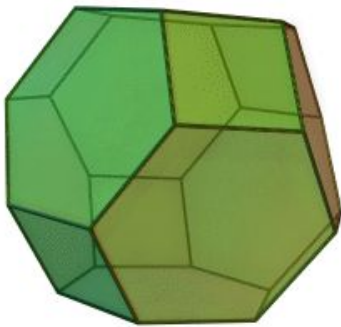


## AA2 Geometry shaders: a matrix of truncated octahedrons

### Introduction to computer graphics. Spring 2019. Delivery 2.

#### Exercise 1: (3 points)

Place 20 points randomly in a volume of 10x10x10. Make the points move in random amounts, always within the defined volume. Make the intensity of the random variations adjustable through a screen slider. Make a geometry shader that creates a truncated octahedron centered in each of the 20 points.



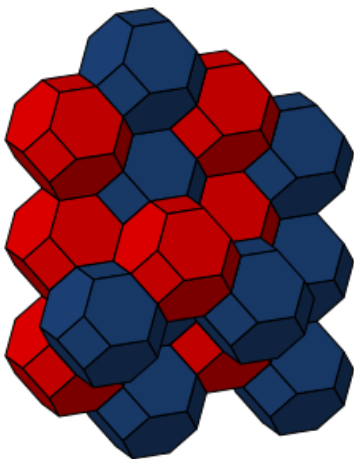
#### Definition

A truncated octahedron is a shape constructed from a regular [octahedron](#) with side length  $3a$  by the removal of six right [square pyramids](#), one from each point. These pyramids have both base side length ( $a$ ) and lateral side length ( $e$ ) of  $a$ , to form [equilateral triangles](#). The base area is then  $a^2$ .

From the properties of square pyramids, we can find the slant height,  $s$ , and the height,  $h$ , of the pyramid. See:

[https://en.wikipedia.org/wiki/Truncated\\_octahedron](https://en.wikipedia.org/wiki/Truncated_octahedron)

Figure 1: a truncated octahedron



**Exercise 2: (3 points) create a cubic lattice that mutates to a bitruncated honeycomb octahedron, in a way similar to the .gif shown in figure 4<sup>1</sup>.**

#### Definition

A bitruncated honeycomb is a particular arrangement of truncated octahedra, which completely fills the space. It can be derived from a lattice of cubes aligned with the axis, through growth. See:

[https://en.wikipedia.org/wiki/Bitruncated\\_cubic\\_honeycomb](https://en.wikipedia.org/wiki/Bitruncated_cubic_honeycomb)

**Hint:** create first the truncated octahedra, convert them into cubes, and then build the cubic lattice

Figure 2: the bitruncated honeycomb

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<sup>1</sup> Also available in

[https://drive.google.com/file/d/1Wna6xi1OMISeUAH1snQV9clpm\\_H6RQrd/view?usp=sharing](https://drive.google.com/file/d/1Wna6xi1OMISeUAH1snQV9clpm_H6RQrd/view?usp=sharing)

