

3D grid cell visualisation software manual

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1. What is this software for?

This software has two main goals. First, to visualize the 3D receptive fields of grid cells in volumetric space, which is known to be a 3D lattice structure (Mathis et al., 2015. Probable nature of higher-dimensional symmetries underlying mammalian grid-cell activity patterns. eLife. 4, e05979). Second, to help users to understand a grid cell's activity that is modulated by the movement direction of an animal relative to the grid axis (Doeller et al., 2010. Evidence for grid cells in a human memory network. Nature. 463, 657–661). To learn more about how to investigate 3D grid cells in the human brain, please check my recent preprint (<https://www.biorxiv.org/content/early/2018/03/14/282327>).

2. Browser and device compatibility

Before we start, let's check browser and device compatibility. This software was developed with the Unity WebGL platform which currently supports Firefox 52, Chrome 57, Safari 11 and Edge 16 or later versions. Full browser compatibility can be checked here:

<https://docs.unity3d.com/Manual/webgl-browsercompatibility.html>. You might experience an unwanted crash if you try to open this software with an older browser like Internet Explorer 11. I mainly tested this software on a Windows 8 PC with Chrome 63. It does not support mobile devices or touchpads. It also requires a minimum screen resolution of 1024 x 384. In addition, a keyboard and a mouse with a middle button (=scroll wheel) are recommended to use the full features of this software.

3. Main menu screen

Once you load the webpage (which might takes a few seconds to a minute depending on the quality of your internet connection and computer), a welcome screen with three buttons will appear (Fig. 1). You can click each of three buttons to move to "1. Grid alignments", "2. Direction-modulated grid signal", or "3. Example 3D volumetric environment" scenes. Let's click the first "Grid alignment" button (it might take a few seconds to load this scene).

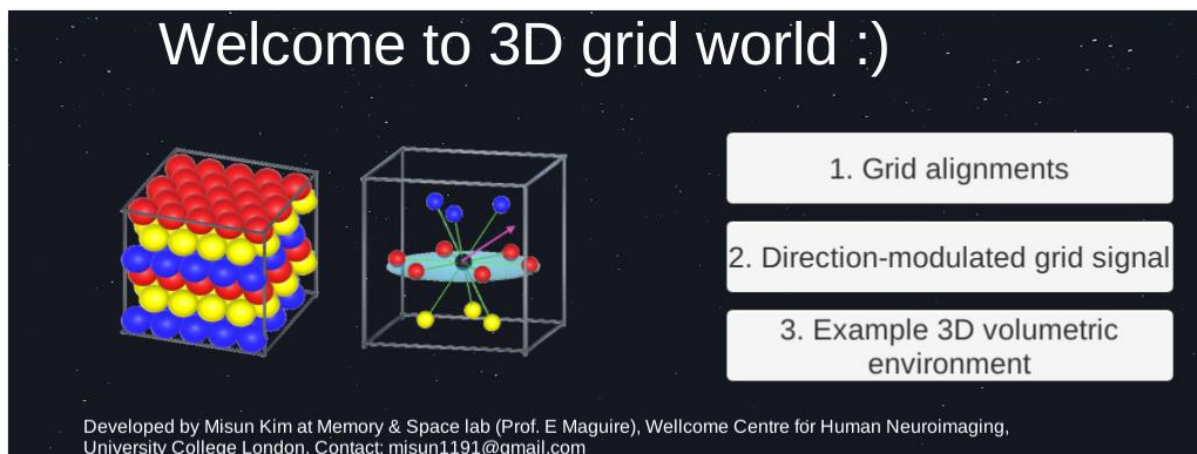


Figure 1. Main menu screen.

4. “Grid alignments” scene

You will see the colourful balls on the left half of the screen and some interactive buttons on the right side of the screen (Fig. 2). Grid cells in 3D volumetric space are expected to fire at locations (called “grid fields”) corresponding to the centre of these balls. The spatial layout of the balls is analogous to that of oranges or cannonballs tightly stacked inside a crate. You can see that each ball is surrounded by other balls with minimal gaps. The high packing density is thought to allow grid cells to efficiently encode volumetric space.

