhombic dodecahedral shaped Voxels are dsiplayed on screen using a default shader program. Both of these can be substituded to obtain more advanced imagery by using a user defined shader program. This will be a brief description of how a given user defined program can be used without going into the details to much.

From the voxel parameters panel, select the Shader tab to bring up a widget as in fig 5a.This widget enables the user to select the shaders to use to display the HCP voxels onto the screen, and just like with the compute shader variables explained in the section Generating a HCP voxel object, the user can change the values of a shader variable with one exception. The user can use a slider widget to change a variable value.

From top to bottom

Vertex, geometry and fragment shaders : A set of buttons that are used just as the Expression button was in the Voxel generation tab widget. To select a user defined shader code file to generate a shader program.

Shader uniform Variables : This operates exactly as described for the compute shader variables with an additional slider widget to interactively change variable values for the real and integer variables.

Left and Right control buttons : These Buttons perform a decrement and increment of one or more of the variables defined in the shader widget to be changed by a given step value.

Generate Shader button : This is the button between the increment and decrement buttons. When any shader variable is added, deleted, renamed or activated etc, this button needs to be pressed to regenerate the shader program. If there is a compilation error, such as a variable name not found in the nominated shader programs above, the compilation error will be displayed in the code log panel, bottom right of the application.

Clear variables button : Clears all the shader variables

Save : Opens a dialog window to save the shader parameters defined in this widget to a formatted text file of suffix .twm.

Load : Opens a dialog window for the user to select a shader parameters (.twm) formatted text file to be imported into the application and the values displayed in this widget ready to be used.

To change to a less bland visualisation.

Step vv01 : Press the vertex shader button labelled “Default_gen_TRD_VS” and navigate to the directory in which the application executable resides Examples/Shader/HCP_Voxel/ and select the vertex shader code file test_TRD_VS.glsl.

Step vv02 : Go to the Shader variables widget and as done with defining a voxel generation real variable, create two variables here. Define one with the name min_height, and the other with max_height. Check all the enable check boxes, and assign for the min_height variable , a value of -10.0, and a step value of 1.0. A variable slider will be visible below these widgets. The left float input widget is the minimum range value of this variable, and the right, its maximum. Enter -10.0 for the minimum, and 0.0 for the maximum. For the max_height variable, enter a value of 10.0, a step value of 1.0, and a slider min and max range value of 0.0 and 10.

This shader widget should appear as in fig 5b. The voxel display shader program can now be generated and the HCP voxel display updated to the functionality as defined by the shader code of the defined shader types.

Step vv03 : Press the generate shader button (middle button with up arrow). If the display disappears (it should not as this problem has been fixed) it is due to a programming bug having the voxel size set to zero. Just go back to the voxel generation tab widget and move the voxel scale slider to display the voxels. A view similar to fig 5c should now appear in the viewer panel.

What the user can now do is move the variable sliders to change the min and max values that are displayed as a color range of the voxels. If the user now selects the increment and decrement buttons, the user will fin that both variable values will change in the same step. If any of the step check boxes for enabling the step action is disabled, that variable will not change while any that are active will.

If the user so wishes, by pressing the save button, the user can select a directory and file name to save the defined parameters here for later use.

This is a basic demonstration of the use of this shader widget. It is intended that the user can create new or use many a variety of shaders to display voxel volume data. The HCP Trapezo-rhombic dodecahedral shaped Voxels are actually drawn using the default geometry shader as only the point data that is observed by enabling the display as points checkbox in the voxel shader widget. It is envisaged that with more development, a whole series of different shader code will be created.

02.2 HCP voxel Cellular Automata

One purpose of creating the HCP spacial data structure and this application is to implement a usage of cellular automata for the purpose of simulation and modelling of real world phenomenon or pure experimental and fractal exploration.With the ability to define any set of simple rules, an infinite realm of possible behaviours can be explored for computer graphics, art or science. The HCP Voxel 3D spacial data structure has the advantage over conventional cubic voxel modelling in that the center of every neighbour of any voxel is of equal distance as the neighbours of a cubic voxel sharing one or more vertex points is not.

HCP voxel cellular automata is implemented as a node in the node editor, which needs to be linked to a HCP voxel generated scene object. To create a hcp cellular automata node, in the node editor where one wishes to place a hcp cellular automata node, right click with the right mouse button and release to bring up the floating menu, and and navigate through the menu to the menu option

Main Menu→Create Node ...→HCP Voxel … → Create HCP Voxel Automata Node.

A HCP vocel automata node should be created. Make a node editor link from the hcp voxel node created above matrix output pin on the right of the node to the hcp automata input matrix pin on the left of the cellular automata node.

Select the cellular automata node to bring up a widget as in fig 6a in the parameters panel. This widget enables the user to define the HCP voxels cellular automata rules that determine the HCP voxel values from one iteration step to the next, and from these values and the shader program that is defined by the shader code defined in the shader widget tab display the HCP cellular automata results.

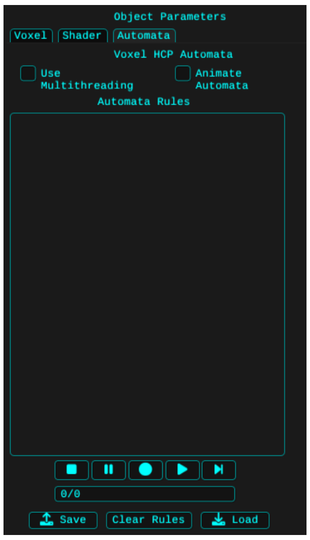


Fig 06a

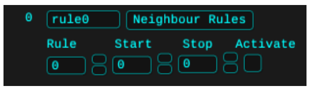
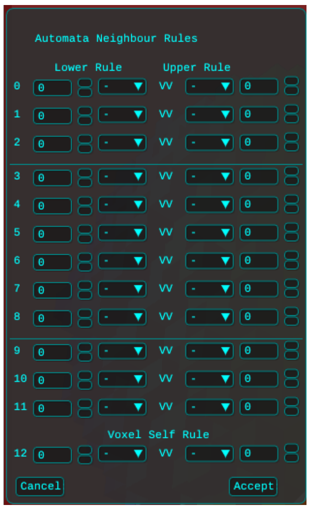
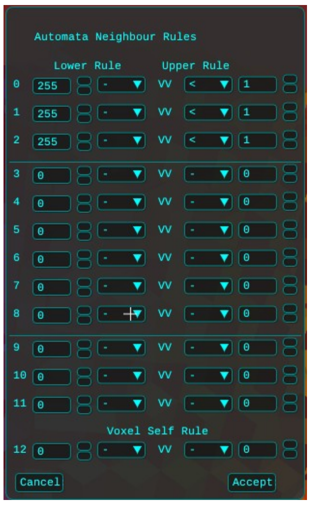


Fig 06b



	Lower Rule				Upper Rule
0	0	-	VV	-	0
1	0	-	VV	-	0
2	0	-	VV	-	0
3	0	-	VV	-	0
4	0	-	VV	-	0
5	0	-	VV	-	0
6	0	-	VV	-	0
7	0	-	VV	-	0
8	0	-	VV	-	0
9	0	-	VV	-	0
10	0	-	VV	-	0
11	0	-	VV	-	0
12	0	-	VV	-	0

Fig 06c



	Lower Rule				Upper Rule
0	255	-	VV	<	1
1	255	-	VV	<	1
2	255	-	VV	<	1
3	0	-	VV	-	0
4	0	-	VV	-	0
5	0	-	VV	-	0
6	0	-	VV	-	0
7	0	-	VV	-	0
8	0	-	VV	-	0
9	0	-	VV	-	0
10	0	-	VV	-	0
11	0	-	VV	-	0
12	0	-	VV	-	0

Fig 06d

From top to bottom

Use Multithreading : A checkbox to enable the processing of the cellular automata rules to be performed as a threaded process. Unfortunately, at this time, this is unable to be performed as the migration of code from Qt to ImGui and using Visual Studio 2022 has lead to linking errors that could not be reconciled.

Animate Automata : A checkbox to enable the cellular automata rules for this voxel object to be used in the animation feature of this application. Ignore this since animations will not be discussed at all.

Automata Rules : The section of this widget in which the user creates and manages the automata rules by which the application will use in a iterative step by step to determine what value to give to all of the individual HCP voxels within the volume defined in the voxel generation tab widget.

Automata control buttons : These are the automata control buttons to step the automata processing from one iteration to the next, play the automata rules, stop pause and record. As of this time, the record button is not implemented.

Progress bar : An indicator of the progress of the automata process

Clear variables button : Clears all the cellular automata rules variables.

Save : Opens a dialog window to save the cellular automata rules parameters defined in this widget to a formatted text file of suffix ABYTER.txt.

Load : Opens a dialog window for the user to select a cellular automata rules parameters (ABYTER.txt) formatted text file to be imported into the application and the values displayed in this widget ready to be used.

Given here is a simple example.

Step va01 : Move the mouse into the automata rules section and press the right mouse button to bring up a one option floating menu add rule. An automata rule should be added to this section of the widget and look like Fig 06b.

The text input widget at the top left of the rule is the name of the rule being applied. Next to this is a button labelled “Neighbour Rules” to bring up a floating widget that defines the rule to be applied. The second line below text “rule” is the value that the voxel will be given if the defined rule is met. The start and stop entry values are the iteration step that the rule will apply over. The Activate check box indicates whether the rule will be applied.

Step va02 : Left click the mouse over the Neighbour Rules button. An Automata neighbour Rules popup widget should be displayed as in fig 06c.

The neighbour rules are the conditions that must be met for the cellula automata rule to be valid and the voxel set to the defined rule value. Each voxel has twelve neighbours, and each neighbour of the voxel is identified by the number on the left of this popup. For information of which neighbour these numbers refer to the section Cellular Automata in the documentation file Virtual Worlds Voxel. A rule also can be defined for the self value of the voxel itself that is being evaluated.

An automata rule for each neighbour or self voxel is defined in this popup according to the mathematical relationship as given in ar01.

A (<,<=,ignore) VV (=, !=, < ,<=, ignore) B - ar01

which states the the rule is met for a neighbour if the voxel value (VV) of the neighbour voxel is one of any of the combinations of conditions that is within the brackets such that it falls within the range of value A, and value B. This may be explained better with some examples.