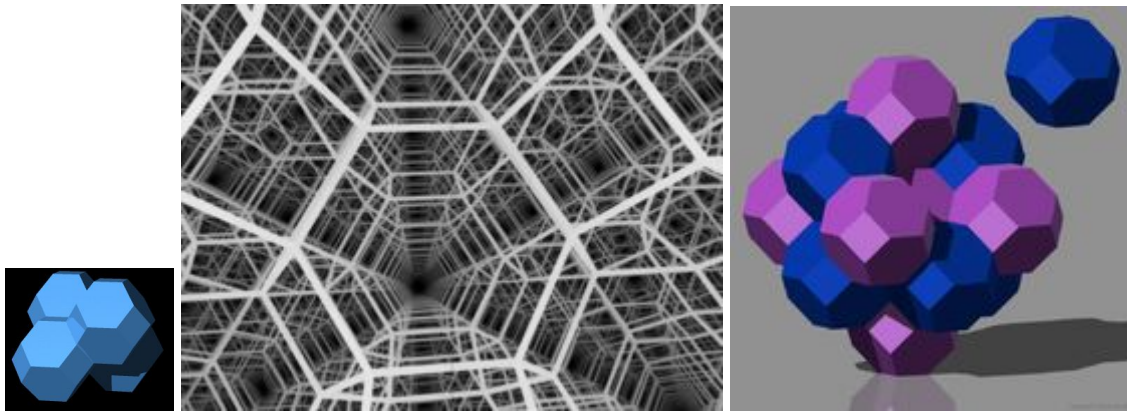


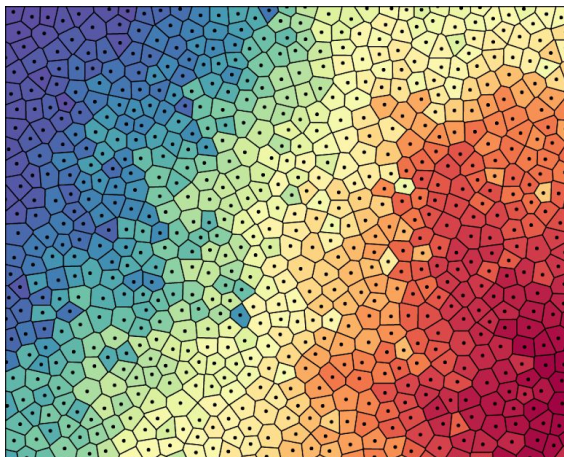
Figure 3: different visualizations of bitruncated honeycombs



Figure 4: gif animation (as created by students Arnau Macia and Edgar Rodríguez)

### Exercise 3: (4 points)

A different way of looking to a bitruncated honeycomb, slightly more abstract, is to consider it as the Voronoi diagram of a body-centered cubic lattice. To understand this, you must understand the following points:



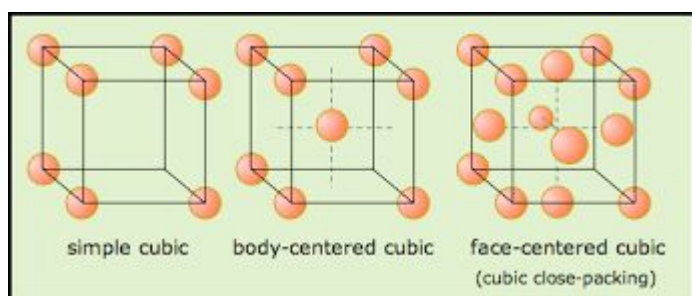
1. A Voronoi diagram of a set of points in 2D is a set of regions defined by the lines that separate a point from its nearest neighbours (see figure 5).

Voronoi diagrams are largely used in computer graphics for physically-based rendering, as well as to simulate living elements. For further details see, for example, <https://thebookofshaders.com/12/>

2. A body-centered cubic lattice is a set of cubes that fill in the entire space, but built around a set of points that are in the center of each cube (see figure 6). We call each of the points in the center of each cube a seed

**Figure 5. An example of a nicely coloured Voronoi diagram<sup>2</sup>**

3. The 3D Voronoi diagram of the seeds of a body-centered cubic lattice is a bitruncated honeycomb. This means that the truncated octahedron of the honeycomb are the voronoi cells of a set of body-centered cubes forming a lattice.
4. If we only consider the previous on the X-Y plane, the seeds of the body-centered cubic lattice simply define a grid of points on a plane, and the truncated octahedron becomes an octagon. The octagon is still the voronoi diagram of the seeds that are on the X-Y plane.



**Figure 6: the difference between a body centered cubic lattice and a face-centered cubic lattice.<sup>3</sup>**

<sup>2</sup> Source: <https://github.com/d3/d3-delaunay#delaunay>

<sup>3</sup>

Source: [https://chem.libretexts.org/Bookshelves/General\\_Chemistry/Book%3A\\_Chem1\\_\(Lower\)/07%3A\\_Solids\\_and\\_Liquids/7.08%3A\\_Cubic\\_Lattices\\_and\\_Close\\_Packing](https://chem.libretexts.org/Bookshelves/General_Chemistry/Book%3A_Chem1_(Lower)/07%3A_Solids_and_Liquids/7.08%3A_Cubic_Lattices_and_Close_Packing)