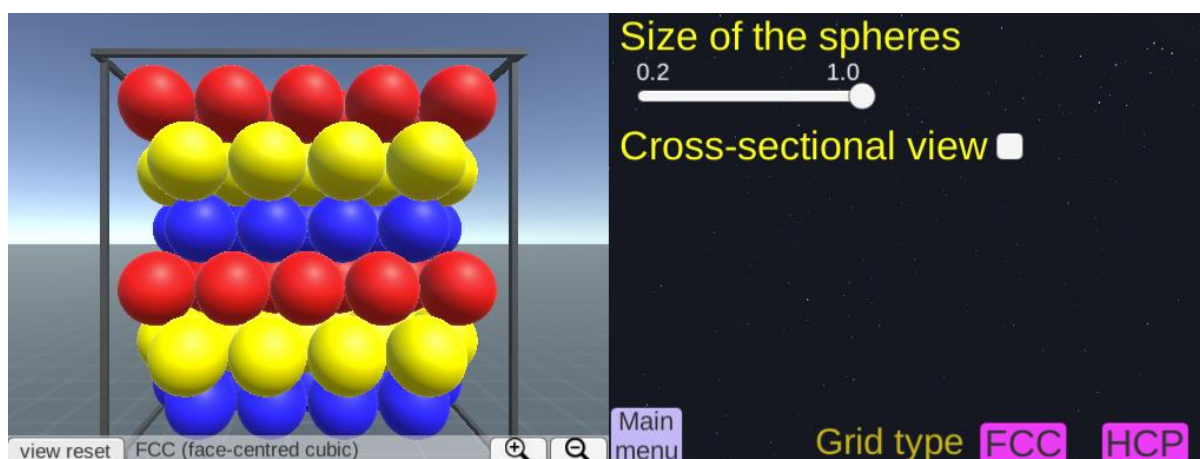


Figure 2. Grid alignments scene.

Here you can switch between two types of 3D arrangements, which are FCC (face-centred cubic) and HCP (hexagonal close packing), by clicking the pink buttons (“FCC”, “HCP”) at the bottom right of the screen. The current grid type is shown on the bottom of the left screen (Tip: You can open two webpages and display FCC layout in one and HCP in the other, and compare them side-by-side). Both FCC and HCP have equally high packing density. These 3D arrangements can be viewed as 2D hexagonal lattices stacked on top of each other with a translational shift between the layers. FCC is composed of three repeating layers (blue, yellow and red spheres) and HCP is composed of two repeating layers (blue and red spheres). To see the cross-sectional view, tick the box next to the “Cross-sectional view” on the right side of the screen (Fig. 3). Then, two sliders will appear. You can change the angle of the cross-sectional view by adjusting the “slant angle” slider. Then, you can move the cross-sectional view front and back with the “translate” slider (Fig. 4).