If have a rule ar02 form one particular neighbour

$A < VV < B$ - ar02

then this rule states that if the neighbours or self voxel value VV is between values A and B, then that rule condition is met for that voxel neighbour.

If have a rule ar03 form one particular neighbour

ignore $VV <= B$ - ar03

then this rule states that if the neighbours or self voxel value VV is less than or equal to value B, then that rule condition is met for that voxel neighbour.

If have a rule ar04 form one particular neighbour

$A < VV$ ignore - ar04

then this rule states that if the neighbours or self voxel value VV is greater than the value A, then that rule condition is met for that voxel neighbour.

So by use of the relationship defined in ar01, any automata rule pertaining to the integer value that the voxel neighbour has can be created with a very large set of possible rules. It is this method of defining the cellular automata rule for each voxel neighbour and itself that is represented in this popup widget, with the lower rule being the left side of ar01 and the upper rule being the right side of ar01.

Note : Virtual worlds currently has the voxel value VV in the one byte range of 1 to 255 that are valid, with the value 0 reserved as an invalid voxel value. So any value of zero for any voxel will not be displayed on screen

With modification, and for different types of data that the voxel value can have, other types of rules can be defined and implemented as desired but for the purposes of this demonstration, the following simple set of rules will be applied.

Step va03 : Enter into the lower rule of neighbour 0 for the value 255. Leave the selection of relationships for the lower rule as the default negative sign. The negative sign means ignore the value. For the upper rule enter 1 as the value that the rule must use, and select the less than (<) rule relationship for the rule of voxel neighbour 0.

What this rule defined in step va03 means is that if the voxel value of the neighbour voxel 0 is less than 1, then the rule for that neighbour is met and the thus valid for this neighbour.

Step va04 : Repeat step va03 for voxel neighbours 1 and 2.

The cellular automata rule to be applied to all voxels should now appear as in fig 06d. Press the Accept button for this neighbours rule to be applied for this cellular automata rule, other wise it will be discarded upon exit.

Step va05 : Going back to the rule definition that was created in step va01 and displayed in fig 06b, enter in the stop widget a value of 5, and activate the rule by enabling the active checkbox fig 07a.

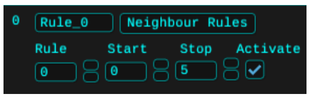
A cellular automata rule has now been defined to operate over the iteration step interval from 0 to 5. The start and stop iteration steps are so that multiple different rules such as defined above can be performed over different periods or iteration steps. This has not been thoroughly tested yet. For the purposes of this demonstration, the user can now perform the cellular automata rule by clicking on the next step button of the control buttons.(ie the right most button)

Do this a couple of times and see if there is a change in the appearance of the sphere. If not, move the mouse into the viewer panel and press the right mouse button to rotate the sphere until something similar to fig 07b is seen.

What this rule does is to assign a value of zero to the voxels that have their neighbour 0,1 and 2 voxels of a value 0. The 0,1, and 2 neighbours are the topmost neighbours of any Trapezo-rhombic dodecahedral shaped voxel, so the hcp voxel sphere has all the voxels with no neighbours of a valid value (ie zero) being assigned as invalid (ie value zero) and thus not being displayed on screen.

Continue pressing the next iteration step control button until no more changes are made and the progress bar is complete. fig 07c. To restore the voxel volume to its original state, go back to the voxel generation tab widget and press the “execute function” to regenerate the data.

Now enter the Automata tab once again and reset the automata rules by pressing the stop button in the button controls (ie far left square shaped button) The progress bar should now be reinitialised. Press the play button (the second to last solid arrow button) and the cellular automata rule should now play over a period of five iterations.


0 Rule_0 Neighbour Rules

Rule	Start	Stop	Activate
0	0	5	✓

Fig 07a

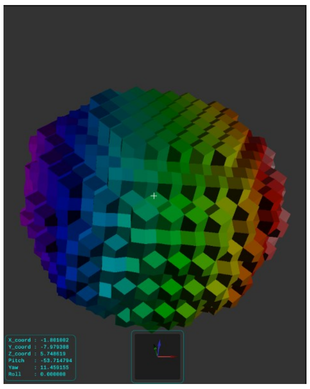


Fig 07b

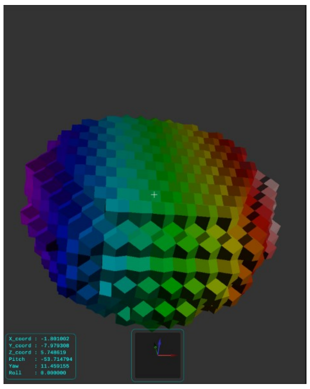


Fig07c

If the user so wishes, by pressing the save button, the user can select a directory and file name to save the defined cellular automata rules here for later use.

02.3 Exporting a HCP voxel object Data

HCP voxel objects that are generated or modified by use of the cellular automata feature of this application can have the current state of the point cloud data of the HCP voxel that is displayed on screen exported as a .ply file to be imported into a third party 3D application such as Blender or Meshlab.

It is assumed that for this tutorial, the user has at least performed the steps and got the result as described in the section **Generating a HCP voxel object**, and has on screen, something familiar to fig 4b, or fig 5c.

Step ev01 : To export the generated HCP voxel point data as a point cloud, the user needs to make sure it is selected as the current voxel object. This is confirmed by having the voxel object clicked in the outliner panel of the scene objects such that the generation, shader and automata tabs is displayed in the object parameters panel.

Step ev02 : With the voxel shader object selected, the user can then right mouse click and release to display a floating menu for this node. Select the menu option

Node/Entity ...→ funtions→ Voxel→ Export→As point Cloud

or one of the other export options.

Point cloud will export the entire generated voxel volume of valid voxel values as displayed to a .ply file

Point surface will export only the voxel point data of the generated voxel volume of valid voxel values that make up the surface of the volume to a .ply file

As Face surface will export only the voxel data of the generated voxel volume of valid voxel values that make up the surface of the volume as triangles to a .ply file. This selection will recreate what the user sees on screen with only the external triangles that makes up the volume surface being exported. This exported face data is of individual triangles, of which the vertices of some will be the same. To obtain a emergence of all these into a single defined surface, an application like mesh mixer or blender will be needed at this time.

Step ev03 : Select the menu option that one wants to export, and another menu sub menu selection will be be visible that is the same for all types of export. For the purpose here, the selection of selected will suffce. A save file dialog will appear for the user to select a file name location to save the exported data.

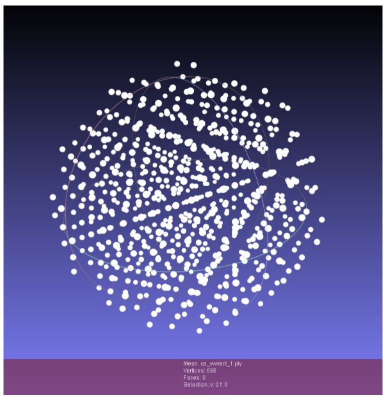
The exported data will have a file name with the format of

cp_object_name.ply for voxel volume center point data as a point cloud

sp_object_name.ply for voxel surface center point data as a point cloud.

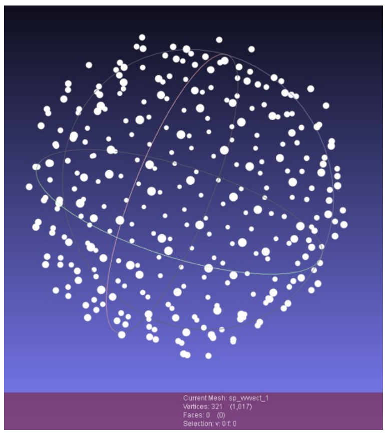
sf_object_name.ply for voxel surface center point data as a triangle vertex surface.

If the user were to use a 3D application like MeshLab, the exported data will appear as in fig 8a, 8b and 8c.



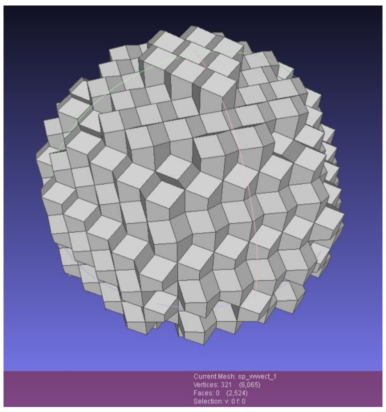
```
Mesh: cp_wwect_1.ply
Vertices: 696
Faces: 0
Selection: v: 0 f: 0
```

Fig 8a



```
Current Mesh: sp_wwect_1
Vertices: 321    (1,017)
Faces: 0    (0)
Selection: v: 0 f: 0
```

Fig 8b



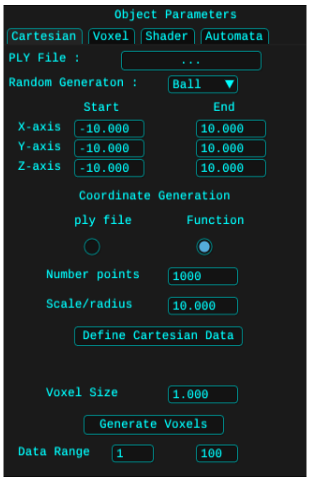
```
Current Mesh: sp_wwect_1
Vertices: 321    (6,065)
Faces: 0    (2,524)
Selection: v: 0 f: 0
```

Fig 8c

The HCP voxel volume point data of what is diplayed on sceen can be exported in any of these foramts, and thus while performing the cellular automata steps, the cellula automata configuration of any step can be exported.

02.4 Create HCP Voxel Object From Cartesian Point Data

If one has a set of point data in Cartesian coordinates that is generated by a C++ function, or exists within a 3D formatted vertex file (eg a .ply formated file), then this point data can be converted into a HCP voxel object to represent the point cloud data as voxels. This is achieved by a HCP voxel matrix of a given origin, size and range attributes that fit within the point data set volume in space being tested to see if any point data exists within the volume of any of the HCP Trapezo-rhombic dodecahedron voxel cells. If a point does exist within a cell, the data attribute value for that cell within the computer data storage array is given a value to indicate one data point exists within that cell. If more than one point exists within a cell, that value is increased to represent the number of coordinate points that are found to exist within that voxel cell. Thus a resultant HCP voxel matrix is formed representing a kind of density of data points within each HCP voxel cell that can be displayed on screen. Presented here is and example of two methods to create a HCP voxel matrix of a cartesian point data set.