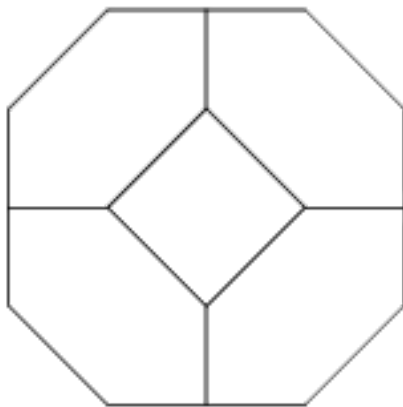
- a) Consider the lattice of truncated octahedrons drawn in exercise 2. Draw the seed of one truncated octahedron and the eight lattice points surrounding it on the X-Y plane ( $z=0$ ). Draw all the mediatrixes between the seed and the eight surrounding points. Make sure you use an orthonormal camera. (1 point)

If you have done it right, the mediatrixes should draw an octagon. This octagon is the 2D Voronoi diagram of the seed. This also corresponds to the silhouette of the truncated octahedron (see figure 7).

- b) Add random noise on the position of the 8 points surrounding the seed. When the positions of the 8 points changes due to the noise, the position and orientation of the mediatrixes will change. Make the noise adjustable through a slider in the GUI. (1pt)
- c) Draw the truncated octahedron aligned with the silhouette drawn before. The faces under the plane X-Y will appear as flat surfaces (`GL_TRIANGLE_STRIP`), but the faces over the plane X-Y will appear only as lines (`GL_LINES`), allowing to still see the seed and the faces below the X-Y plane. (1 point)
- d) Reprogram the geometry shader of the truncated octahedron in order that, when the positions of the points change due to the noise the faces of the truncated octahedron move accordingly, thus remaining always aligned with the octagonal silhouette defined by the mediatrixes. (1 point)

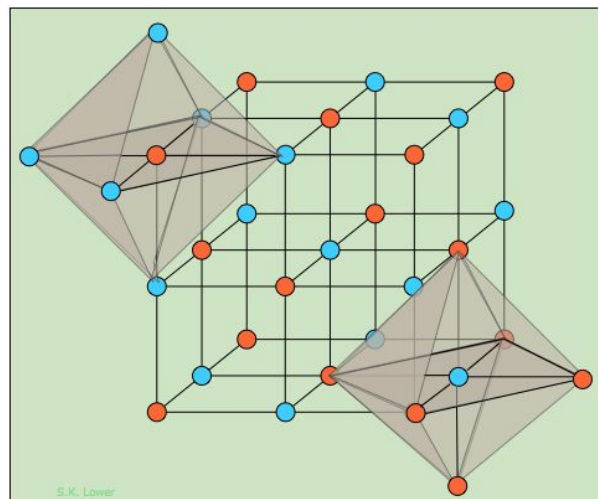
For this purpose, remember that the vertices were created from a (non-truncated) octahedron. For example, the points forming one hexagon in the truncated octahedron can be found taking one third and two thirds of the side of the triangle.

Before starting, make also sure that you understand the relation between the points forming the body-centered cubic lattice and the points defining the octahedron (see figure 8).



**Figure 7: Octahedron as seen from an orthonormal perspective. If we consider only a vertical plane aligned with the seed, we will only see the silhouette. In this orientation, it will correspond to an octagon.<sup>4</sup>**

**Figure 8: the elements defining the octahedron keep a very close relation with the elements defining the body-centered cubic lattice<sup>5</sup>**



<sup>4</sup> Source: <http://mathworld.wolfram.com/TruncatedOctahedron.html>

<sup>5</sup> Source idem than note 3

**Delivery format:** To do the task, use the starting project provided in class (GL\_framework.sln), and update **only** the file render.cpp

The delivery has 3 exercises, make them as scene modes and switchable with a ImGui button: **ImGui::Button("Click");**

Other GUI elements that you may require you will find how to use through the example window of ImGui.

Do not introduce keyboard input, and keep the camera manageable through the mouse.

The delivery must be a .zip file with the following elements:

- a) a clear readme.txt file explaining how to run the project
- b) the file render.cpp, with the code commented

The .zip file will be named: Delivery1\_GROUP\_MEMBER1\_MEMBER2.zip where GROUP is your group number (M01, for example), and each member appears as the combination of its first Surname and Name.

**As a reminder, if you use any other file of code, include it too!!**

**If the file render.cpp does not work immediately in the project, the rest of the delivery will NOT be corrected**