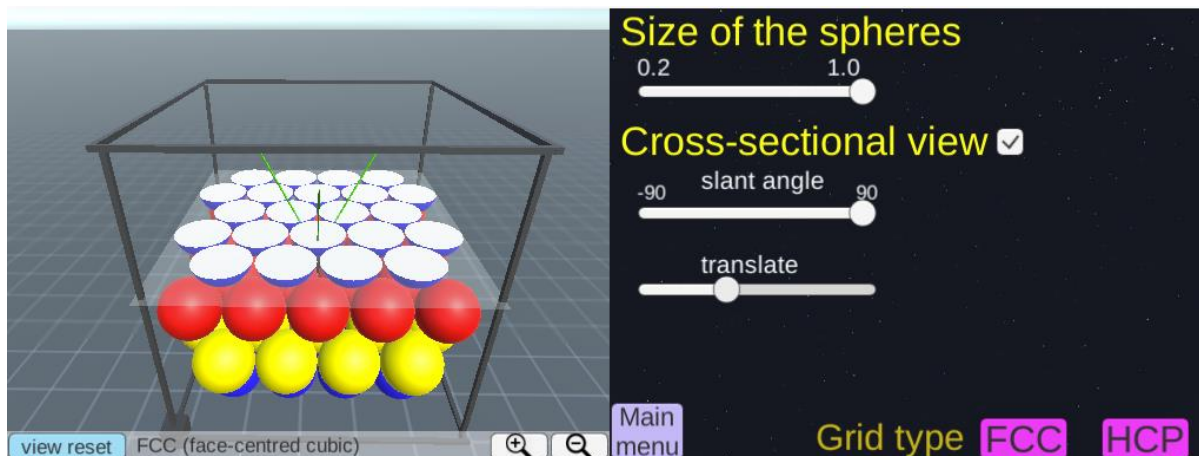


Figure 3. A cross-sectional view of grid fields at the level of the blue balls.

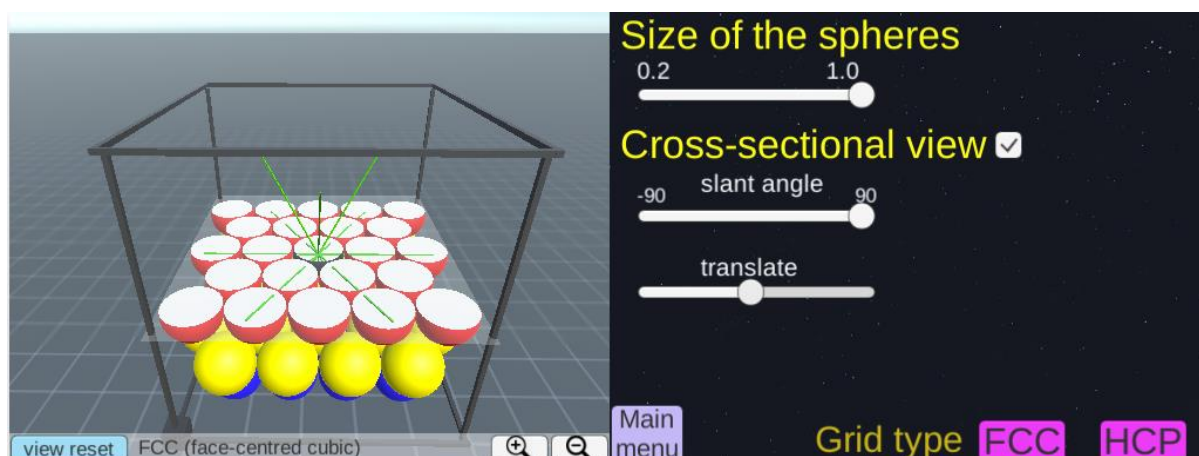


Figure 4. A cross-sectional view of grid fields at the level of the red balls.

If you hover the mouse on the left half of the screen (the one with the coloured balls), the cursor will change to an eye shape (*There is a cursor invisibility bug in Microsoft Edge). You can change the viewpoint using the mouse. To rotate, left click and hover. To pan, right click and hover. To zoom in and out (=the camera moves forwards and backwards), click the middle button of the mouse (which is a wheel) and drag the mouse up and down. If you don't have a middle button or you are using a laptop touchpad, don't worry, you can alternatively click the magnifier button to zoom in and out. (But I do recommend using a mouse with a middle button. A middle button permits smooth viewpoint changes). Below are examples of different viewpoints (Fig. 5). You can always go back to the initial viewpoint by clicking the "view reset" button.

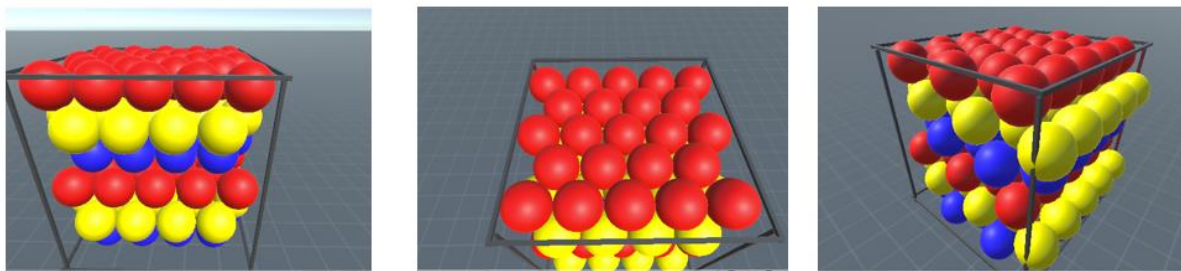


Figure 5. Different viewpoints.