Object Parameters

Cartesian | Voxel | Shader | Automata

PLY File : ...

Random Generaton : Ball

	Start	End
X-axis	-10.000	10.000
Y-axis	-10.000	10.000
Z-axis	-10.000	10.000

Coordinate Generation

ply file ○ Function ●

Number points 1000

Scale/radius 10.000

Define Cartesian Data

Voxel Size 1.000

Generate Voxels

Data Range 1 100

Fig 09a

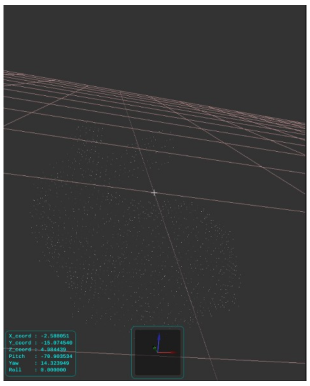


Fig 09b

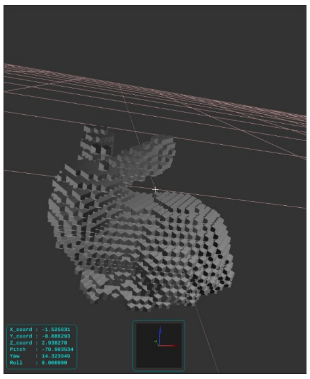


Fig 09c

The following steps describe how to create a voxel matrix of HCP Trapezo-rhombic dodecahedron voxel cells from a .ply file.

Step vc01 : In a similar manner to creating a HCP voxel object, in a location in the node editor where one would like to place a cartesian hcp voxel node, with no node selected, click the right mous button and release it to display a node editor's floating menu. Make the menu selection

Main Menu→ Create Node→ HCP Voxel→ Create Cart to HCP Voxel Node.

Select the created node and in the parameter panel a widget similar to that of fig 09a will be displayed.

From top to bottom

PLY File : A button to bring up a file dialogue for the user to select a PLY file that contains vertex xyz point data to be used to create a HCP voxel matrix.

Random Generation : A button drop down list to for the user to select a method of generating a set of random xyz point data to be used to create a HCP voxel matrix. Available in this demonstration are Ball and Sphere. Ball generates a solid sphere of random points, and Sphere is a spherical shell of random points.

Definition of the x-y-z volume limits of that the HCP voxel volume generation is to be confined to. This is automatically updated to fit the Cartesian data that is generated or imported.

Coordinate Generation : Two radio buttons to select the type of point data that is to be used to create the voxel matrix. Ply is to use the nominated PLY file defined by the PLY button, or function to use the random data selected in the Random Generation drop down list.

Number Points : Is to specify the number of points that the random function is to generate if the function radio button is selected.

Scale/Radius : Is to specify a Scale factor of the imported xyz data points of the imported PLY file, if the PLY generation is selected, or the radius of the sphere of the random generated point data if the function generation is selected.

Define Cartesian Data : Is to import or generate the point data to be used to create the voxel matrix. This will also get the boundary of the volume that this data will occupy in 3D space and update the start and end boundary limits. If the user wishes, these boundary limits can be changed.

Voxel Size : This is the size of the resultant voxel matrix cells. The size chosen will determine the level of detail of the point data to be viewed.

Generate Voxels : Pressing this button will create a matrix of HCP Trapezo-rhombic dodecahedron voxel cells. A value is given to each cell to indicate the number of points that exist within it.

Voxel Scale : Widget to scale the HCP voxel size when not displayed as points.

Data Range : Widget to select the range of number of points that each voxel cell must have for that voxel cell to be displayed on the screen.

Step vc02 : Select the .ply file selection button to open a file selection dialogue. Select the bunny .ply file that should be present in the Data directory that this application executable is located within. The button text should now have the text bunny present.

Step vc03 : If the ply file radio button is not selected, then select it to highlight and activate the selection that the unstructured Cartesian data in the ply file bunny.ply is to be displayed as a set of structured HCP Trapezo-rhombic dodecahedron voxel cells.

Step vc04 : The number of points has no effect in this case, so can be ignored, but for this bunny.ply data it is known that the x,y,z data values are in the range of ± 0.5, which is rather small to represent as voxel cells, so need to be scaled by at least 10. If the Scale/Radius value is not a value of 10.0, then enter this value into the entry box.

Step vc05 : Press the “Define Cartesian Data button to import the bunny.ply xyz point data set at at scale factor of 10.0. The values of the volume limits to create the voxel matrix should change and be in the rage of ± 5 units.

Step vc06 : For a reasonable representation of the data, change the Voxel size to 0.2 units. Press the Generate voxels button.

In the viewer display, a default view of points representing the centers of the HCP voxel cells should appear in the shape of a rabbit in a sitting position. If necessary, rotate and/or move the camera to get a better view of this data.(Fig 09b).

Step vc07 : To obtain an image of the HCP Trapezo-rhombic dodecahedron voxel cells, deselect the voxel “Display as points” checkbox. The viewer should now switch from a display of points to a display of voxel cells. If necessary, rotate and/or move the camera to get a better view of this data.(Fig 09c).

Note : Following not working yet as need to modify the glsl program

To obtain an image of the HCP Trapezo-rhombic dodecahedron voxel cells such that the cells are colored and sized to give an indication of how many data points exist within each cell, select the shader tab (fig 5a) . Entering in the vertex shaders to use and defining shader variables is performed as in the section **Visualising HCP voxel object**. The steps to perform the task to define the shader code files and variables will not be described here. What the user can do is to import a parameter file with all these parameters defined.

Step vc08 : Select the “Load” button at the bottom right of the shader widget to bring up the file dialouge to select a shader parameter file to import. Navigate to the directory Examples/Shader/CtoV and select the file ctov_range.twm. This will load the shader parameters needed to display the HCP voxels in a different style.

Step vc09 : The directory path names to the vertex, point, geometry and fragment shader pathnames will probably be be different to that on the user computer. One by one, select the button for each of these files to open a file dialogue and navigate to the directory

<user directory this application exist within>\Resources\Shaders\Default\C_to_V\

and select the default_CtoV_VS.glsl, default_CtoV_PGS.glsl, default_CtoV_GS.glsl and default_CtoV_FS.glsl files that are listed. This will define the exact path name required to create the shader programs.

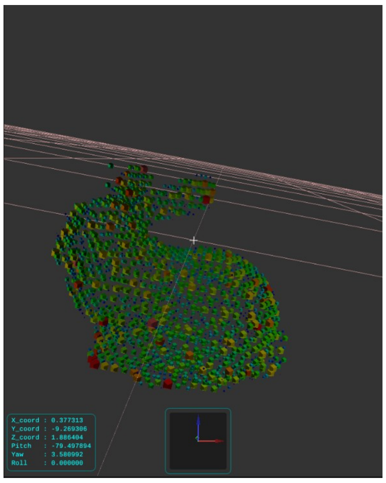
Step vc10 : Press the Shader update or regeneration button to generate the shader program. No error messages should occur and the voxels from the display may disappear. If an error message(s) are present, it is because an incorrect shader file has been selected or a variable name has been changed or is absent, or not defined to be used. Examine the error message and make the appropriate correction.

Step vc11 : If The display is blank, (it should not as this problem has been fixed) it is due to a programming bug having the voxel size set to zero that has not yet been fixed. Just go back to the voxel generation tab widget and move the voxel scale slider to display the voxels. A view similar to fig 10a or fig 10b should now appear in the viewer panel.

To flip between the views of fig 10a or fig 10b, activate and deactivate the boolean variable scale_density that is defined in the shader tab widget.That is the checkbox right of the boolean variable scale_density.

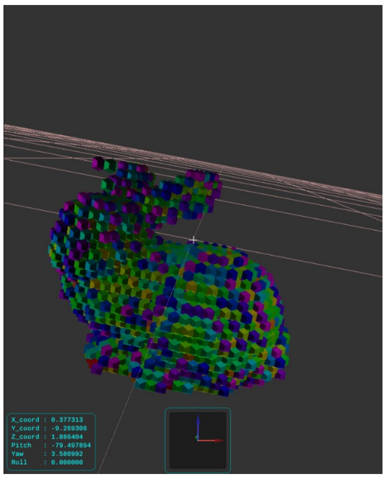
The colors and size of the individual voxels give an indication to the number of coordinates that lie within each HCP voxel cell volume. By moving the slider widgets named min_density and max_density, the user can specify the range of data points that are to be displayed. Moving the min_density will mean that only voxels with data points above this value are considered, while moving the max_density slider means that only data points below this value are considered. Red colors are voxels with high number of data points in this specified range, while violet to purple, low number of points in the specified range that exist within the voxel cell.

The same procedure for displaying the data of a .ply file can be applied for a function as well. If the user now repeats the above steps vc02 to vc06, but select the radio button "Function" a sphere of random voxels similar to fig 10c should be present.



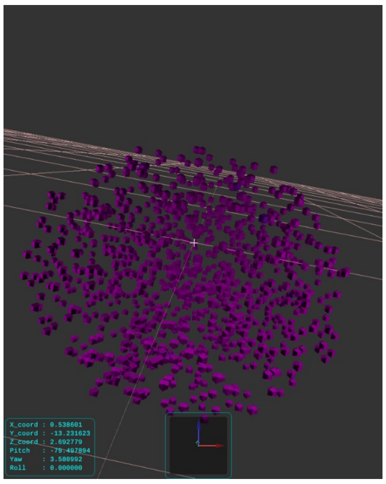
```
X_coord : 0.377313
Y_coord : -9.269306
Z_coord : 1.886404
Pitch   : -79.497894
Yaw     : 3.580992
Roll    : 0.000000
```

Fig 10a



```
X_coord : 0.377313
Y_coord : -9.269306
Z_coord : 1.886404
Pitch   : -79.497894
Yaw     : 3.580992
Roll    : 0.000000
```

Fig 10b



```
X_coord : 0.538601
Y_coord : -13.231623
Z_coord : 2.692779
Pitch   : -79.497894
Yaw     : 3.580992
Roll    : 0.000000
```

Fig 10c

For experimentation, the voxel size and/or number of points for a function can be changed to get different results. Change in the voxel size is also a change in level of detail of the point data being displayed. If the voxel size is too small relative to the distribution or data, large blank spaces become apparent. If too large, only a few voxels, if not only one are present and the shape of the data is lost.

