Perceptual Optics

3. Bank Necessities

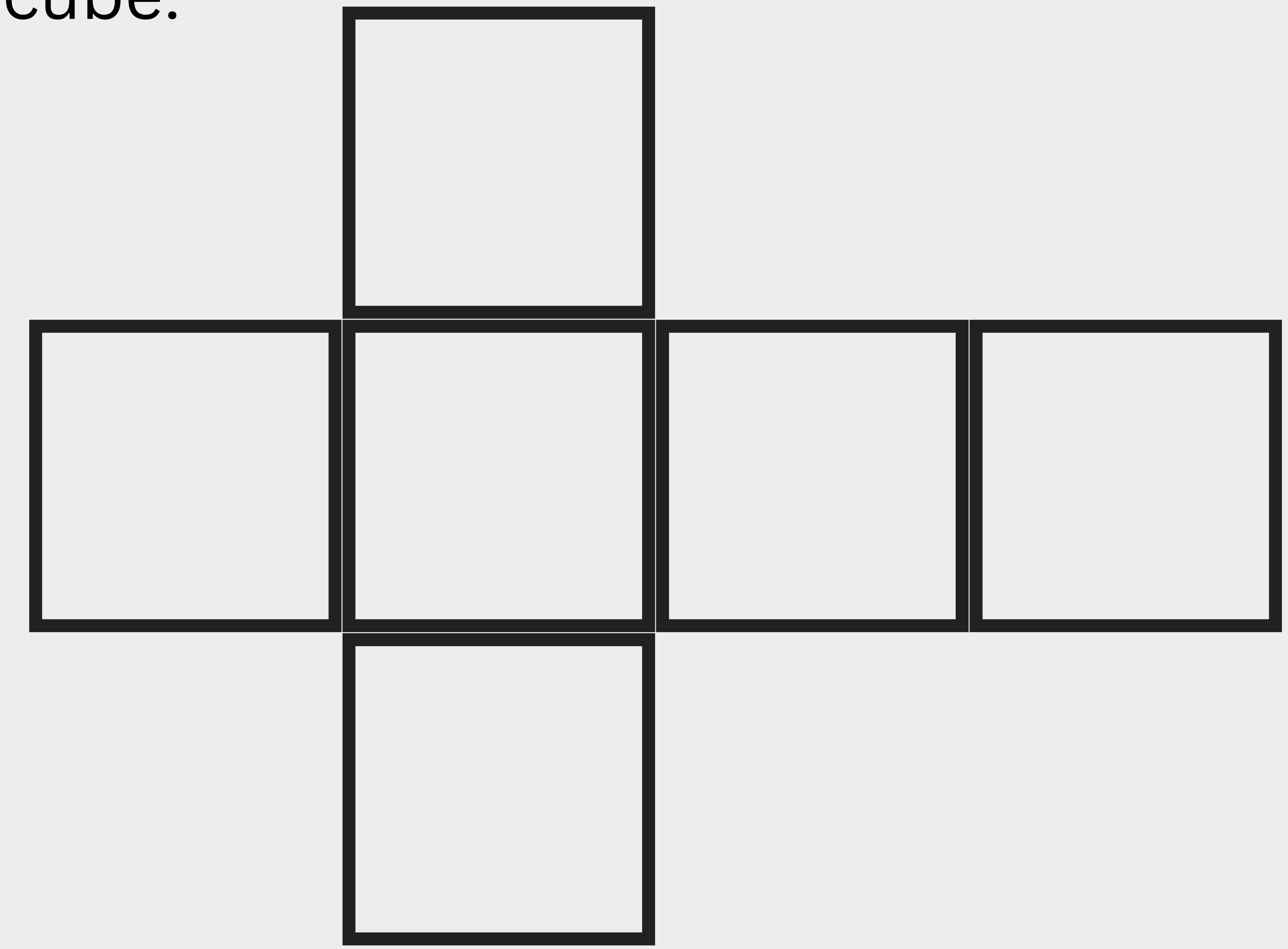
3. Bank Necessities

Outline of this class:

- Illusions
- Baddeley's working memory model and bank theory
- Mapping pixels on a spherical surface
- Understanding 3D vector orientations
- Voxel location mapping options
- Spatial movement of attention
- Color opponency and representation
- Postulated storage map within the bank
- Chirality and mirroring of bank
- Exploring neural correlates underlying Baddeley's working memory model and bank theory

Illusions

Task: Mental manipulation. Close your eyes and use your imagination to fold this cutout into a 3D cube.



Takeaway:
Demonstrates our ability to mentally rotate and envision in 3D.

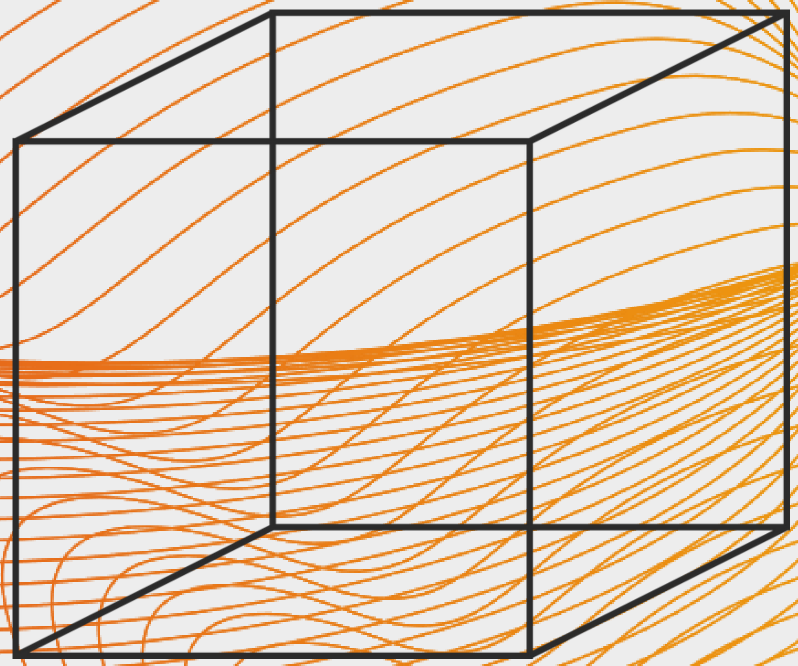
Illusions

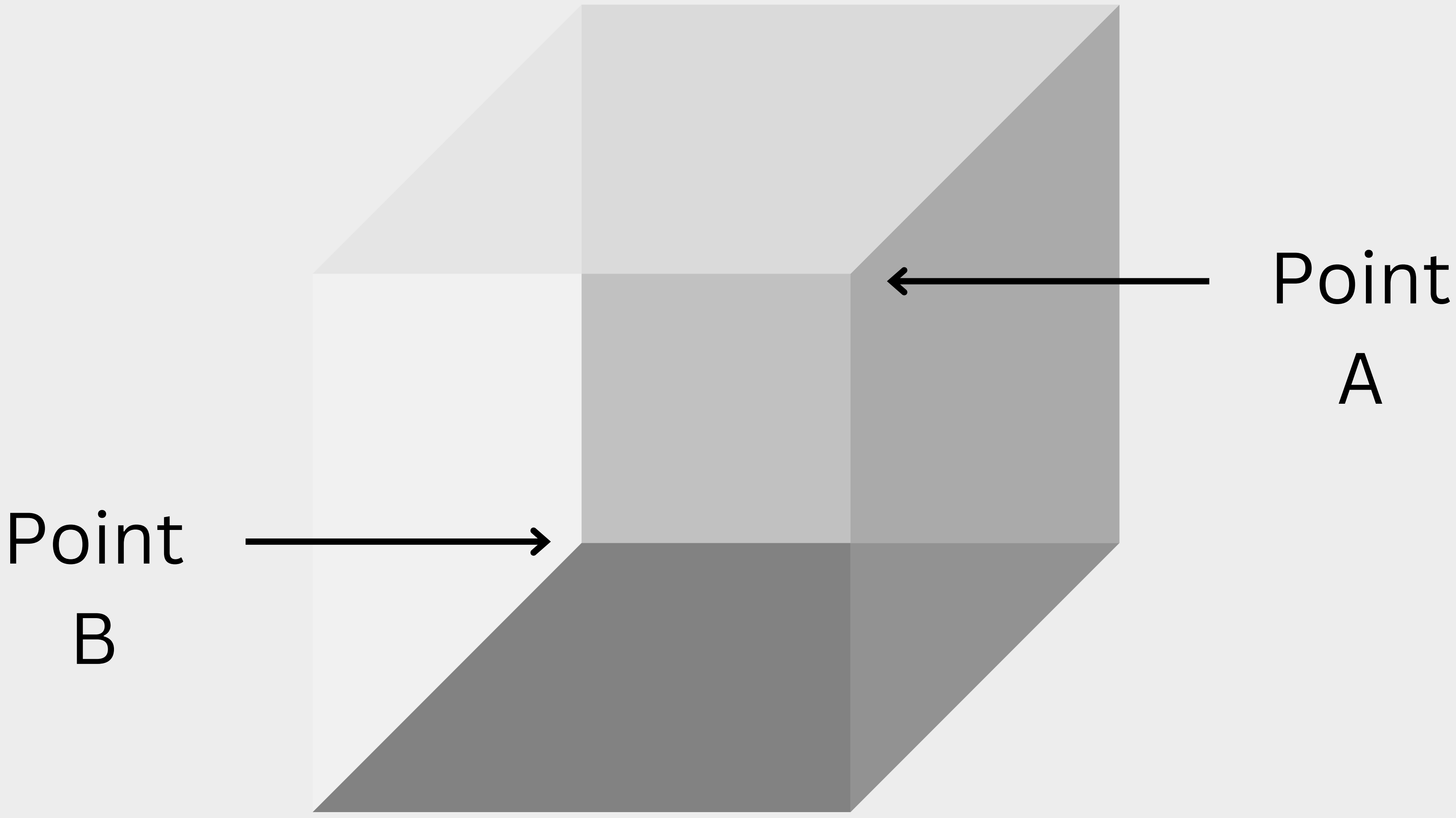
Task: Moving mind's eye. Close your eyes and ask, how many windows are in your living room?