You can also reduce the radius of the spheres to see the spatial layout of balls (Fig. 6). You simply adjust the slider under the “Size of the spheres” section. This will reveal the green line that links a centre ball (shown in a black colour) to its 12 neighbouring balls. These green lines are the “grid axes” which are the important property of grid cells that will be explained more detail in the next scene “2. Direction-modulated grid signal”. Meanwhile, you can zoom in and move the camera inside the balls, and if you rotate the view point, you will feel like you are surrounded by hundreds of floating balls in 3D space. Once you finish exploring the 3D grid lattice, you can go back to the “main menu” scene by clicking the “main menu” button.

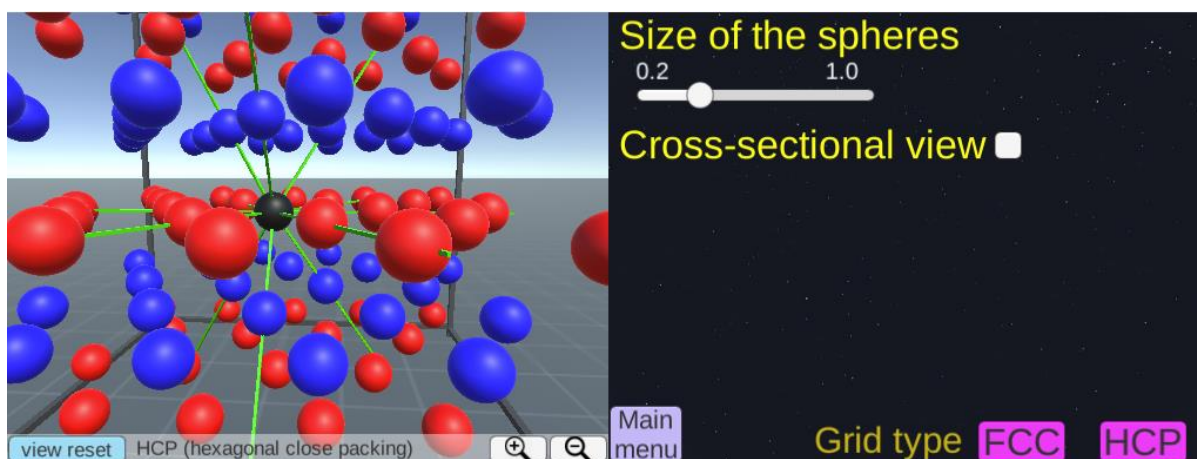


Figure 6. The radius of the spheres are reduced in this example.

5. “Direction-modulated grid signal” scene

In this scene, you will again see the balls on the left side of the screen and the interactive buttons and sliders on the right side (Fig. 7). Unlike the previous “grid alignment” scene which contained hundreds of balls, there are just 13 balls in this scene. This is a unit cell of a 3D grid lattice. Each ball is surrounded by twelve balls (green lines linking the centre black ball to the surrounding balls). It has been reported that grid cells fire more when an animal is moving along the direction aligned to these green lines (“grid axis”). This direction-modulated grid signal was only tested in rodents moving on a flat 2D plane, but here I assume this principle will also hold in 3D (no electrophysiological recordings are available yet that address this issue). The black arrow on the left screen represents the movement direction of agents which can be rodents, bats or humans. Users

can change the movement direction using the slider bar on the right side. “Azimuth” is the horizontal component of the 3D vector (e.g. turn clockwise 60 degrees, in a 2 o’clock direction) and “Pitch” is the vertical component of the 3D direction (e.g. tilt up by 40 degrees). If you change the movement direction, the black arrow rotates accordingly and the nearest grid axis turns from green to white (if the black arrow sits equidistant from multiple green axes, only one green axis will turn to white). The angle to the nearest grid axis (the numerical value is shown on the right side) is used as a grid alignment score that predicts the activity of the grid cells (yellow bar graph). When the movement of an agent is aligned to the grid axis (small angular deviation), grid activity will be high (Fig. 7, the long yellow bar). In contrast, when the movement of an agent is not aligned to the grid axis (a large angular deviation), grid activity will be low (Fig. 8, the short yellow bar). Of note, as in the previous scene, you can change the view using a mouse left, right, and middle click to closely examine the angular deviation between the movement direction (black arrow) and grid axes (green and white lines). You can also switch between the FCC and HCP arrangements.