This is the end of the instructive demonstration of the implementation of the concept of use of a hexagonal closed packed 3D spacial structure of voxels. It is hoped that this is enough to give an indication that there is a potential for wider developments that any reader may find worth investigating and inquiring about.

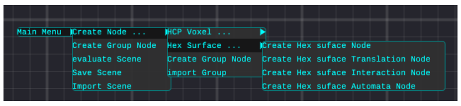
For further information on this topic and what coding has been written to implement this concept, please read the other documentation that is present with this document.

03.0 Generating a hexagonal Voxel object

Hexagonal voxel objects are generated using a text file with an OpenGL compute shader program. So before doing anything else, the user needs to create or have an opengl compute shader program source code text file to use. Virtual worlds already has some examples available for use in the examples directory of where the Virtual_Worlds executable is located. To find out how to create a Virtual Worlds compute shader code, see the documentation on how to do this in the section writing a compute shader program.

To generate a hexagaonal voxel object, move the mouse cursor to within the node editor described in section 03.1 and right mouse click over an empty region where one wishes to place a node to represent a hexagaonal voxel and release it.

A floating menu should appear with the option Main Menu. Move the mouse cursor over this option to display a sub menu. One of these options should be Create Node …. Move the mouse cursor over this menu option and another sub menu should appear with a menu option Hex Surface …. Move the mouse cursor over this menu option and yet another last sub menu will appear with one option being Create Hex surface Node.(fig **03.0.1**). Left click with the mouse on this option, and where the mouse cursor was placed in the node editor should be a HCP Voxel node similar to **Fig 03.0.2**



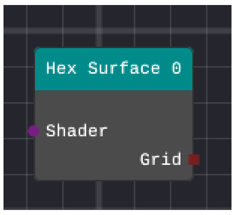


Fig 03.0.1 **Fig 03.0.2**

Select this newly created node and so as to highlighted it with the left mouse button. In the parameters panel, select the tab with the label object. Within this object tab widget, more tab widgets should appear. Select the tab with the label Generation. A widget as in fig 02.0.3 should be displayed. The parameters in this widget required to generate the hexagaonal voxel data. From top to bottom.

Expression button : to select the virtual worlds OpenGL compute shader program file that generates the hexagonal surface voxel data.

Definition of the x-y area limits of that the hexagonal surface voxel area generation is to be confined to.

Compute invocation is a number that is relevant to the OpenGL compute shader process where the number indicates the number of threads running in parallel is used in the calculation. Generally from documentation, the higher numbers are used if have a large number of calculations to be performed.

Execute button : Generate the hexagonal surface voxel data. Only press when everything is ready.

Min/Max surface values : These are the minimum and maximum permissible values that the voxels can posses to be designated as a valid voxel to be stored in computer memory and displayed on screen. At the time of this documentation, this should be left as the defaults as any other value may not work Something for a future update.

Resolution step : Basically, this is the spacing between each hexagonal surface voxel.

Threshold : Generation of hexagonal surface voxels is of the form voxel value = F(x,y) and the threshold is the minimum absolute value that this voxel value can have to be considered as a valid voxel to be stored in computer memory.

Display as points : Change the display of the generated data from points to voxels. This display is determined by the shader program and parameters that are defined in the the shader tab widget which is discussed below.

Voxel Scale : Widget to scale the size of the hexagonal voxel when it is selected to not display the data as points.

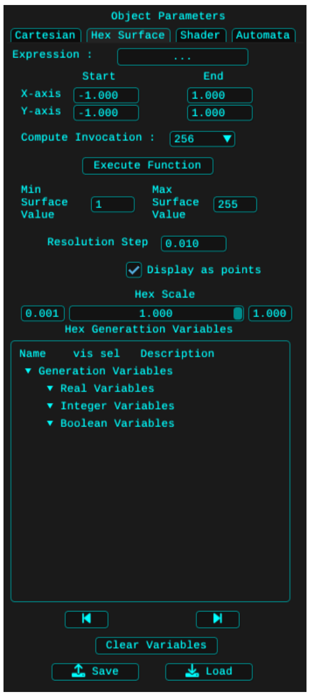
Voxel Generation Variables : A set of widgets that enable the user to manage and view the set of variables that are used to generate the area of voxels within the area as defined in the parameters above this widget. Any variables defined here must have an equivalent uniform shader variable that is defined in the compute shader program code that is used to generate the hexagoanal area or there will be a shader compilation error and no voxel area generated.

Left and Right control buttons : These Buttons perform a decrement and increment of one or more of the variables defined in the heaxgonal generations widget to be changed by a given step value, and then regenerate the hexagonal area and display it on screen.

Clear variables button : Clears all the voxel generation variables

Save : Opens a dialog window to save the voxel parameters defined in this widget to a formatted text file of suffix .hgp (hexagonal generation parameters)

Load : Opens a dialogue window for the user to select a hexagonal generation parameters (.hgp) formatted text file to be imported into the application, and the values displayed in this widget ready to be used.



Object Parameters

Cartesian | Hex Surface | Shader | Automata

Expression : ...

	Start	End
X-axis	-1.000	1.000
Y-axis	-1.000	1.000

Compute Invocation : 256

Execute Function

Min Surface Value 1 | Max Surface Value 255

Resolution Step 0.010

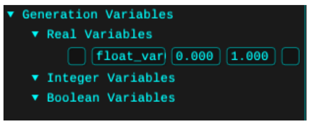
✓ Display as points

Hex Scale 0.001 | 1.000 | 1.000

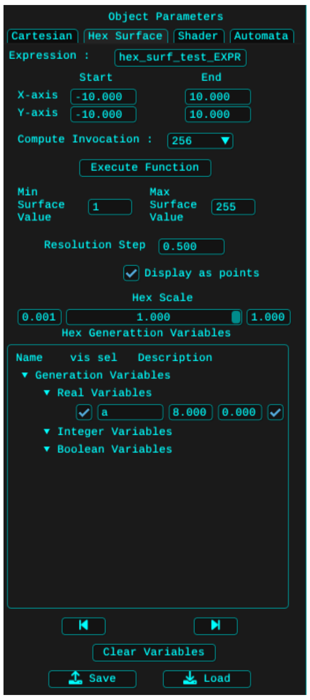
Hex Generattion Variables

Name vis sel Description

- Generation Variables
  - Real Variables
  - Integer Variables
  - Boolean Variables



- Generation Variables
  - Real Variables
    - float_var | 0.000 | 1.000
  - Integer Variables
  - Boolean Variables



Object Parameters

Cartesian | Hex Surface | Shader | Automata

Expression : hex_surf_test_EXPR

	Start	End
X-axis	-10.000	10.000
Y-axis	-10.000	10.000

Compute Invocation : 256

Execute Function

Min Surface Value 1 | Max Surface Value 255

Resolution Step 0.500

✓ Display as points

Hex Scale 0.001 | 1.000 | 1.000

Hex Generattion Variables

Name vis sel Description

- Generation Variables
  - Real Variables
    - ✓ a | 8.000 | 0.000 ✓
  - Integer Variables
  - Boolean Variables

Fig 12a **Fig 12b** **Fig 12c**

The details of creating a hexagonal surface generating compute shader program to be selected for use here is in the section Create Voxel Compute Shader Program. Creating a hexagonal surface compute shader program is identical to that for a HCP voxel with the exception that the output value is the z value of a surface function of the form z = f(x,y). For the present as this is an overview of generating a hexagonal surface area and displaying it, it is only required for the user to select an existing example.

Step hg01 : Select the Expression Button at the top of this widget to bring up the file load dialogue.

Step hg02 :Navigate to the Examples/Generation/Hex_surfaces/ directory that the Virtual Worlds application resides in and select the file name hex_surf_test_EXPR.txt.

The button name should now be changed to hex_surf_test_EXPR. If not repeat steps hg01 and hg02 above.

Step hg03 : To define the area that the hexagonal surface voxels will be generated over, change all of the start x,y values to -10, and the end values to 10

Step hg04 : Go to the hex generation variables section and with the mouse cursor, navigate to and hover over the Real Variables tree node widget to highlight it. Press the right mouse button to bring up the only available floating menu option "add variable", and select it to create a new real (ie floating) variable.

The variable widget that is displayed (fig 12b) is the same for float and integer shader variables. From left to right.

Checkbox to indicate if the variable is defined and to be used in the shader program.

Select and left mouse click to enable this variable to be used in the voxel generation compute shader.

Name of the variable that is defined in the voxel generation compute shader code.

Select the text input widget and change the name to b.

The initial or set value that this variable is defined to be assigned to.

Select the floating number input widget and type in the value 8.0

The next floating point input widget is the incremental step value to change the variable by as a step action if the increment or decrement button is selected.

It it is not 1.0 enter 1.0.

The last checkbox widget is to indicate to the application if the step variable is to be used or not when performing incremental or excremental steps operations.

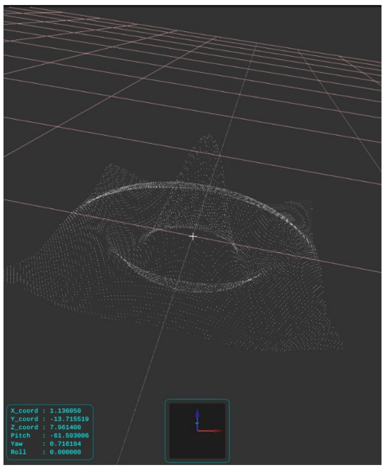
Select and set this widget to enable the step variable to be used.

The hexagonal generation panel should now look like that of Fig 12c.

The generation of a simple hexagonal voxel surface can be performed.