Takeaway:
Attention can move within imagination to count. (You probably envisioned the room, then counted along one wall, then counted along another wall).

Illusions

Task: Necker cube. Imagine point A facing you, then imagine point B facing you.

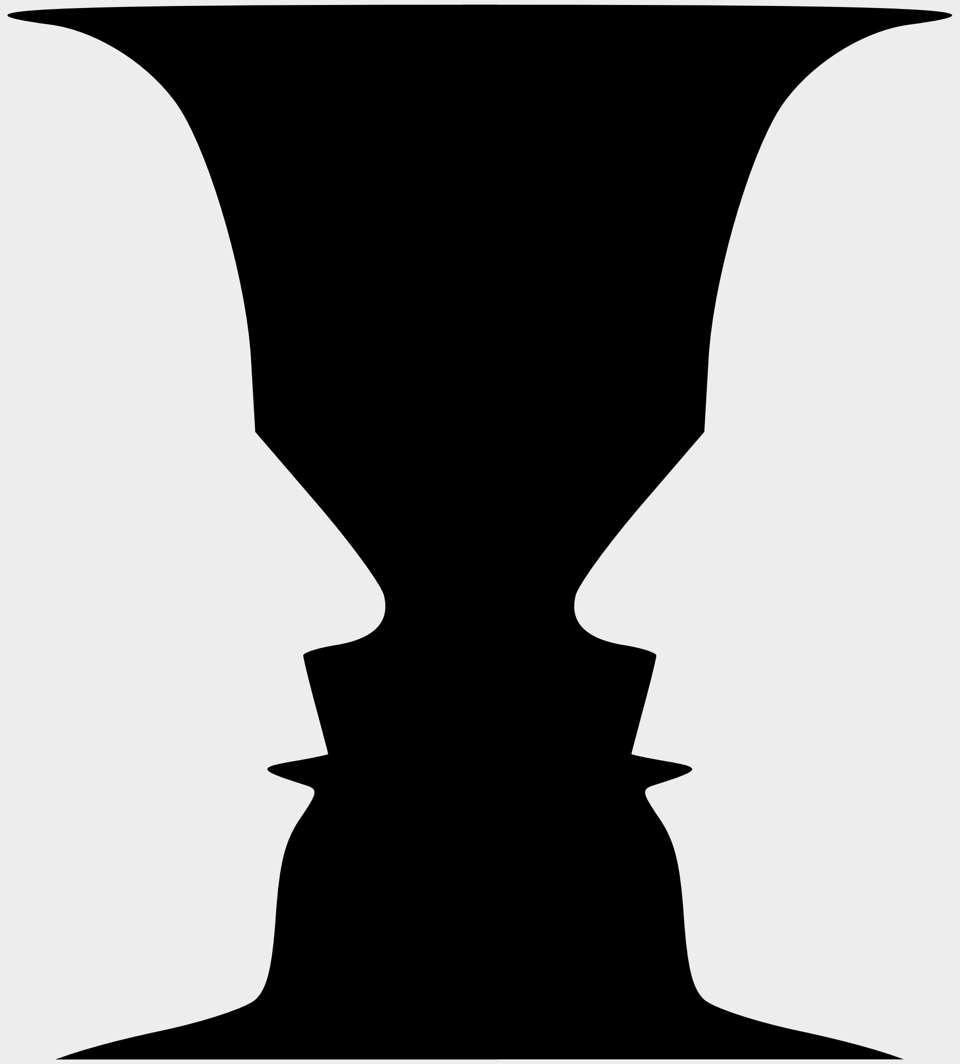




Takeaway:
Identical visual input can result in two completely differently oriented perceptions of a cube.

Illusions

Task: Rubin's vase illusion. See the faces. Then see the vase.

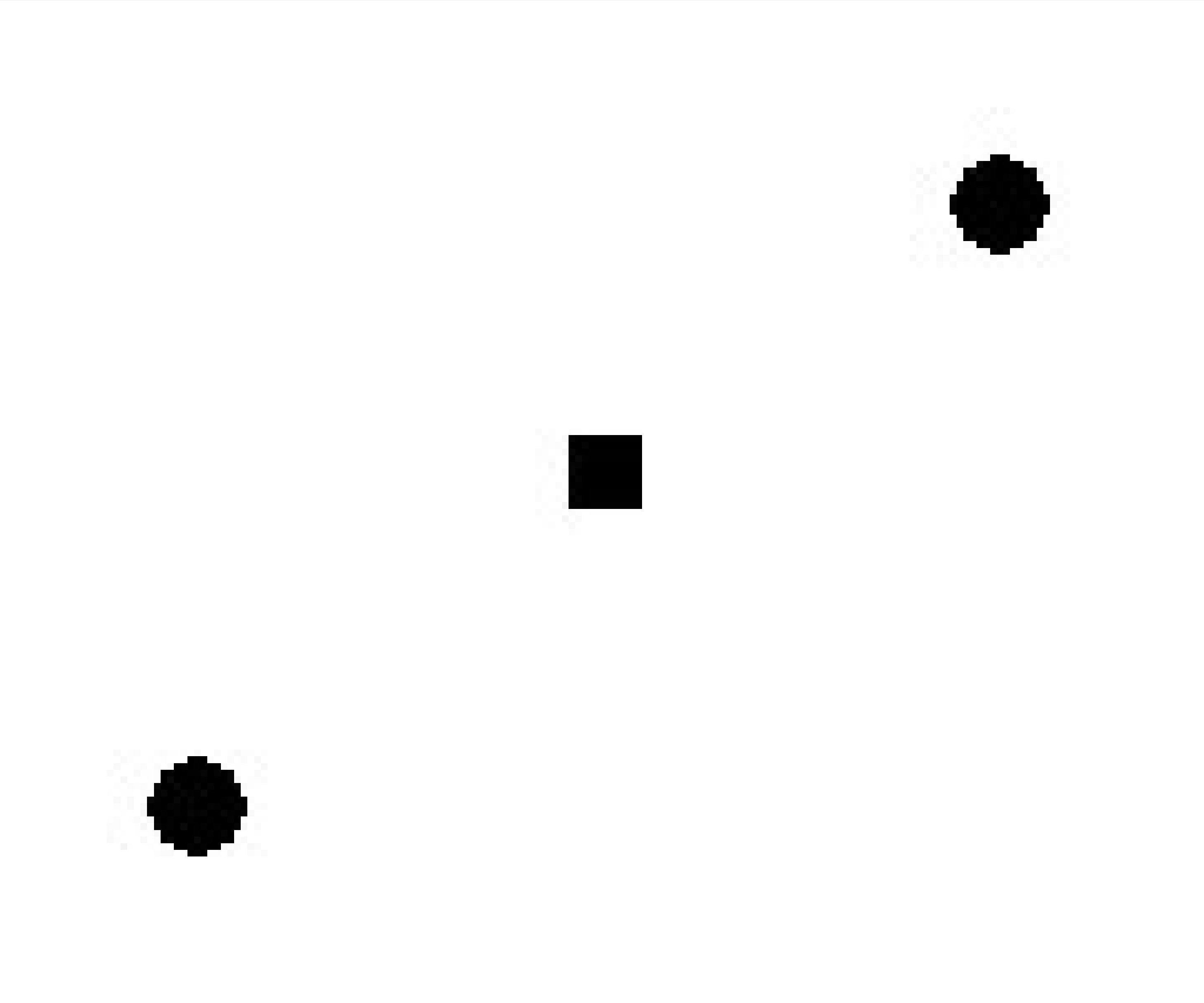


Takeaway:

Multistability is a phenomenon in which a visual stimulus can be perceived in multiple, mutually exclusive ways. For example, the Rubin's vase illusion, which can be perceived as either a vase or two faces in profile, is a classic example of multistability. In this illusion, the same visual input can be interpreted in two different ways, and the perception can switch back and forth between these interpretations over time. Other examples of multistability include the Necker cube, which can be perceived as a 3D cube in two different orientations, and the motion quartet, which can be seen as either rotating squares or a spinning propeller. Multistability is an important concept in perceptual psychology and has been studied extensively to better understand how the brain processes and organizes sensory information.

Illusions

Task: Motion quartet. Imagine CW or CCW rotation. Imagine vertical or horizontal sliding.



Takeaway:

At first glance, this illusion may appear bistable. In fact, it is stable in at least four ways. The same input can result in four different interpretations and schema representations of movement.

Hawkseraph. Creative Commons 4. A bistable motion quartet, where the dots' movement can be seen as either vertical or horizontal. This motion quartet is biased towards vertical perception.