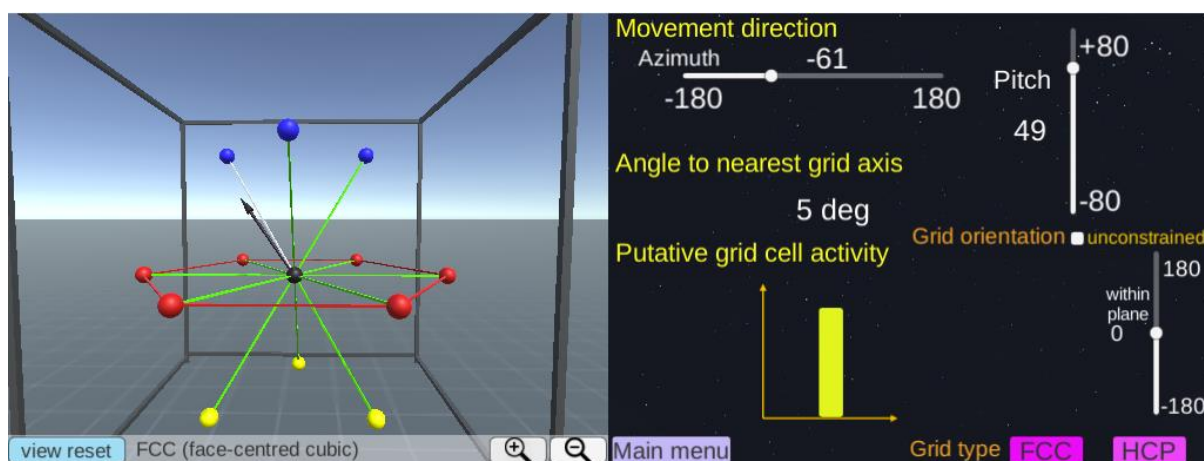


Figure 7. Direction-modulated grid signal. When the movement direction is closely aligned to the grid axis.

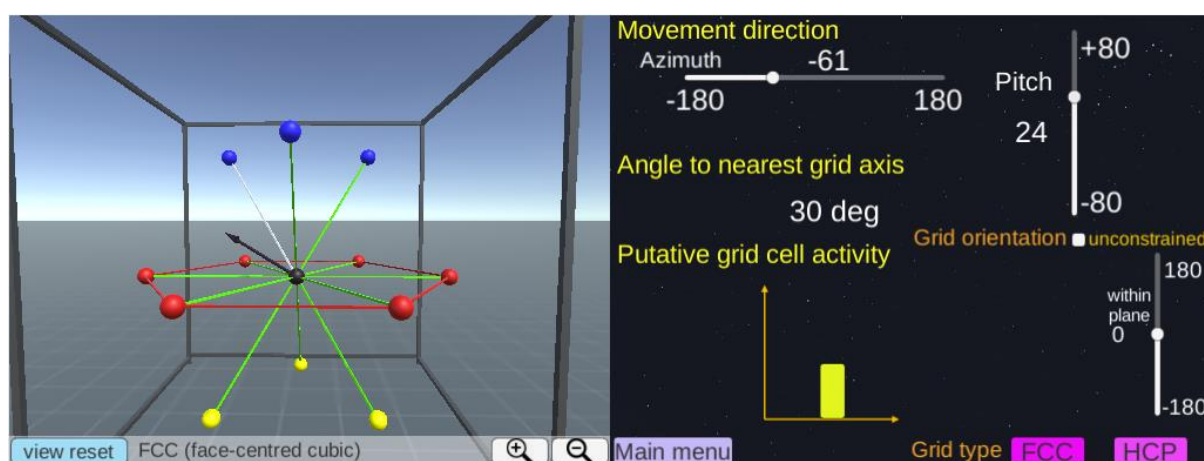


Figure 8. Direction-modulated grid signal. When the movement direction deviates from the grid axis.