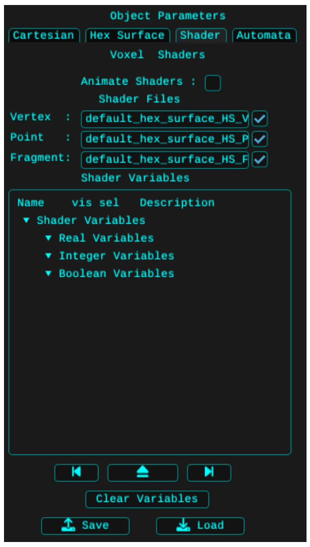
Step hg05 : Press the button labelled "Execute Function"

This will generate a hexagonal surface voxel point cloud of data, and in the viewer panel to the right of this voxel generation widget will be displayed some points that represent the centers of a surface of hexagonal shaped Voxels. These points are the centers of the equally spaced 3D hexagons of the same size. There are probably too few points to see this surface adequately. To increase the number of points, enter a value of 0.1 in the resolution step float input box and repeat step hg05. If the camera is too close to or within the generated voxel shape, move the camera away from the object by selecting the number 2 or down arrow on the number keypad. (Note: Number lock must be disabled) Keep pressing this key until the scene in the viewer panel looks similar to Fig 13a.



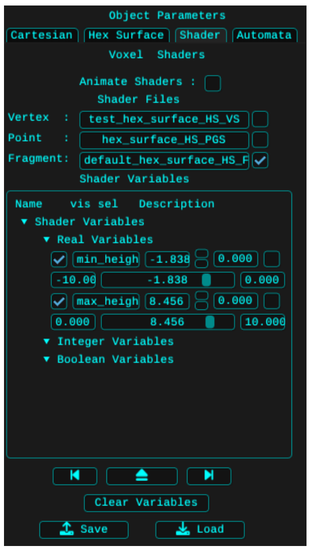
```
X_coord : 1.136050
Y_coord : -13.715519
Z_coord : 7.961400
Pitch   : -61.593006
Yaw     : 0.716194
Roll    : 0.000000
```

Fig 13a



```
Object Parameters
Cartesian | Hex Surface | Shader | Automata
Voxel  Shaders
Animate Shaders : ☐
Shader Files
Vertex   : default_hex_surface_HS_V ✓
Point    : default_hex_surface_HS_P ✓
Fragment: default_hex_surface_HS_F ✓
Shader Variables
Name    vis sel   Description
▼ Shader Variables
   ▼ Real Variables
   ▼ Integer Variables
   ▼ Boolean Variables
```

Fig 13b



```
Object Parameters
Cartesian | Hex Surface | Shader | Automata
Voxel  Shaders
Animate Shaders : ☐
Shader Files
Vertex   : test_hex_surface_HS_VS ☐
Point    : hex_surface_HS_PGS ☐
Fragment: default_hex_surface_HS_F ✓
Shader Variables
Name    vis sel   Description
▼ Shader Variables
   ▼ Real Variables
      ✓ min_heigh  -1.838   0.000 ☐
      -10.00       -1.838         0.000
      ✓ max_heigh  8.456    0.000 ☐
      0.000        8.456          10.000
   ▼ Integer Variables
   ▼ Boolean Variables
```

Fig 13c

To see the hexagonal voxels surface as hexagon columns, an existing shader program exists that can be used to do this.

Step hg06 : Select the tab Shader in the parameters panel to bring up the shader widget as in Fig 5a of the section **Visualising HCP voxel object**.

Step hg07 : Select the tab Shader in the parameters panel to bring up the shader widget as in Fig 13b. Press the vertex shader button labelled "Default_hex_surface_VS" and navigate to the directory Resources/Shaders/Hex_surface/ in which the application executable resides and select the file

test_hex_surface_HS_VS.glsl

After doing this, uncheck the checkbox next to this button to select this glsl code file to be used in the shader program compilation.

Repeat this for the point shader by selecting the file hex_surface_HS_PGS.glsl and deselect the checkbox next to this button.

Step hg08: Go to the Shader variables widget and as done with defining a voxel generation real variable, create two variables here. Define one with the name min_height, and the other with max_height. Check all the enable check boxes, and assign for the min_height variable , a value of -10.0, and a step value of 1.0. A variable slider will be visible below these widgets. The left float input widget is the minimum range value of this variable, and the right, its maximum. Enter -10.0 for the minimum, and 0.0 for the maximum. For the max_height variable, enter a value of 10.0, a step value of 1.0, and a slider min and max range value of 0.0 and 10.

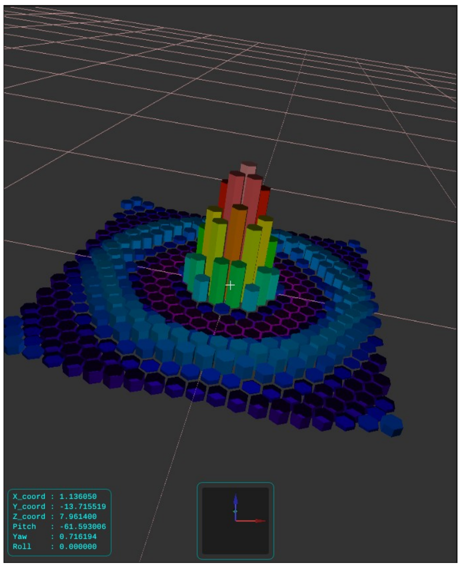
This shader widget should appear as in fig 13c. The voxel display shader program can now be generated and the hexagonal voxel display updated to the functionality as defined by the shader code of the defined shader types.

Step hg09 : Press the generate shader button (middle button with up arrow). The display may go all blank (it should not as this problem has been fixed) due to a programming bug having the voxel size set to zero that has not yet been fixed. Just go back to the voxel generation tab widget and move the voxel scale slider to display the voxels. A view similar to fig 14 should now appear in the viewer panel. If the hexagon surface voxels are too small, change the resolution step value to 0.5 and repeat step hg05.

What the user can now do is move the variable sliders to change the min and max values that are displayed as a color range of the voxels. If the user now selects the increment and decrement buttons, the user will fin that both variable values will change in the same step. If any of the step check boxes for enabling the step action is disabled, that variable will not change while any that are active will.

If the user so wishes, by pressing the save button, the user can select a directory and file name to save the defined parameters here for later use.

This is a basic demonstration of the use of this shader widget. It is intended that the user can create new or use many a variety of shaders to display voxel surface data. The hexagonal shaped Voxels are actually drawn using the defined geometry shader as only the point data that is observed by enabling the display as points checkbox in the voxel shader widget. It is envisaged that with more development, a whole series of different shader code will be created.



```
X_coord : 1.136050
Y_coord : -13.715519
Z_coord : 7.961400
Pitch   : -61.593006
Yaw     : 0.716194
Roll    : 0.000000
```

.

Fig 14

03.1 Hexagonal voxel Cellular Automata

One purpose of creating the hexagonal spacial data structure and this application is to implement a usage of cellular automata for the purpose of simulation and modelling of real world phenomenon or pure experimental and fractal exploration. With the ability to define any set of simple rules, an infinite realm of possible behaviours can be explored for computer graphics, art or science. The hexagonal voxel 2D spacial data structure has the advantage over conventional cubic voxel modelling in that the center of every neighbour of any voxel is of equal distance as the neighbours of a cubic voxel sharing one or more vertex points is not.

The hexangonal voxel cellular automata is implemented as a node in the node editor, which needs to be linked to a hexagonal voxel generated scene object. To create a hexagonal cellular automata node, in the node editor where one wishes to place a hexagonal cellular automata node, right click with the right mouse button and release to bring up the floating menu, and and navigate through the menu to the menu option

Main Menu→Create Node ...→Hex Surface… → Create Hex Surface Automata Node.

A hexagonal voxel automata node should be created. Make a node editor link from the hexagonal voxel node created above grid output pin on the right of the node to the hexagonal automata input grid pin on the left of the cellular automata node.

Select the hexagonal cellular automata node to bring up a widget as in fig 15a in the parameters panel. This widget enables the user to define the hexagonal voxels cellular automata rules that determine the hexagonal voxel values from one iteration step to the next, and from these values and the shader program that is defined by the shader code defined in the shader widget tab display the hexagonal cellular automata results.

From top to bottom

Use Multithreading : A checkbox to enable the processing of the cellular automata rules to be performed as a threaded process. Unfortunately, at this time, this is unable to be performed as the migration of code from Qt to ImGui and using Visual Studio 2022 has lead to linking errors that could not be reconciled.

Animate Automata : A checkbox to enable the cellular automata rules for this voxel object to be used in the animation feature of this application. Ignore this since animations will not be discussed at all.

Automata Rules : The section of this widget in which the user creates and manages the automata rules by which the application will use in a iterative step by step to determine what value to give to all of the individual hex voxels within the area defined in the voxel generation tab widget.

Automata control buttons : These are the automata control buttons to step the automata processing from one iteration to the next, play the automata rules, stop pause and record. As of this time, the record button is not implemented.

Progress bar : An indicator of the progress of the automata process

Clear variables button : Clears all the cellular automata rules variables.

Save : Opens a dialog window to save the cellular automata rules parameters defined in this widget to a formatted text file of suffix AHSR.txt.

Load : Opens a dialogue window for the user to select a cellular automata rules parameters (AHSR.txt) formatted text file to be imported into the application and the values displayed in this widget ready to be used.

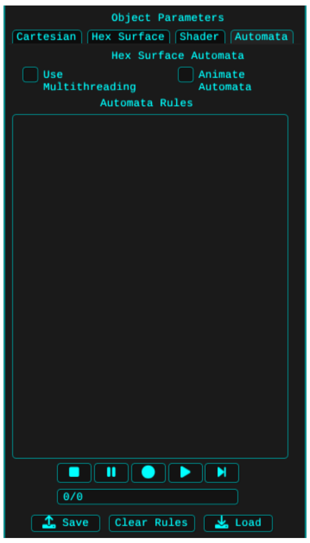


Fig 15a

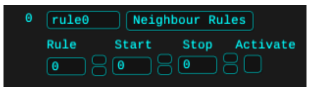


Fig 15b

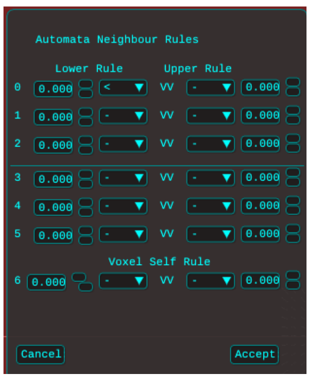


Fig 15c

Given here is a simple example.