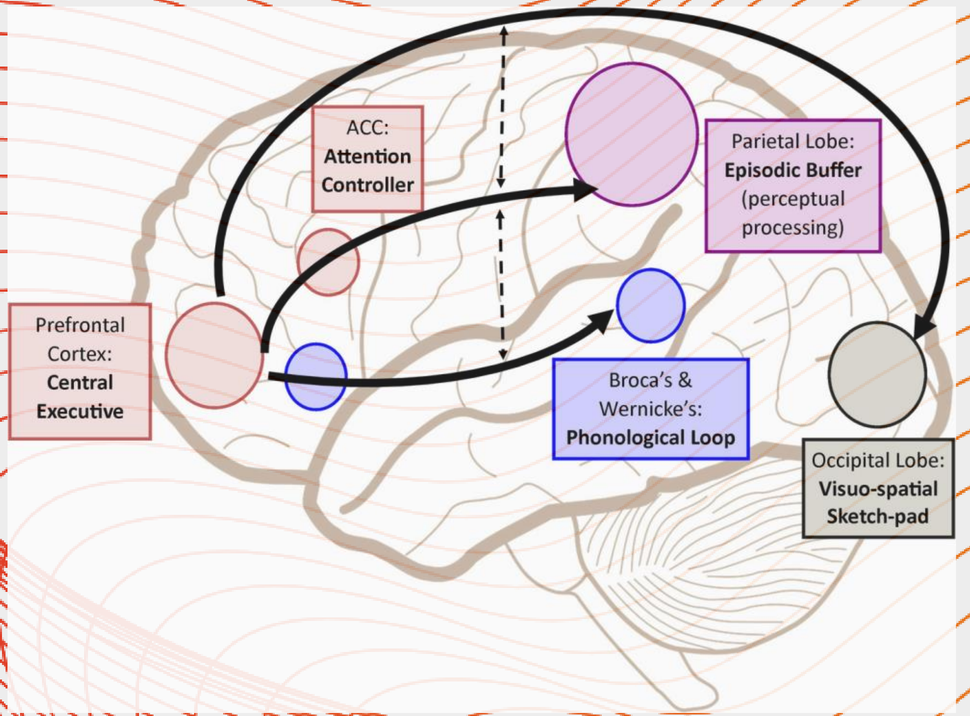
Perceptual Optics: Bank

- Disclaimer: The concept of a perceptual volume ("bank") to which shapes are saved is postulated, but not yet proven.

- However, one theory that is related to this concept is the idea of the mental workspace (including visuo-spatial sketchpad), which suggests that our brains store and manipulate mental representations of perceptual objects.

Baddeley, A., & Hitch, G. (2011). Exploring working memory: Selected works of Alan Baddeley. Oxford University Press.

Baddeley's Working Memory Model



Central Executive

Controls attention and coordinates information from the phonological loop, visuo-spatial sketchpad, and episodic buffer.

Visuo-Spatial Sketchpad

Maintains visual and spatial information, such as mental images and spatial relationships.
2D perimeter & 3D surface shapes.

Episodic Buffer

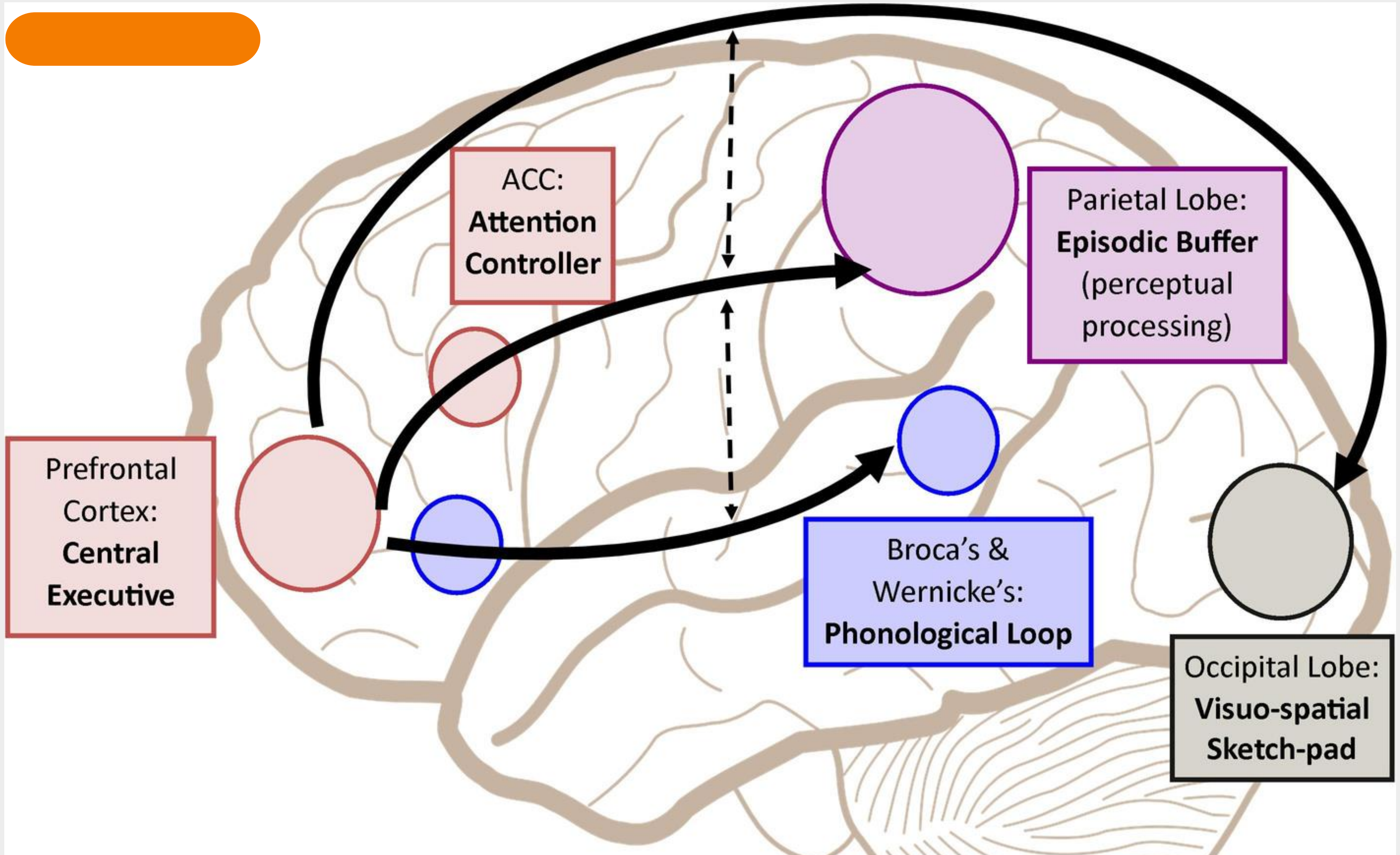
Integrates information from the phonological loop, visuo-spatial sketchpad, and long-term memory into a coherent episode.

Phonological

Maintains auditory and verbal information, such as speech sounds and words.
Speech production & hearing.

Long-Term Memory

Baddeley's Working Memory Model



What "Bank" Shares with Baddeley's Model

- Allow 2D and 3D imagery.
- Allow transformation (mental rotation, scaling, moving).
- Fusing of visuo-spatial sketchpad with phonological loop, including *Broca's area* (subvocal rehearsal of speech sounds and words) and *Wernicke's area* (process auditory information and link it with meaning).
- Allow storage of 2D and 3D imagery, with ability to cross-activate imagery with hearing speech or making speech.
- Stored imagery may stay "fixed" "where" it was stored on 3D sketchpad (unsure if he included this idea).

Where "Bank" Differs from Baddeley's Model

- The storage of 2D and 3D shapes to the 3D "sketchpad" involves highly controlled categorization within the space of the sketchpad.
- Short-term and long-term memory needs to encode actual voxel locations within this sketchpad, allowing similar shapes that are stored overlaying each other (in a categorization region) to slightly "trigger" each other, giving rise to familiarity or understanding and allowing for brainstorming.
- The bank schema serves as a "tether" between the real world schema and imagination schema.
- Sensory and motor information is assigned a temporal and spatial alignment, moment-by-moment, via stored episodic memory traces left recorded onto the bank "tether."
- The bank model proposes the existence of "triggers" (via shape or artificially saved similarities) which result in "skewers" (associated memories). The most salient, recent, or pertinent of these is selected and replayed (0.1-0.5 s?) to give understanding.
- The temporal order of a set of episodic memories, skewered/recalled by some shared similarity, can be encoded by depth, with the most recent instances at the surface and a gradient of age descending.

Bank Clarifications

- The ability to shift attention and focus within the bank schema is analogous to the ability to move attention from one item to another in the real world schema and shift from one thought to another in imagination. The shifting can go on simultaneously.

- The degree of freedom in moving within the bank schema is influenced by the frequency of frame sampling and underlying automatic categorization processes.

- With longer gaps between samples, the brain is able to engage in more creative exploration of the stored shapes and locations, enabling more options with the current intra-bank movement.

- Fast sample times would encourage routine, entrenched responses.