Importantly, the orientation of the grid axis relative to the environment (the rectangular frame in the left screen) can be different for different agents and different grid cells. Therefore, even when

two agents move in the same direction, grid cell activity can differ depending on the orientation of the grid axis. To understand this, users can change the grid orientation using the slider bar under the “grid orientation” section. In the examples below, grid activity is high for one grid orientation (Fig. 9, “within plane”=-3) and low for other grid orientation (Fig. 10, “within plane”=22).

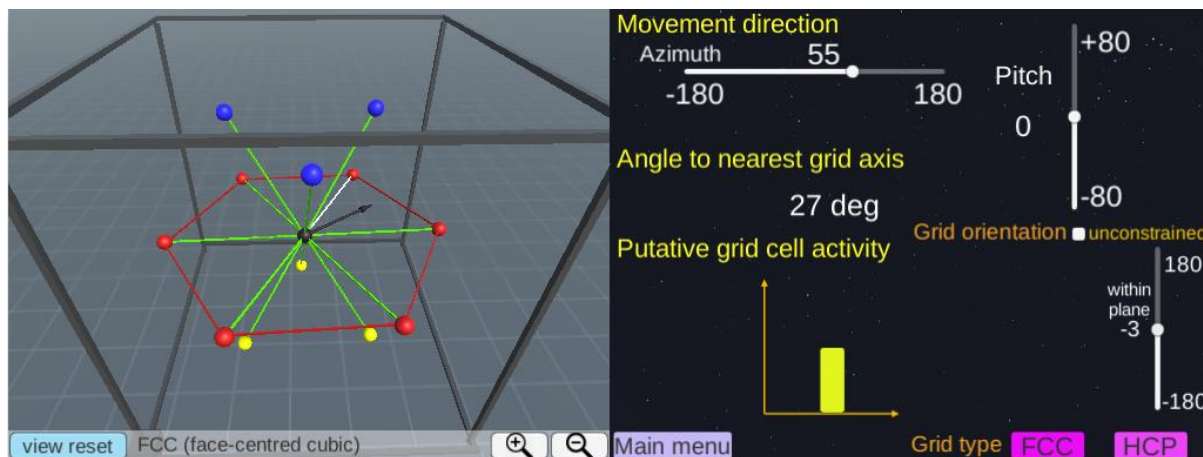


Figure 9. Direction-modulated grid signal for different grid orientations (e.g. orientation=-3deg).

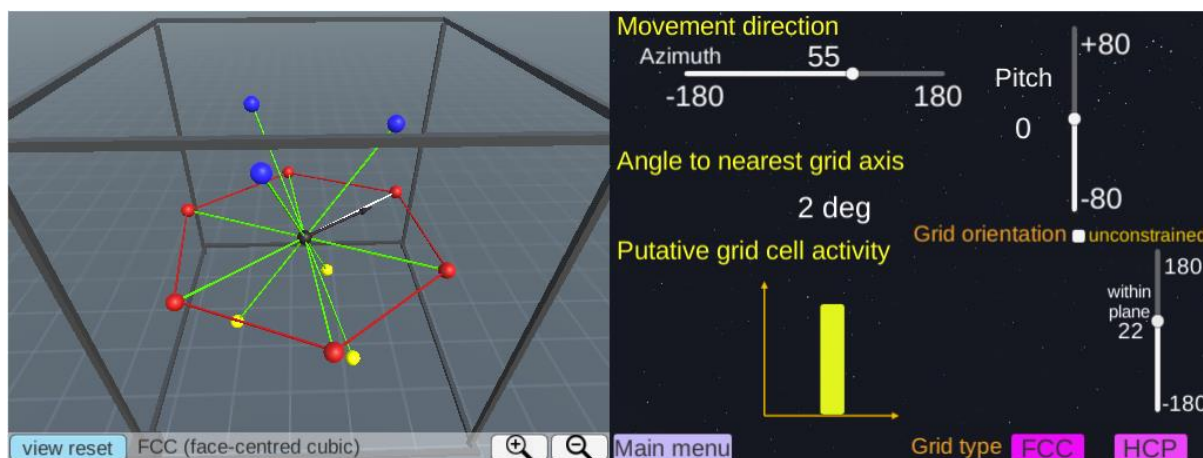


Figure 10. Direction-modulated grid signal for different grid orientation (e.g. orientation=22deg).