Step ha01 : Move the mouse into the automata rules section and press the right mouse button to bring up a one option floating menu add rule. An automata rule should be added to this section of the widget and look like Fig 06b.

The text input widget at the top left of the rule is the name of the rule being applied. Next to this is a button labelled “Neighbour Rules” to bring up a floating widget that defines the rule to be applied. The second line below text “rule” is the value that the voxel will be given if the defined rule is met. The start and stop entry values are the iteration step that the rule will apply over. The Activate check box indicates whether the rule will be applied.

Step ha02 : Left click the mouse over the Neighbour Rules button. An Automata neighbour Rules popup widget should be displayed as in fig 15c.

The neighbour rules are the conditions that must be met for the cellula automata rule to be valid and the voxel set to the defined rule value. Each hex voxel has six neighbours, and each neighbour of the voxel is identified by the number on the left of this popup. For information of which neighbour these numbers refer to the section Cellular Automata in the documentation file Virtual Worlds Voxel. A rule also can be defined for the self value of the voxel itself that is being evaluated.

An automata rule for each neighbour or self voxel is defined in this popup according to the mathematical relationship as given in har01.

A (<,<=,ignore) VV (=, !=, < ,<=, ignore) B - har01

which states the the rule is met for a neighbour if the voxel value (VV) of the neighbour voxel is one of any of the combinations of conditions that is within the brackets such that it falls within the range of value A, and value B. This may be explained better with some examples.

If have a rule har02 form one particular neighbour

A < VV < B - har02

then this rule states that if the neighbours or self voxel value VV is between values A and B, then that rule condition is met for that voxel neighbour.

If have a rule har03 form one particular neighbour

ignore VV <= B - har03

then this rule states that if the neighbours or self voxel value VV is less than or equal to value B, then that rule condition is met for that voxel neighbour.

If have a rule har04 form one particular neighbour

A < VV ignore - har04

then this rule states that if the neighbours or self voxel value VV is greater than the value A, then that rule condition is met for that voxel neighbour.

So by use of the relationship defined in har01, any automata rule pertaining to the integer value that the voxel neighbour has can be created with a very large set of possible rules. It is this method of defining the cellular automata rule for each voxel neighbour and itself that is represented in this popup widget, with the lower rule being the left side of har01 and the upper rule being the right side of har01.

Note : Virtual worlds currently has the voxel value VV in the one byte range of 1 to 255 that are valid, with the value 0 reserved as an invalid voxel value. So any value of zero for any voxel will not be displayed on screen

With modification, and for different types of data that the voxel value can have, other types of rules can be defined and implemented as desired but for the purposes of this demonstration, the following simple set of rules will be applied.

Step ha03 : Enter into the lower rule of neighbour 0 the value 0. Change the selection of relationships for the lower rule by selecting the rule drop down selection menu and select the < (less than) rule condition. The negative sign means that any value less than 0 will mean that the rule has not been met. For the upper rule enter 0 as the value that the rule must use, and select the negative sign (-) rule relationship for the upper rule of voxel neighbour 0. The negative sign means ignore the value.

What this rule defined in step ha03 means is that if the voxel value of the neighbour voxel 0 is grater than 0, then the rule for that neighbour is met and the thus valid for this neighbour.

Step ha04 : make sure all other rules have their rule conditions set to a ignore (ie minus) rule.

The cellular automata rule to be applied to all voxels should now appear as in fig 15c. Press the Accept button for this neighbours rule to be applied for this cellular automata rule, other wise it will be discarded upon exit.

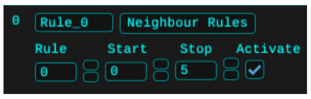
Step ha05 : Going back to the rule definition that was created in step ha01 and displayed in fig 15b,enter the value 6 in the rule input entry box, and enter in the stop widget a value of 5. Activate the rule by enabling the active checkbox fig 16a.

A cellular automata rule has now been defined to operate over the iteration step interval from 0 to 5. The start and stop iteration steps are so that multiple different rules such as defined above can be performed over different periods or iteration steps. This has not been thoroughly tested yet. For the purposes of this demonstration, the user can now perform the cellular automata rule by clicking on the next step button of the control buttons.(ie the right most button)

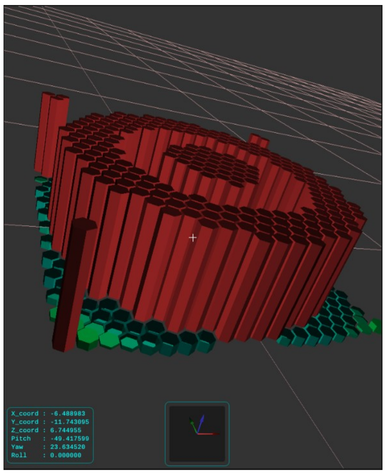
Do this a couple of times and see if there is a change in the appearance of the hex surface. If not, move the mouse into the viewer panel and press the right mouse button to rotate the sphere until something similar to fig 16b is seen.

What this rule does is to assign a value of 6 to the voxels that have their neighbour 0, having a value greater than the value 0. Thus all the hex voxels in fig 16b have a zero neighbour with a value greater than 0. Looking at fig 14, fig 16b looks to be correct.

Continue pressing the next iteration step control button a few times and at the end, one should end up with something that looks like fig 16c. To restore the hex surface to its original state, go back to the hex generation tab widget and press the “execute function” to regenerate the data.



```
0  Rule_0   Neighbour Rules
   Rule     Start   Stop   Activate
   0        0       5      ✓
```



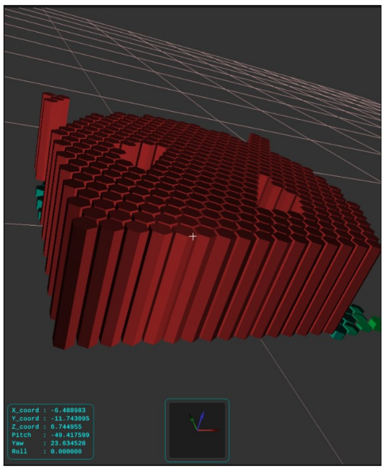


Fig 16a **Fig 16b** **Fig 16c**

Now enter the Automata tab once again and reset the automata rules by pressing the stop button in the button controls (ie far left square shaped button) The progress bar should now be reinitialised. Press the play button (the second to last solid arrow button) and the cellular automata rule should now play over a period of five iterations.

If the user so wishes, by pressing the save button, the user can select a directory and file name to save the defined cellular automata rules here for later use.

03.2 Create Hexagonal Voxel Object From Cartesian Point Data

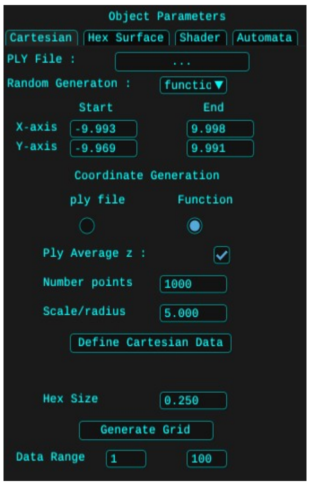
If one has a set of point data in Cartesian coordinates that is generated by a C++ function, or exists within a 3D formatted vertex file (eg a .ply formated file), then this point data can be converted into a hexagonal voxel object to represent the point cloud data as a surface of voxels. This is achieved by a hexagonal voxel grid of a given origin, size and range attributes that fit within the point data set volume in space being tested to see if any point data exists within the area of any of the hexagonal voxel cells. If a point does exist within a cell, the data attribute value for that cell within the computer data storage array is given a value to indicate one data point exists within that cell. If more than one point exists within a cell, that value is increased to represent the number of coordinate points that are found to exist within that voxel cell. Thus a resultant hex voxel matrix is formed representing a kind of density of data points within each HCP voxel cell that can be displayed on screen.

An alternative method of generating a hexagonal voxel object from Cartesian point data is that if the Cartesian data has a z value that corresponds to a surface value. Then the resultant voxel value for a voxel is an average of all of the z values that exist within that voxel area. Thus a resultant visualisation of that data can be representative of a surface and not the number of points that exist within a voxel ares or cell.

The following steps describe how to create a hexagonal grid of hexagonal voxel cells from a .ply file.

Step hc01 : Create a HCP voxel object from the outliner panel as described in the section **Generating a HCP voxel object**. and select the voxel object to get displayed the panel as in Fig 17a.

The Catesian tab is by default the selected tab. This is where point data is defined and a voxel matrix is created from that point data.



Object Parameters

Cartesian | Hex Surface | Shader | Automata

PLY File : ...

Random Generaton : functic▼

	Start	End
X-axis	-9.993	9.998
Y-axis	-9.969	9.991

Coordinate Generation

ply file ○ Function ●

Ply Average z : ✓

Number points 1000

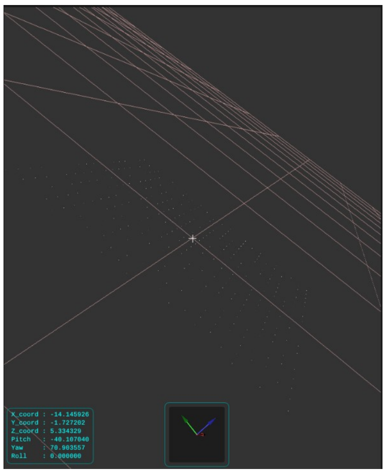
Scale/radius 5.000

Define Cartesian Data

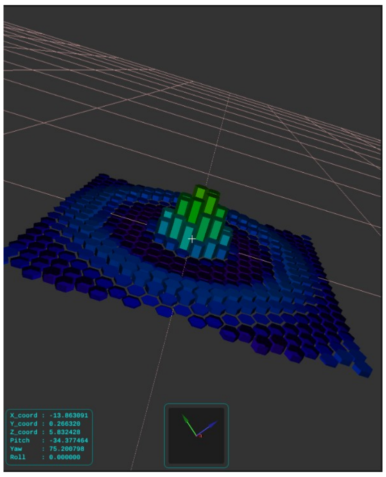
Hex Size 0.250

Generate Grid

Data Range 1 100



```
X_coord : -14.145926
Y_coord : -1.727202
Z_coord : 5.334329
Pitch   : -40.107040
Yaw     : 70.903557
Roll    : 0.000000
```



```
X_coord : -13.863091
Y_coord : 0.266320
Z_coord : 5.832428
Pitch   : -34.377464
Yaw     : 75.200798
Roll    : 0.000000
```

Fig 17a **Fig 17b** **Fig 17c**

From top to bottom

PLY File : A button to bring up a file dialogue for the user to select a PLY file that contains vertex xyz point data to be used to create a hexagonal voxel grid.