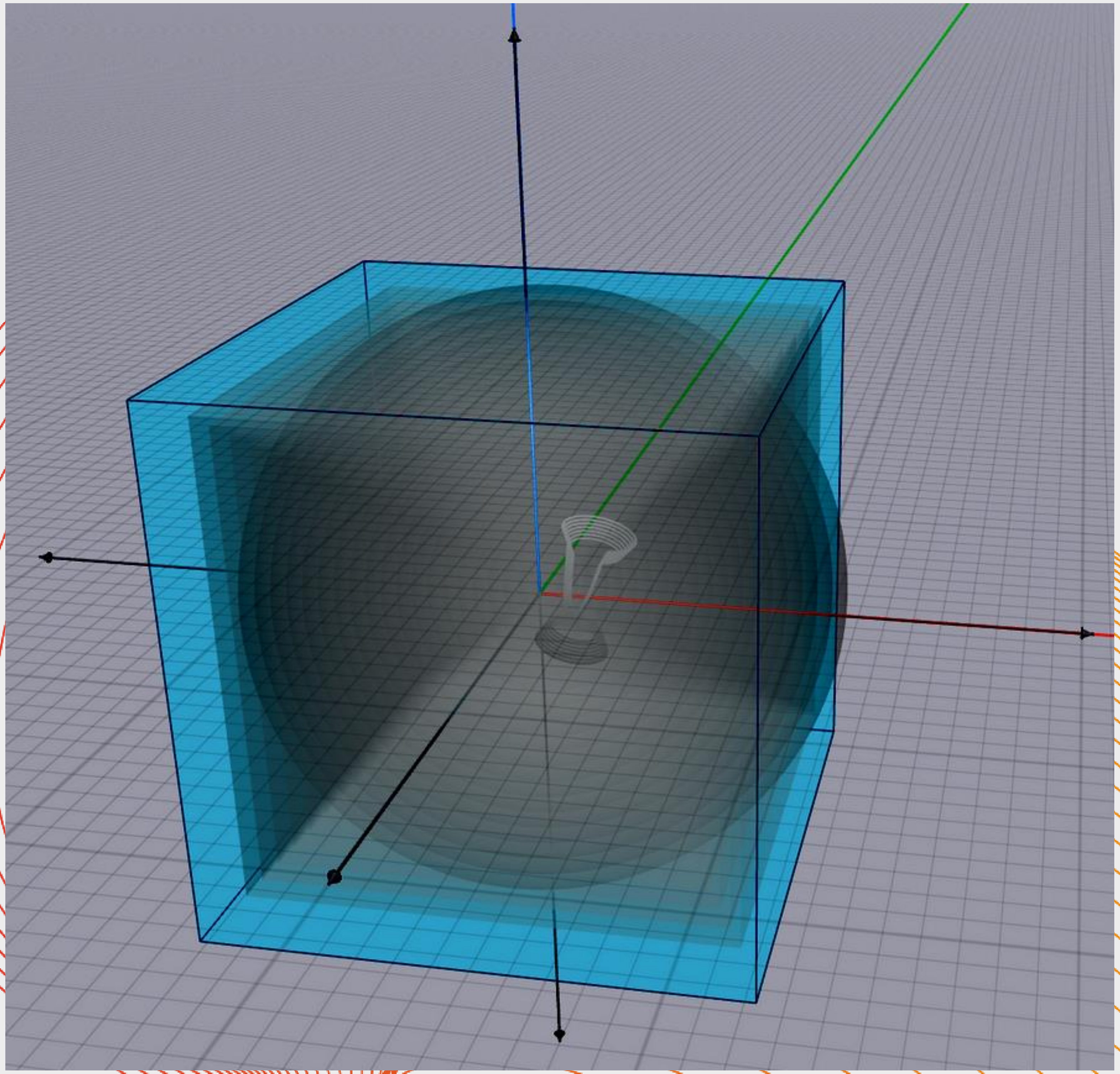
- This suggests that the bank storage system (and rate of sampling) may play a role in the generation of creative ideas and the ability to explore novel connections between stored information.

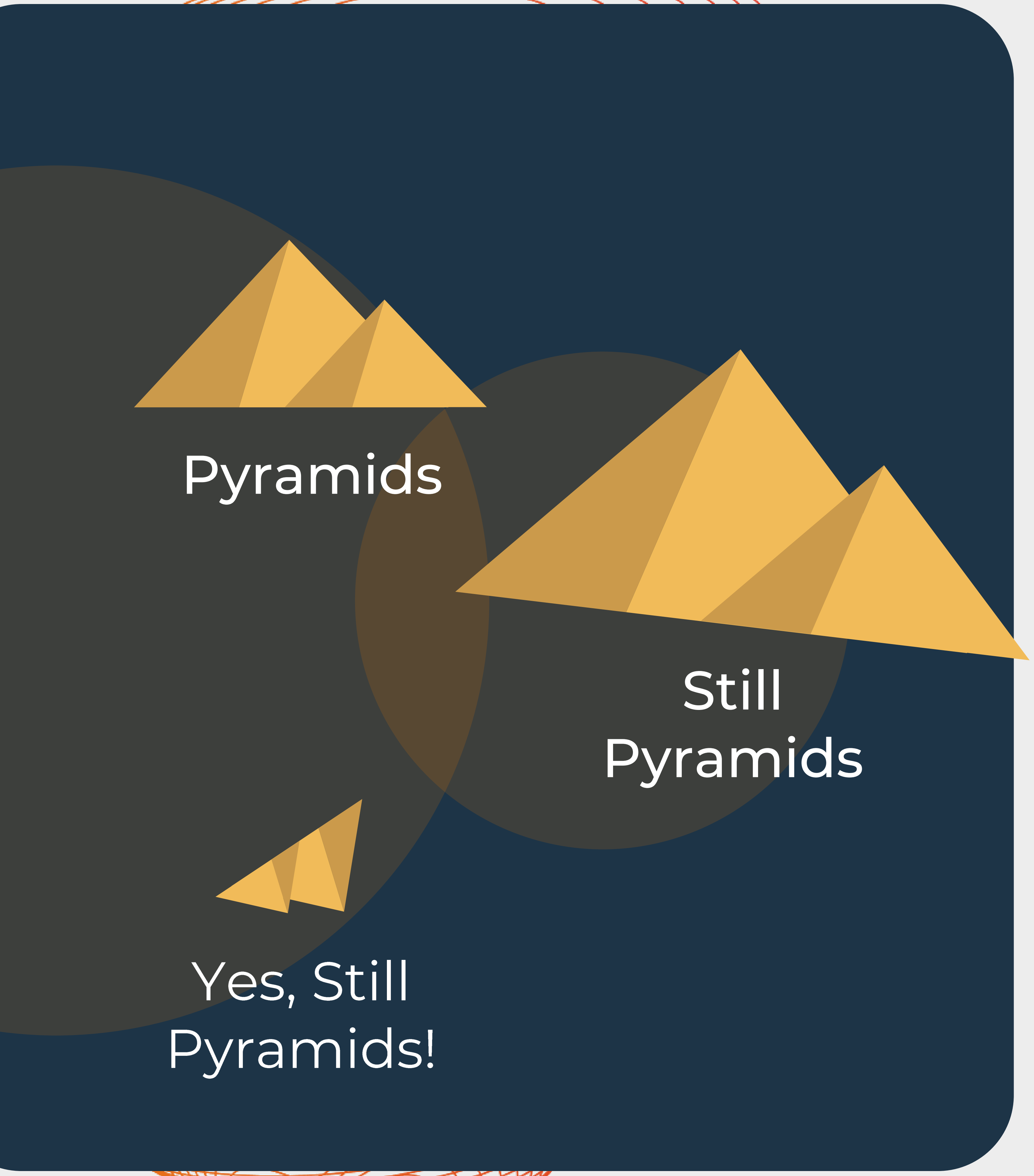
3. Bank Necessities

- Voxel skins are 3D object surfaces made of individual voxels (3D pixels).
- To save voxel skins, they must be stored relative to an invariant Euclidean storage system (x, y, z) that allows for rotation, scaling, and translation of itself.
- This enables multiple voxel skins to be overlaid in the same 3D space for neatness and familiarity.
- Understanding color processing and representation is also important for the storage and perception of 3D objects.

The "Bank": Transformable, Organized Shape Storage

- The "bank" reference/storage system has definite up, right, and front vectors (axes).
- The Transformable Organized Shape-Storage system saves objects according to specific organizational guidelines, such as tools to cylinder region, fixation point to centroid, and flat surfaces to cube face.
- These guidelines allow for a logical and structured arrangement of objects within the storage system.
- The entire bank can be rotated, scaled, and translated within the real-world schema as needed for storing or understanding an object.

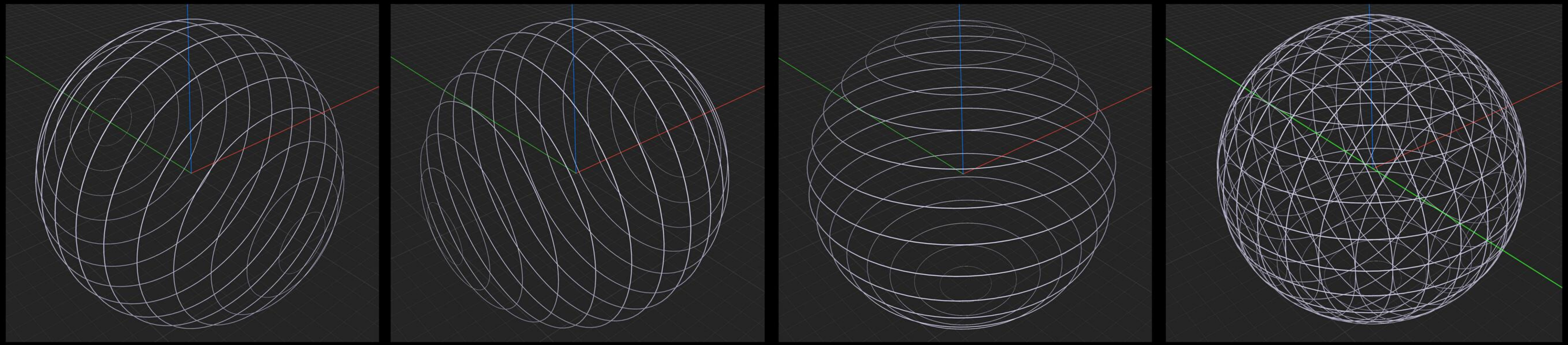




Shape Invariance: Pyramids Across Scales and Rotations

The "bank" is a useful concept that captures the brain's ability to map groups of neurons to enable the invariance of shape regardless of location, scale, or orientation. This means that a saved shape can be resized, rotated, or moved to a new location while still being recognized as the same object. The entire set of saved shapes, or "bank," comes along for the ride, making it a flexible and versatile storage system.