There is a question about whether there should be any constraints on the grid orientation relative to the environment. In the above examples, the grid axis rotates along only one axis so that six grid fields (the red balls) remain parallel to the ground, because grid cells show such hexagonal lattice patterns on a horizontal 2D plane. But the grid axis might be rotated along any three arbitrary axes in 3D. Users can explore this unconstrained rotation option by ticking the “unconstrained” box. Then, two additional sliders bars (“normal pit” and “normal azi”) will appear and users can now adjust the three rotation angles (Fig. 11).

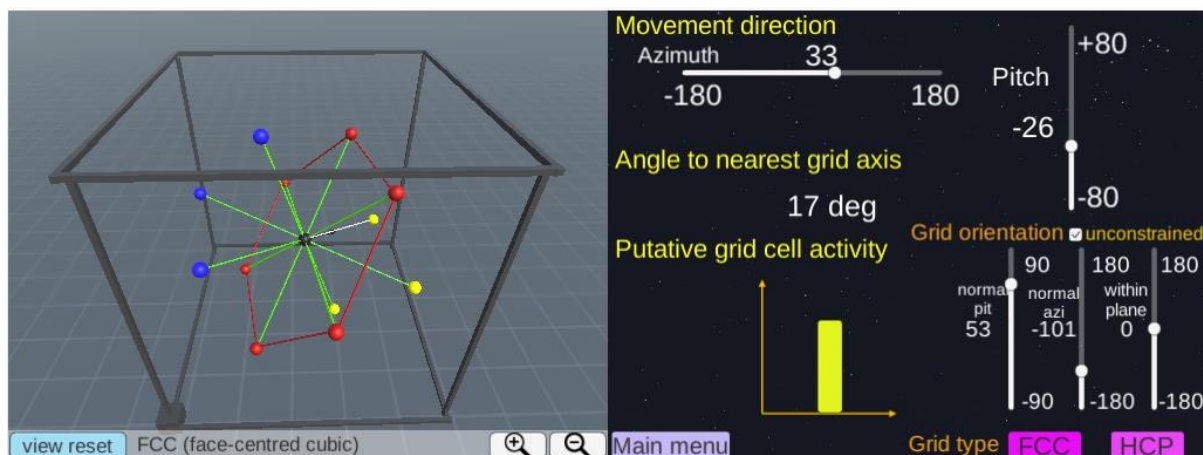


Figure 11. When grid axis is rotated freely along all three axes.

6. “Example 3D volumetric environment” scene

In this scene, you can see an example volumetric 3D space (“spaceship”) where 3D grid cells might develop (Fig. 12). This is a virtual environment that I devised to investigate 3D grid cells in the human brain (<https://www.biorxiv.org/content/early/2018/03/14/282327>). Users can explore this environment by rotating (press up/down/left/right arrow keys) and moving forward (‘w’) and backward (‘s’). I hope you don’t feel nauseous when you float in this virtual zero gravity environment!



Figure 12. A virtual spaceship environment.

7. A final note

I hope you enjoy exploring the world of 3D grid cells with this software. If you have any questions, email me (Misun Kim, misun1191@gmail.com). I developed this software using Unity 5.4, employing some of the shader, textures and objects that I downloaded from the Unity Asset Store. These are the examples of Unity assets that I used:

<https://assetstore.unity.com/packages/vfx/shaders/cross-section-66300>

<https://assetstore.unity.com/packages/3d/environments/sci-fi/clean-sci-fi-modular-corridors-and-rooms-32700>

<https://assetstore.unity.com/packages/3d/environments/sci-fi/extreme-sci-fi-lite-50727>

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