Random Generation : A button drop down list to for the user to select a method of generating a set of random xyz point data to be used to create a hexagonal voxel grid. Available in this demonstration are function, square and circle. Square generates a zero plane square of random points, Circle a zero plane circle of random points, and function generates a surface of random points of the function z = sin(r)/r * scale where r is the radius from the origin point (0,0)..

Definition of the x-y-z area limits of that the hexagonal voxel grid generation is to be confined to. This is automatically updated to fit the Cartesian data that is generated or imported.

Coordinate Generation : Two radio buttons to select the type of point data that is to be used to create the voxel grid. Ply is to use the nominated PLY file defined by the PLY button, or function to use the random data selected in the Random Generation drop down list.

Ply average z : Is to specify if the resultant value that is given to the hexagonal grid voxel cell when a .ply file is used to import Cartesian coordinate data is the number of points within a voxel cell, or is an average of the z values of the point data that are found to be within that voxel cells area domain.

Number Points : Is to specify the number of points that the random function is to generate if the function radio button is selected.

Scale/Radius : Is to specify a Scale factor of the imported xyz data points of the imported PLY file, if the PLY generation is selected, or the radius of the sphere of the random generated point data if the function generation is selected.

Define Cartesian Data : Is to import or generate the point data to be used to create the voxel matrix. This will also get the boundary of the volume that this data will occupy in 3D space and update the start and end boundary limits. If the user wishes, these boundary limits can be changed.

Hex Size : This is the size of the resultant hexagonal voxel grid cells. The size chosen will determine the level of detail of the point data to be viewed.

Generate Voxels : Pressing this button will create a matrix of hexagonal voxel cells. A value is given to each cell to indicate the number of points that exist within it, or for the case of a importing data from a .ply file and activating the Ply average z option. The average z value of all the points within a voxel cell.

Data Range : Widget to select the range of number of points that each voxel cell must have for that voxel cell to be displayed on the screen.

Step vc02 : Select the .ply file selection button to open a file selection dialogue. Navigate to the directory Data that this application executable is located within and select the file named

hex_surface.ply

The button text should now have the text hex_surface present.

Step hc03 : If the ply file radio button is not selected, then select it to highlight and activate the selection that the unstructured Cartesian data in the ply file hex_surface.ply is to be displayed as a set of structured hexagonal voxel cells. If the Ply Average z checkbox is not activated, then activate this option by selecting the checkbox so as to have it highlighted with a tick mark.

Step hc04 : The number of points has no effect in this case, so can be ignored. The hex_surface.ply data is known to have the x,y,z data values are in the range of ± 10.0, which should be fine to leave the Scale/Radius value as 1.0. If it is not 1.0 then change the Scale/Radius value to 1.0.

Step hc05 : Press the “Define Cartesian Data button to import the hex_surface.ply xyz point data set at at scale factor of 1.0. The values of the volume limits to create the voxel matrix should change and be in the rage of ± 10 units.

Step hc06 : For a reasonable representation of the data, change the Hex size to 0.5 units. Press the Generate voxels button.

In the viewer display, a default view of white points representing the centers of the hexagonal grid voxel cells should appear in the shape of a flat grid If necessary, rotate and/or move the camera to get a better view of this data.(Fig 17b).

To obtain an image of the hexagonal voxel cells such that the cells are colored and sized to give an indication of how many data points exist within each cell, select the shader tab (fig 13b) . Entering in the vertex shaders to use and defining shader variables is performed as in the section **Visualising Hexagaonal voxel object**. The steps to perform the task to define the shader code files and variables will not be described here. What the user can do is to import a parameter file with all these parameters defined.

Step hc07 : Select the “Load” button at the bottom right of the shader widget to bring up the file dialogue to select a shader parameter file to import. Navigate to the directory Examples/Shader/Hex_Surface and select the file hex_surface_columns.twm. This will load the shader parameters needed to display the hexagonal voxels.

Step hc08 : The directory path names to the vertex, point, geometry and fragment shader pathnames will probably be be different to that on the user computer. One by one, select the button for each of the vertex and point files to open a file dialogue and navigate to the directory

<user directory this application exist within>\Example\Shader\Default\Hex_surface\

and select the hex_surface_HS_VS.glsl, and hex_surface_HS_PGS.glsl, files that are listed. For the fragmant shader program file, select the fragment shader button and navigate to the directory

<user directory this application exist within>\Resources/Shaders/Default/Hex_surface

and select the file

default_hex_surface_HS_FS.glsl

Step hc09 : Press the Shader update or regeneration button to generate the shader program. No error messages should occur. If an error message(s) are present, it is because an incorrect shader file has been selected or a variable name has been changed or is absent, or not defined to be used. Examine the error message and make the appropriate correction.

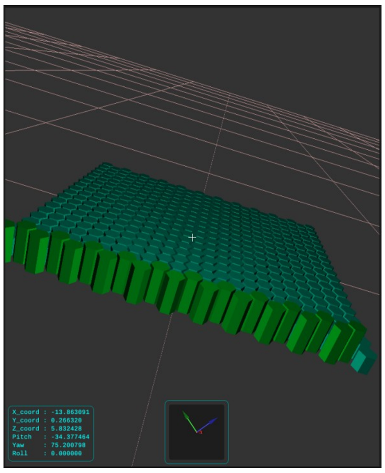
Step hc10 : If The display is blank (it should not as this problem has been fixed), it is due to a programming bug having the voxel size set to zero that has not yet been fixed. Just go back to the voxel generation tab widget and move the voxel scale slider to display the voxels. A view similar to fig 17c should now appear in the viewer panel.

The colors and hieght of the individual hexagonal voxel columns give an indication of the average z value of the points that exist within eac hexagonal voxel cell. By moving the slider widgets named min_density and max_density, the user can specify the range of data points that are to be displayed. Moving the min_density will mean that only voxels with data points above this value are considered, while moving the max_density slider means that only data points below this value are considered. Red colors are voxels with high number of data points in this specified range, while violet to purple, low number of points in the specified range that exist within the voxel cell.

Step hc11 : Go back to the to the Cartesian widget tab and deselect the Ply average z checkbox. Repeat steps hc05 and hc06 so as to generate for each hex voxel cell, the number of points that exist within that cell. The diaply should change and have a similar appearance to that of fig 18a.

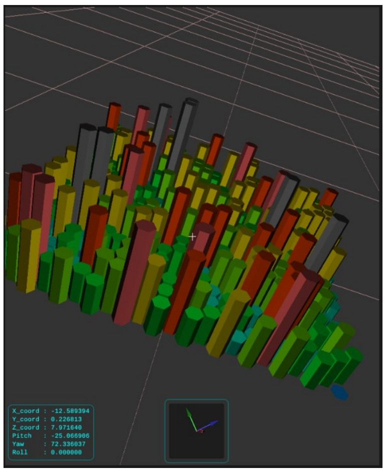
The same procedure for displaying the data of a .ply file can be applied for a function as well. If the user now repeats the above steps hc02 to hc06, but select the radio button “Function”, and from the drop down list of the Random Generation option select square, what should be seen in the display is something similar to fig 18b. The column heigths in this cas representats the number of points that lie within each hexagonal voxel cell.

If user were to select the option Circle from the random generation drop down list, change the Scale/Radius value top 5.0 and perform step hc05, the start and end coordinate range should change to ± 5 units. Change the x and y start coordinates to -10.0, and the x and y end coordinates to +10.0. performing step hc06 should result in something similar to fig 18c being displayed. A circle of random points of radius 5 units.



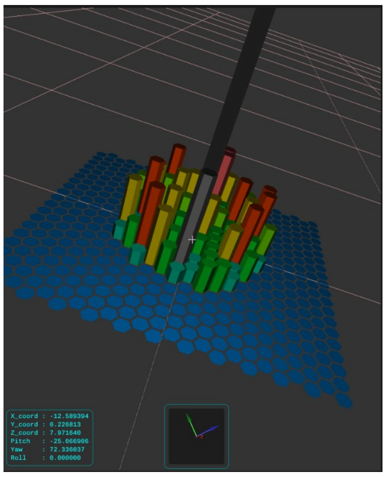
```
X_coord : -13.863091
Y_coord : 0.266320
Z_coord : 5.832428
Pitch   : -34.377464
Yaw     : 75.200798
Roll    : 0.000000
```

Fig 18a



```
X_coord : -12.589394
Y_coord : 0.226813
Z_coord : 7.971640
Pitch   : -25.066906
Yaw     : 72.336037
Roll    : 0.000000
```

Fig 18b

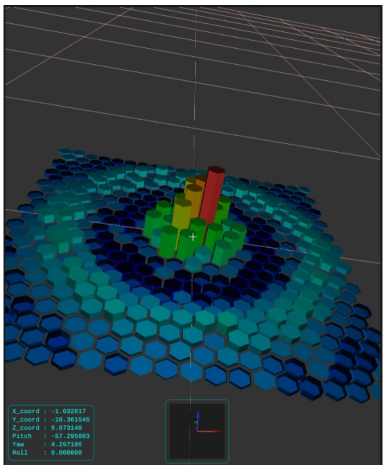


```
X_coord : -12.589394
Y_coord : 0.226813
Z_coord : 7.971640
Pitch   : -25.066906
Yaw     : 72.336037
Roll    : 0.000000
```

Fig 18c

A provision to allow a function of z coordinates can be also created in code to allow a display similar to fig 17c to be viewed rather than just the number of points that exist within each hexagonal voxel cell. Select function from the random generation drop down list, make sure the Ply Average z option is activated and that the scale/radius value is set to something like 5.0. Repeat steps hc05 and hc06 to generate the hexagonal voxel data, and a display similar to fig 19 can be obtained after modifying the min_height and max_height of the shader variable sliders. Note that the heights of these columns are low because an average of all of the data points within each cell is calculated. The height of the columns can be changed by changing the scale/radius value and repeating steps hc05 and hc06.