Euclidean space, specifically a unit sphere, can be difficult to subdivide uniformly.

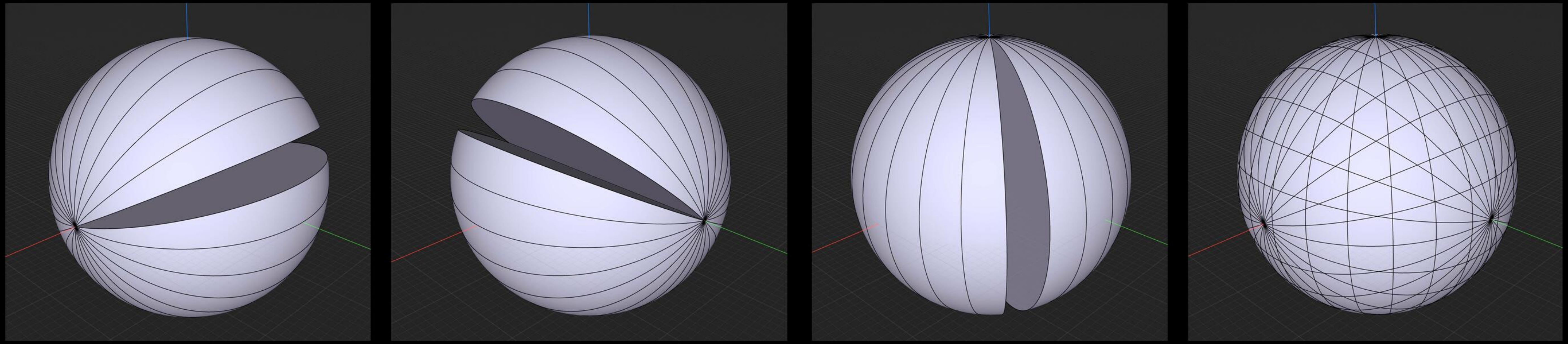


Coronal Circle Divisions "Radius" of Theta=Phi Circles

Sagittal Circle Divisions "Radius" of Gamma=(Theta-90°) Circles

Horizontal Circle Divisions "Radius" of (Gamma+90°)=(Phi+90°) Circles

Combination (Messy Segments)



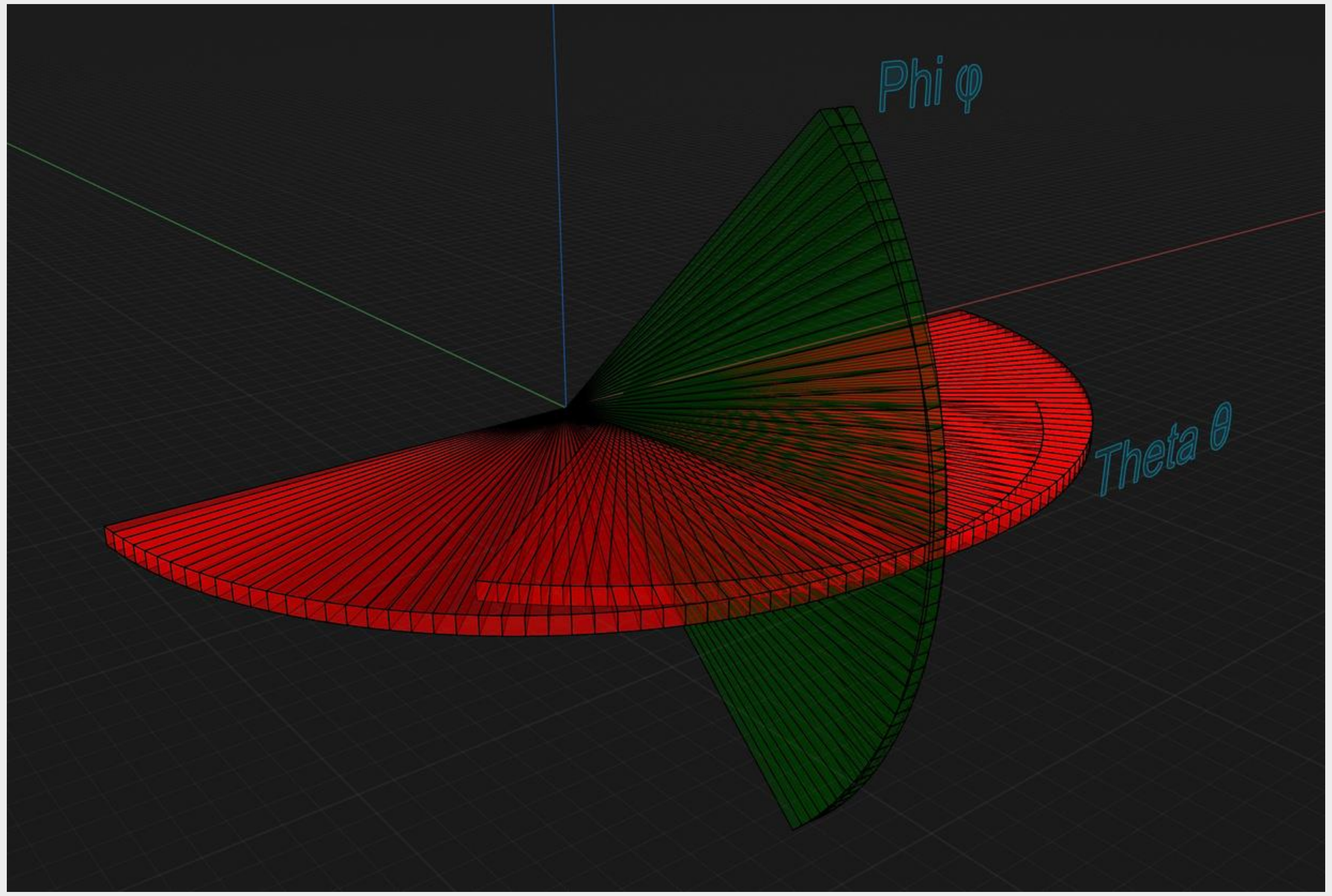
Lateral-Medial Axis 24 Equal "Cantaloupe" Slices ("Phi" Slices)

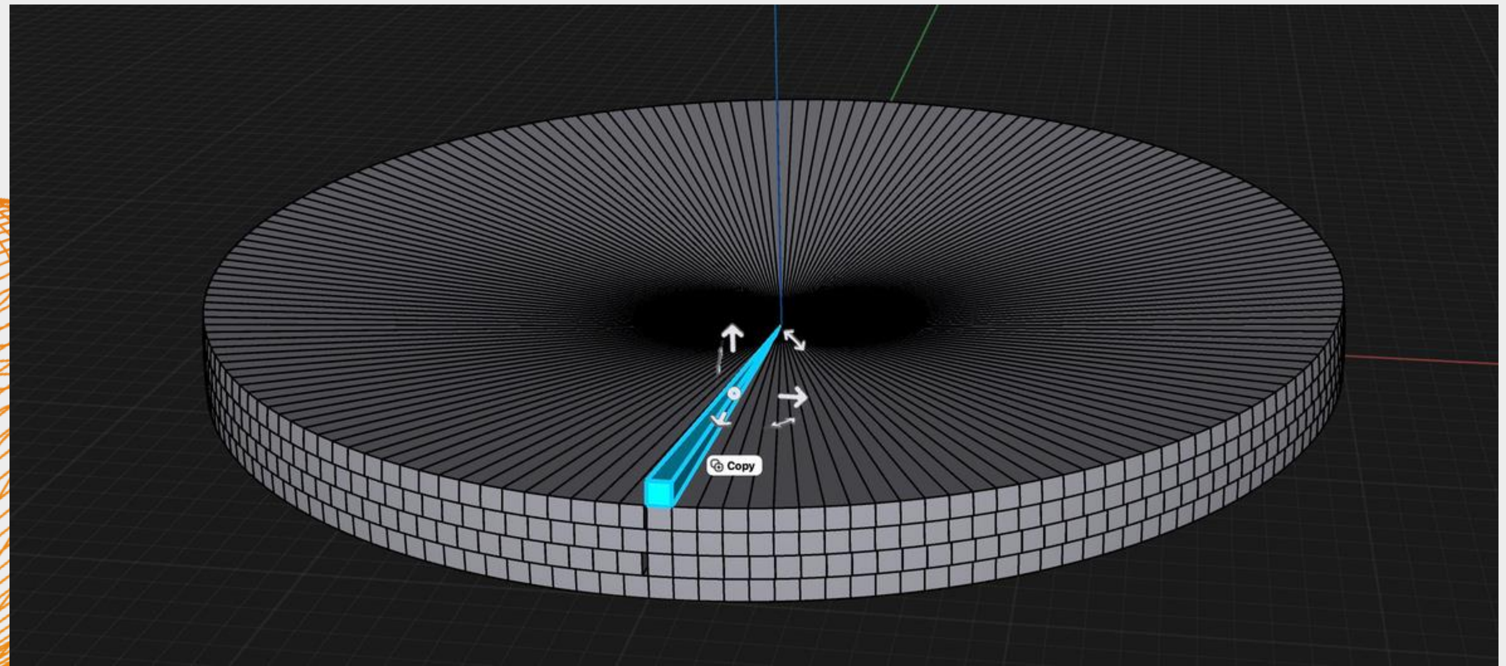
Anterior-Posterior Axis 24 Equal "Cantaloupe" Slices ("Gamma" Slices)

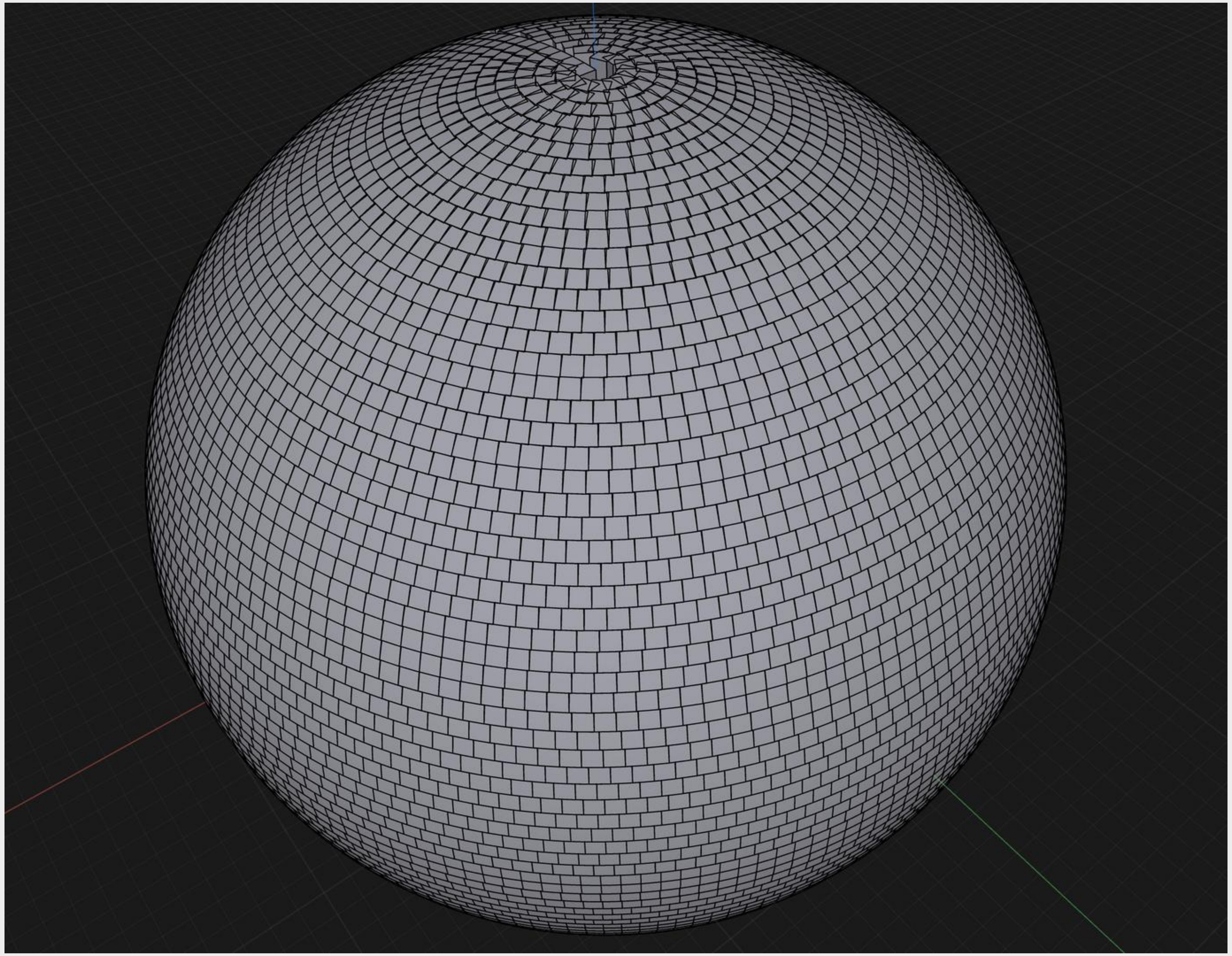
Superior-Inferior Axis 24 Equal "Cantaloupe" Slices ("Theta" Slices)

Combination (Messy Segments)

While the sphere is useful for reconstructing isometric models, it lacks orientational specificity. Adding a cube reduces the possible orientations to six. Then adding an offset cylinder with a unique front feature provides exact orientational specificity.