Other possibilities can be applied in code to create other forms of data for computer graphics, simulation and automata. It is up to the user programmer to create such applications.



```
X_coord : -1.032017
Y_coord : -10.361545
Z_coord : 6.673148
Pitch   : -57.295883
Yaw     : 4.297186
Roll    : 0.000000
```

Fig 19

Writing the Code for the generation of voxel data using a Compute Shader program

Virtual worlds compute shader code uses a system that requires only certain customised snippets of code to create the data and display graphics without the need to reuse and copy blocks of the same required glsl code in every file. Without too much further detail, a simple format of this snippet code to be in a Virtual Worlds glsl compute,program is given in listing sc01

```
begin_function
<user defined functions and variables>
end_function

begin_expression
<user defined variables and main function>
end_expression
```

Listing sc01

Between the begin_function and end_function block identifiers the functions and variables to use in them are defined.

Between the begin_expression and end_expression block identifiers is the main function code and the variables to use in the main function. The main function block code “main() {“ to begin the main function or “}” to end the main function must not be used as this is added by the Virtual Worlds application.

In using the application, the user may define some uniform variables such as “a” in the **Generating a HCP voxel object** section, or the uniform variables “min_height”, “max_height” in the **Visualising HCP voxel object** section. These uniform variables are added to the final shader code text string that is compiled by the application, so there is not need to add any additional text like “uniform variable_name” to these section blocks. Doing so will create a compilation error that a variable has been redefined.

The code however must have any uniform variable defined in the application used in the custom shader snippet code to be of exactly the same name. A common compile error that can occur is to use names in the shader code that is different, or is not defined by the user in the application.

Another restriction in writing this custom shader code is that there are certain reserved words for variables that cannot be used or a redefinition of variable names compilation error is generated.

For all of the the shader code the user should not use the version number of the glsl code. eg #version 430 core

The compute shader custom user code has a few restrictions on the names of variables that the user cannot use. The following variable names are reserved and should not be redefined.

voxel_size
threshold
min_surface_value
max_surface_value
e_time
frame
origin
matrix_dimension_x
matrix_dimension_y
matrix_dimension_z
min_voxel_value
max_voxel_value
invalid_voxel_value
value

The voxel generation shader program will have other internal variable names that are reserved as well as function names depending on which type of data generation is being performed. If the user gets a compilation error because of a redefinition, a renaming of that variable or function will be needed in the custom shader snippet code.

When a compilation error occurs, the code logger will display the entire shader code program with line numbers and the compile error message to be corrected. The error message should only concern the custom code that was created in a text file by the user. The user should correct the errors, and then attempt to submit that code to be used in the voxel generation or displaying graphics.

Below in listing sc02 is an example of the compute shader code used to generate the sphere of the section **Generating a HCP voxel object**.

```
begin_function


end_function


begin_expression
    if((a*a-(x*x+y*y+z*z)) > 0){
       value = uint(abs(a*a- (x*x+y*y+z*z)));
     } else
       value = invalid_voxel_value;
end_expression
```

Listing sc02

The generation of the voxel vertex data is of the form of using the mathematical relationship

$$\text{voxel value} = f(x,y,z) = \text{radius}^2 - (x^2+y^2+z^2) \quad \text{- eqvg-01}$$

what the code in listing sc02 does is to calculate the mathematical relationship defined by eq vg-01, and if it greater than zero, assign the voxel at location x,y,z (which is a location of the center of a HCP voxel) this value, otherwise assign an invalid value to the HCP voxel at that x,y,z location. Without going in to details, voxels with an invalid value are not displayed by the application.

As can be seen from this code, no user defined functions have been made, but there are variables a, x,y,z, value and invalid_voxel_value that are not defined. Even though there are no custom functions or variables defined, the function section with the block code identifiers begin_function and end_function must be present, or an error will occur in attempting to read the file that this custom program snippet exists in.

For the HCP compute voxel generation shader, x,y,z are reserved variable names defined by the core HCP compute shader code that the user cannot access. However the variable a is a uniform variable, and the same variable name defined in the section **Generating a HCP voxel object** that was given in the generation variables widget. This variable a is the radius that the user can change in the application to use to explore or get different results in generating voxel matrix data.

The variable invalid_voxel_value is a uniform variable that is defined by the application, and value is an internal shader variable of type unsigned integer that is used to assign a value from the compute shader program back to the application so as to be stored and used in displaying this generated data. This value must be used in every generation of voxel data.

This is the simplest of examples of how a custom compute shader snippet code can be defined.

Other examples of using this system can be found in the Examples directory in which the executable file of Virtual Worlds exists in.

Creating custom shader programs to display generated voxel data

The vertex, geometry and fragment shaders used to display the generated voxel data are all dynamically generated and managed by the Virtual Worlds application during its execution. Thus a certain knowledge and skill of the glsl programming language and will be needed for one to create a custom shaders to display voxel data outside the provided shaders.

Virtual Worlds is designed as closely as possible to compile vertex, geometry and fragment shader code written in a similar fashion to C. Include statements of separate external files can be defined so as to better organise and reuse code. With this a design concept, predefined glsl files need to be included with every vertex,geometry and fragment shader code file. A main function must be present as with all glsl to compile correctly and run.

For the creation of a custom shader program,default template shader programs for the vertex, geometry and fragment shaders exist within the directory Assets/Shaders/Default/, which can be copied and saved to a designated directory to be modified. There are include statements within these templates that are to load mandatory predefined text files of glsl code that are essential for the display of voxel point cloud data. A relative path name from the location of the source code should be reflected in this include statement. If a compilation error occurs that these predefined glsl files cannot be found because the path name is incorrect, then the user needs to modify the line(s) with the include statement to give the correct path name to these glsl files, as with any normal C/C++ code.

The code of a template for any shader program is of the structure given in listing CSP-01.

```
#version 450 core

// -------------- Shader Reserved Uniforms -------------------

//#include "shader_basis_code/Universal_reserved_uniforms.glsl"

#include "shader_basis_code/vs_reserved_uniforms.glsl"

// Comment uncomment following as needed
//layout(location = 1) in vec4 color;
//layout(location = 2) in vec3 nomrmal;
// -------------- User Defined Uniforms ---------------------

// -------------Application dynamicly defined uniorms---------
// Do not delete next line with DDU as application defined uniforms are placed here
// Must exist in every glsl code unless user wishes to manually enter uniforms that
// the application generates.
// #DD#

// -------------- Shader Reserved functions ----------------

// -------------- User Defined Functions -------------------

void main(){
        vertex = vec3(vertex_data.x,vertex_data.y,vertex_data.z);

        gl_Position = vec4(vertex, 1.0f);                  // required as a min
        //gl_Position = mvpMatrix* vec4(vertex, 1.0f); // required as a min if not using geometry shader program
        value = int(vertex_data.w);                        // required as a min

        vs_out.varyingColor = vec4(1.0,1.0,1.0,1.0);
}
```

Listing CSP-01

Within this template are sections below the comments statements with User Defined where the user can add their own variables and/or functions. Other sections are given that that need to be present for the Virtual Worlds application to add code to before compilation begins.

The shader program will have variable names that are reserved as well as function names depending on which type of data generation is being performed. If the user gets a compilation error because of a redefinition, a renaming of that variable or function will be needed in the custom shader snippet code.

For the vertex, geometry, fragment shaders the reserved variable name that should not redefine are

vertex;
voxel_value;
value;
mvpMatrix;
camera_loc;

camera_front_vector;
camera_up_vector;
camera_right_vector;
light_color;
lighting_direction;
ambience
specular_strength
lighting_intensity
camera_lighting_type
use_camera_lighting
lighting_camera_offset
t_frame
uniform float voxSize;
voxel_matrix_dimension;
voxel_origin;
voxel_hcp_z_increment;
voxel_min_surface_display_value;
voxel_max_surface_display_value;
vEnabledFaces;
flat out int gEnabledFaces;
VertexData
vs_out;
fvaryingColor;
raw_color;

If any of these are used in a custom vertex,geometry or fragment shader, a compilation error will occur.

These glsl code text files are created and modified using an external text editor of the users choice as there is no internal text editor that the virtual worlds application uses. Once a coded text file is created, the user then selects this shader file for the appropriate shader type under the shader tab of the selected application object that this shader program is to be used on.(**Fig 5a**, **Fig 5b**) To compile the custom shader program, click the checkbox on the right to have the box deselected (ie no tick marked) to indicate that the use of a the designated custom shader program is to be used, and then click the update button. (middle button with up arrow above the “clear variables” button after the list of shader variables.

The user can create uniform variables that the user can use and interactively change in the shader program by creating a shader variable of a particular datatype and name in the shader variables section of the object shader tab. The user can use this variable in their code of the same name and datatype to interact with the display of graphical data.

If the compilation was successful, (even if the display is not due to logical or other errors) then a message will be given in the application log. If not, then a message will be displayed stating this, and a listing of the resultant shader code and error message given in the code log panel. When errors occur or modifications need to be made, the user can make these changes in the text editor and recompile the shader code. The application will automatically discard the old shader program and define a new one to be used.

With knowledge and skill, the user can create a set of shader programs to display the data in any way they wish, with interactivity of changing variables in the shader variable section of the object file definition.

Examples

A series of examples to give an illustration of some of the capabilities of the Virtual Worlds application is given in the directory Examples. These examples are defined formatted text files of different types that are to be loaded into the appropriate sections of the application.

This directory is divided into

Automata : Simple cellula Automata rules

Generation : Examples of surfaces and volumes that can be generated

Shader : location of the default shaders that the application requires to function and examples of some simple custom shader programs that the user can load and compile, and then copy and modify

Each of these directories has a subdirectory related to the object type that this application currently has as modules that can be generated and viewed.

Also within the Examples directory are formatted files that are fully configured to display a geometry that the user can load into the application and then generate the objects, shaders and run any defined cellular automata rules.

Use the included user guide text as a guide to make changes, experiment or export geometry.