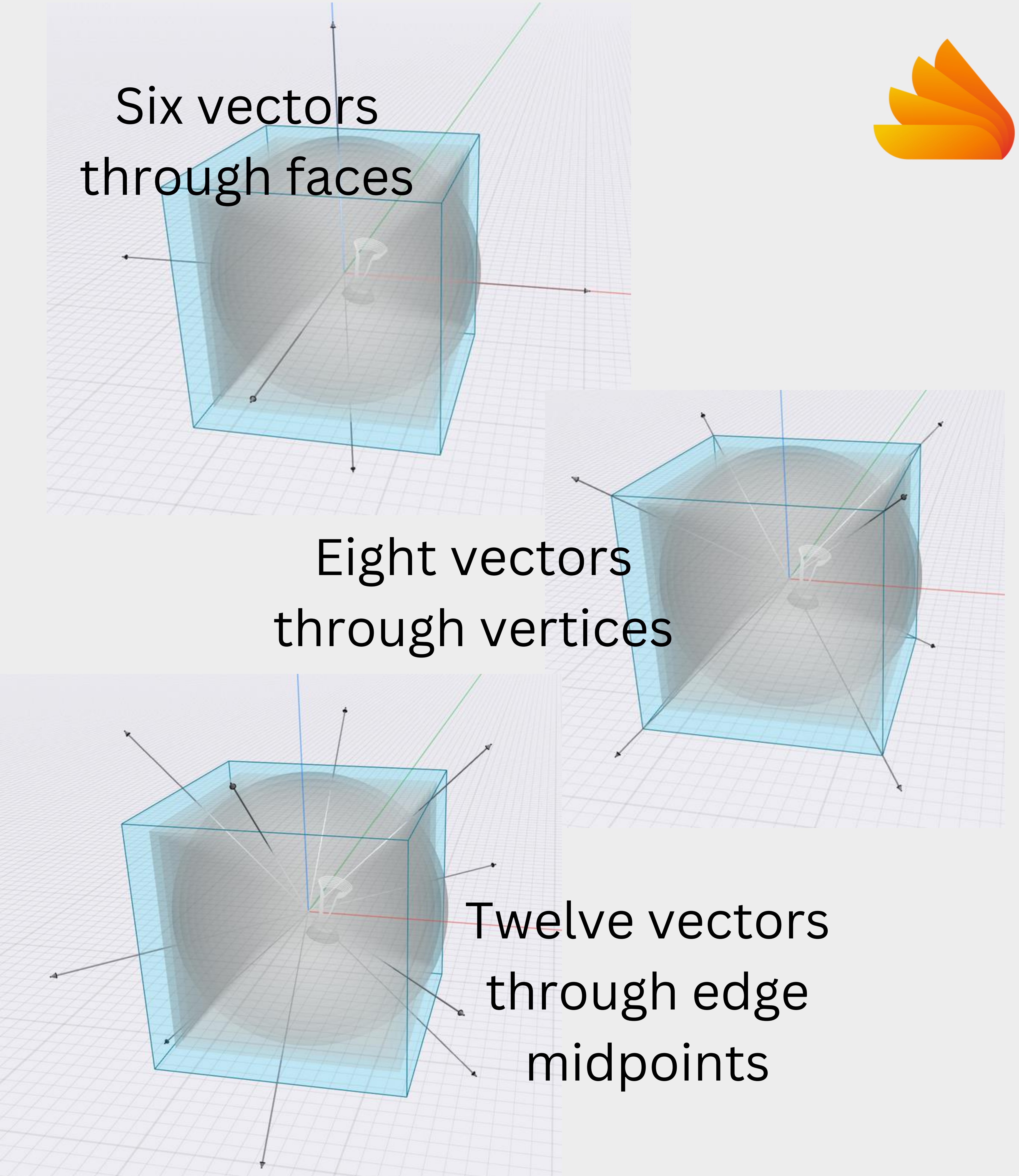






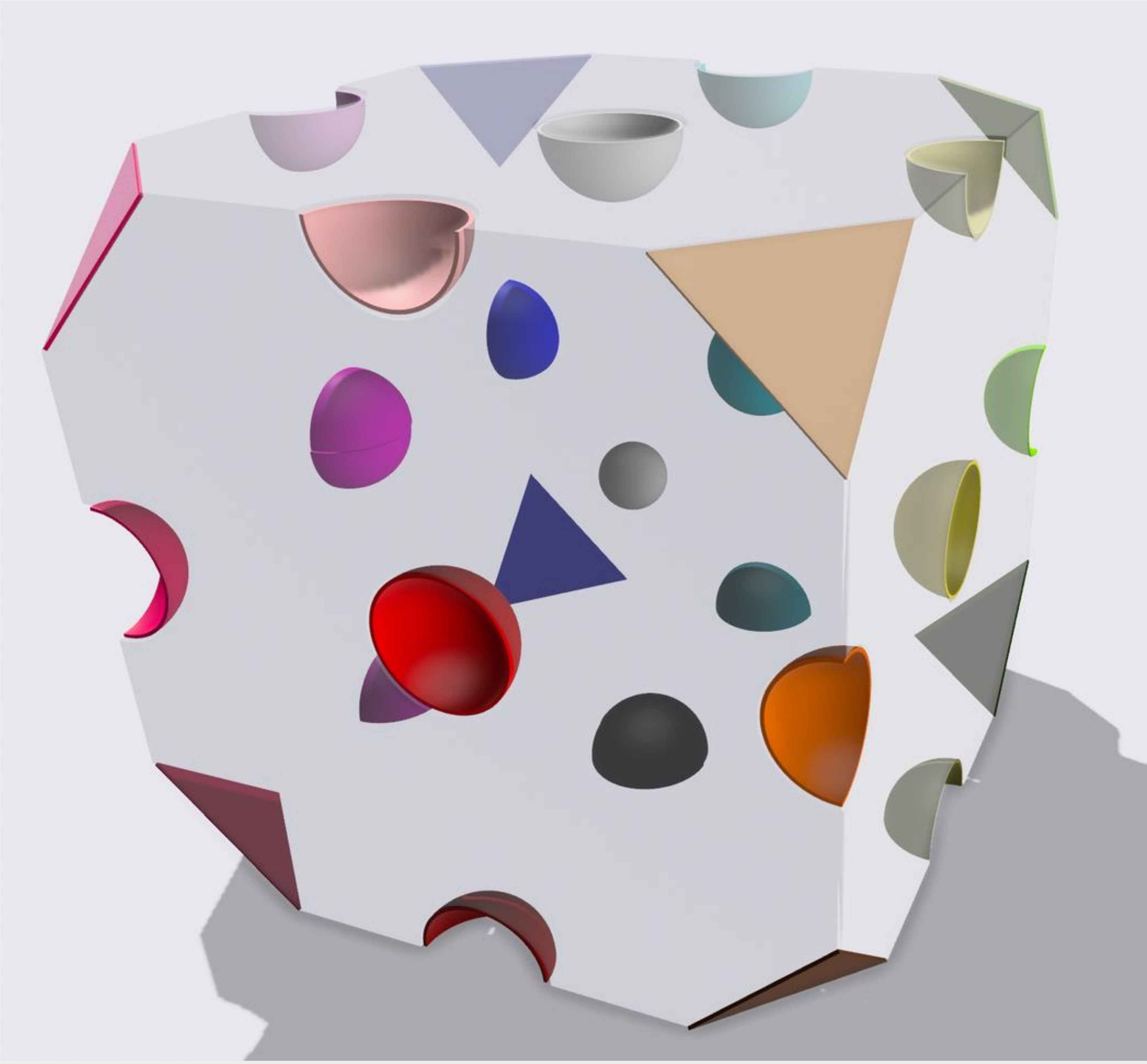
Orienting in 3D Space

A cube can fairly neatly divide 3D space into 26 vectors going from centroid outwards. Each can conveniently be lettered for easy conceptualization. More importantly, a cube with some rightward offset feature (cylinder) with a frontward offset feature (broken face) can now specify orientation in full, 3D, Euclidean space.



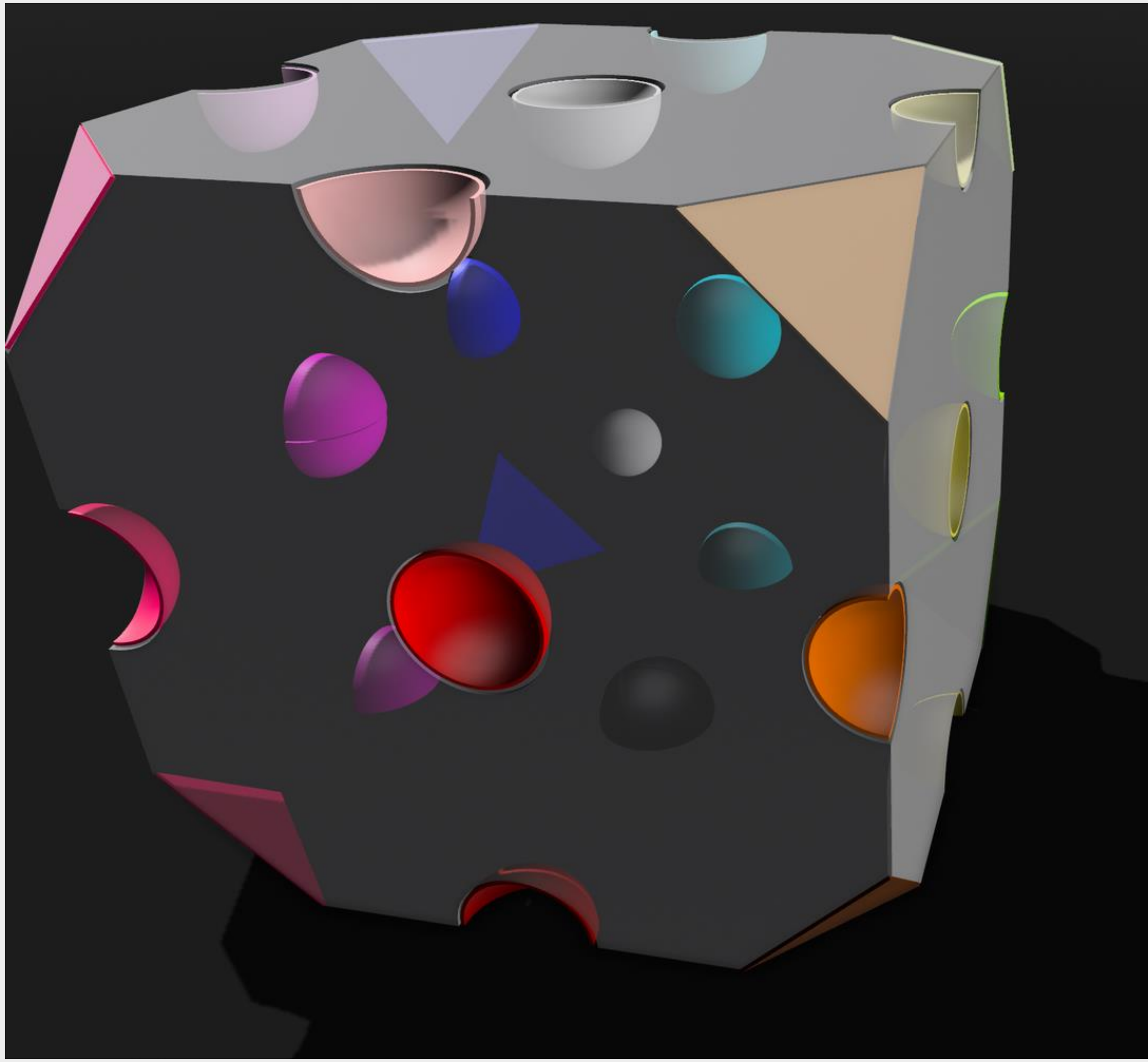
Let's Explore 3D Space

You could also think of one vector through top center (white), one through bottom center (black), a set of eight on x-y plane (full color), and two copies of the x-y plane, bent half-way towards the up (light color) or down (dark color) vector.



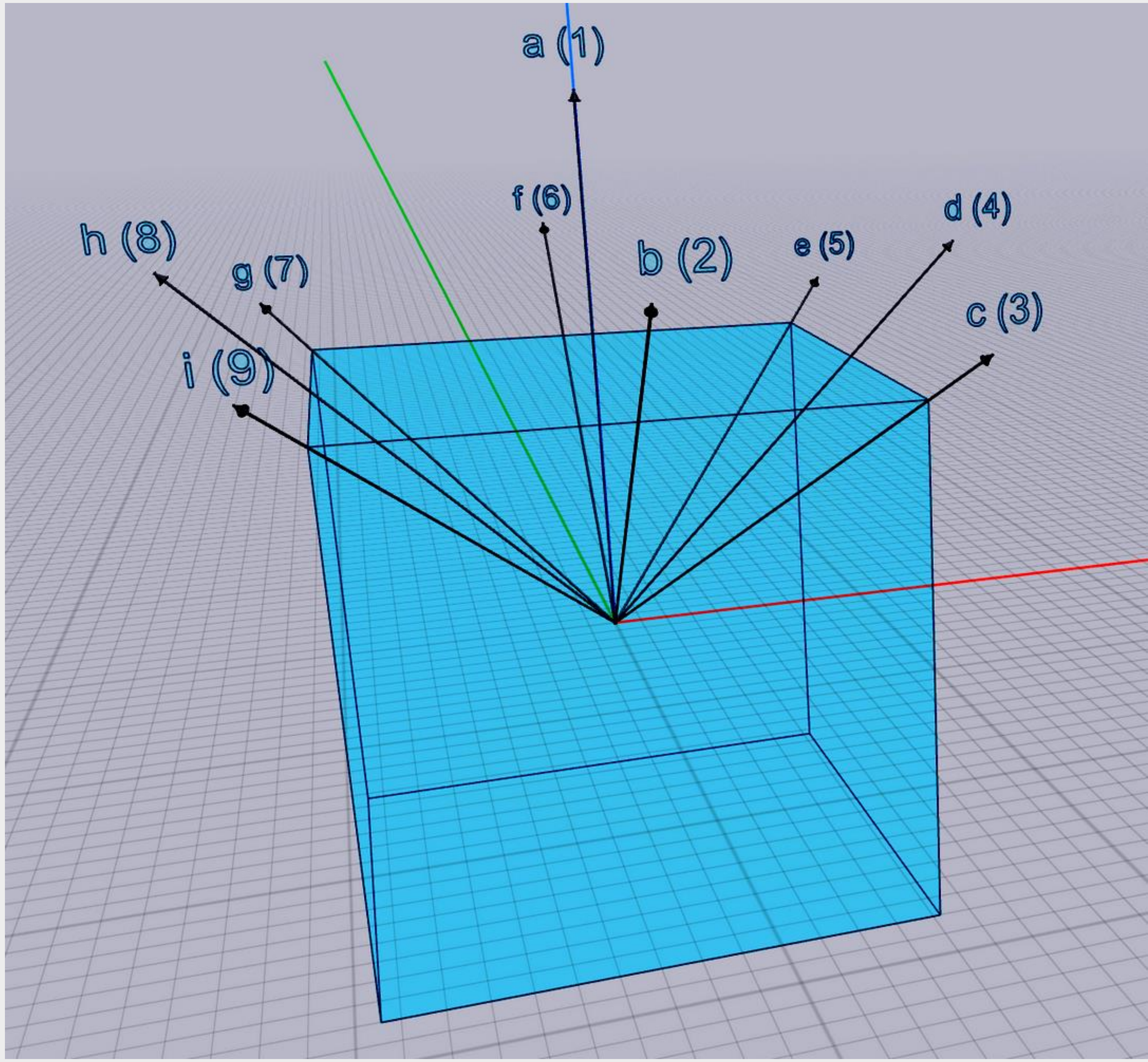
Naming 3D Vectors

White (up) could be labeled a (or 1); black (down) could be labeled z (or 26); a spiral of order could name the remaining directions of vectors. The grey origin dot could just be called "origin" (or a period) or zero (0).



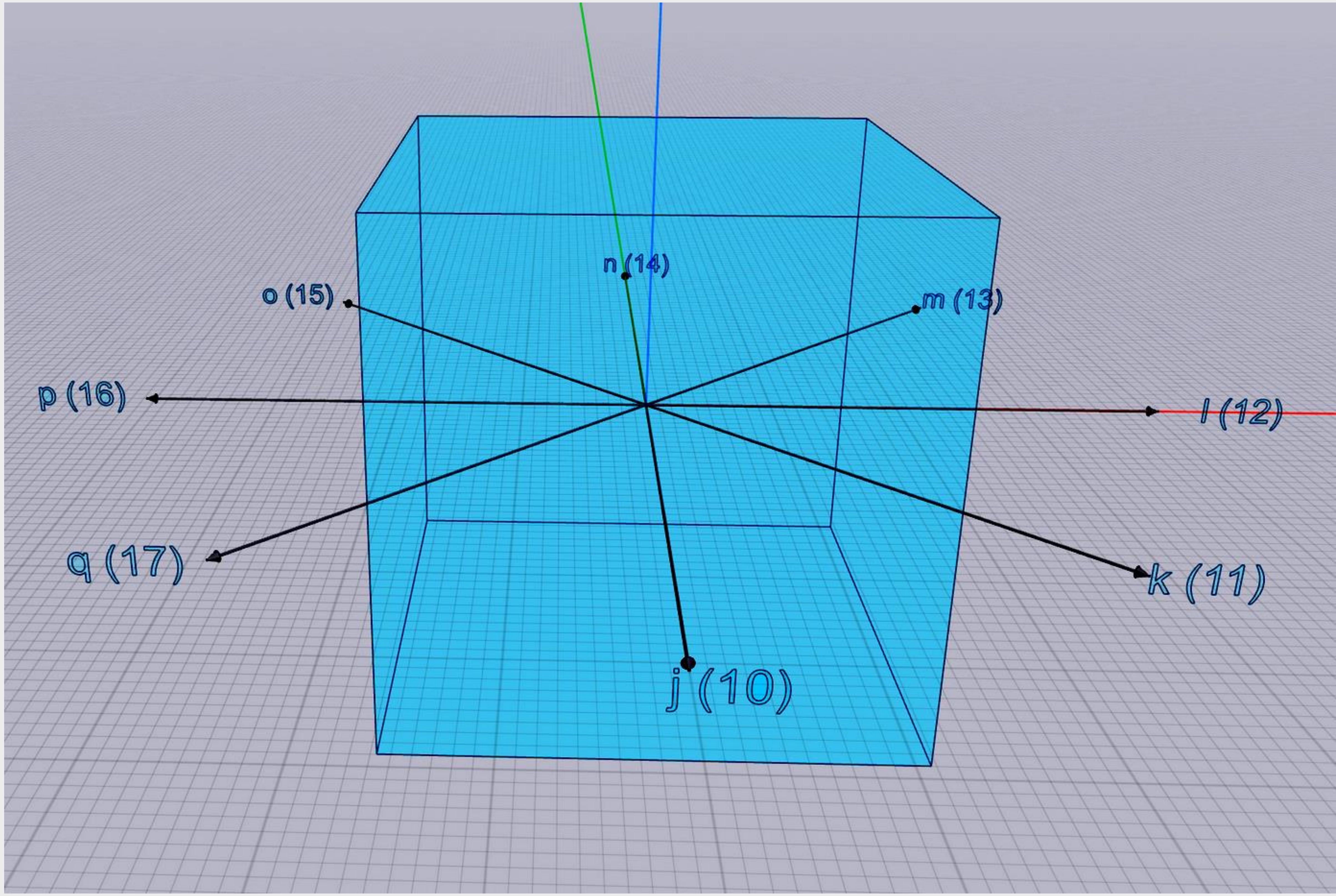
Spiral Naming of Vectors

In this depiction, up is labeled "a" or "1." "b" is towards you, and "c" through "i" continue the spiral around. In the next slide, we will "step down" to the "full color" vectors.



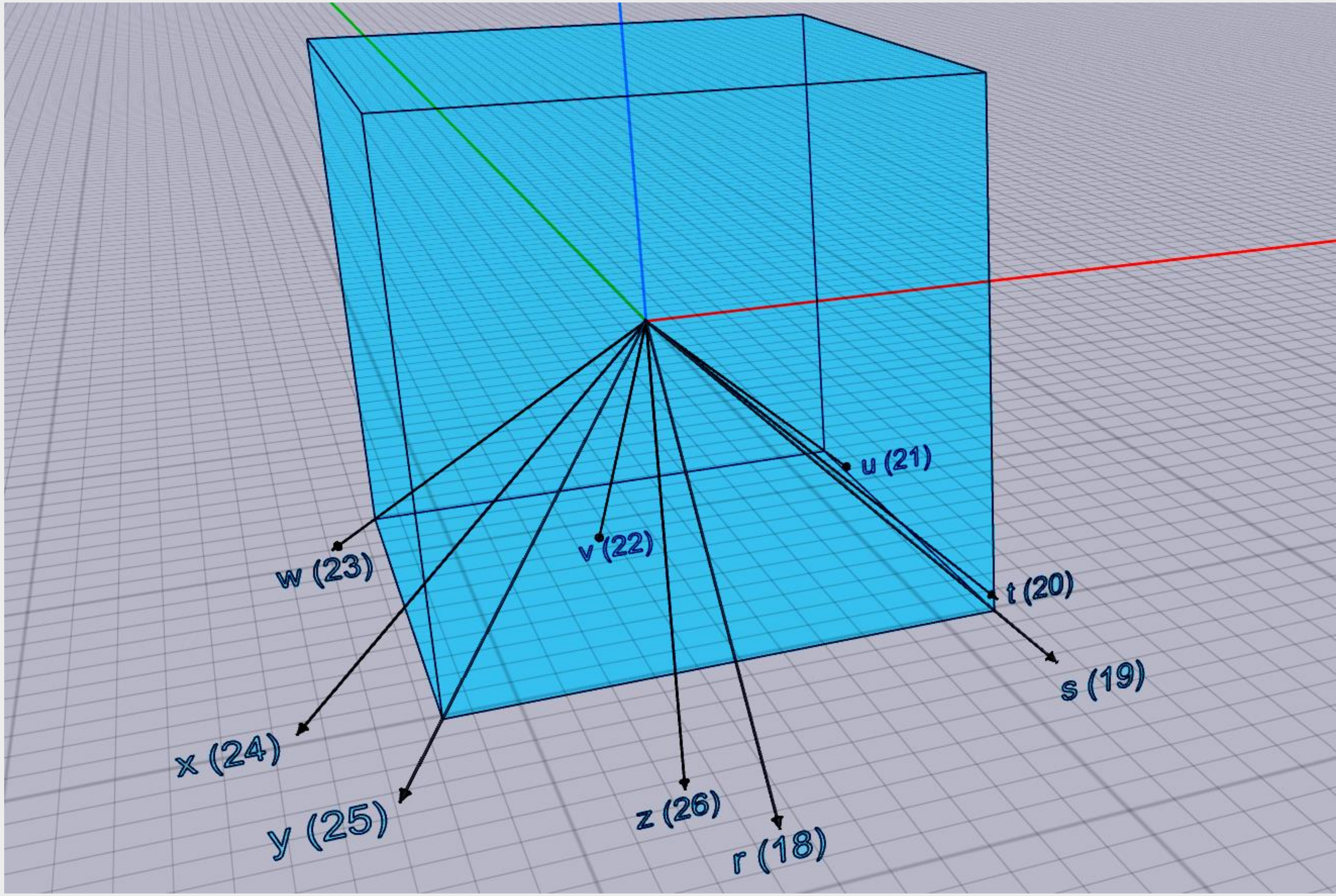
Naming Vectors

Continuing, "j" (10) is towards you, and circles around all the way to q (17). Then, we jump down again.



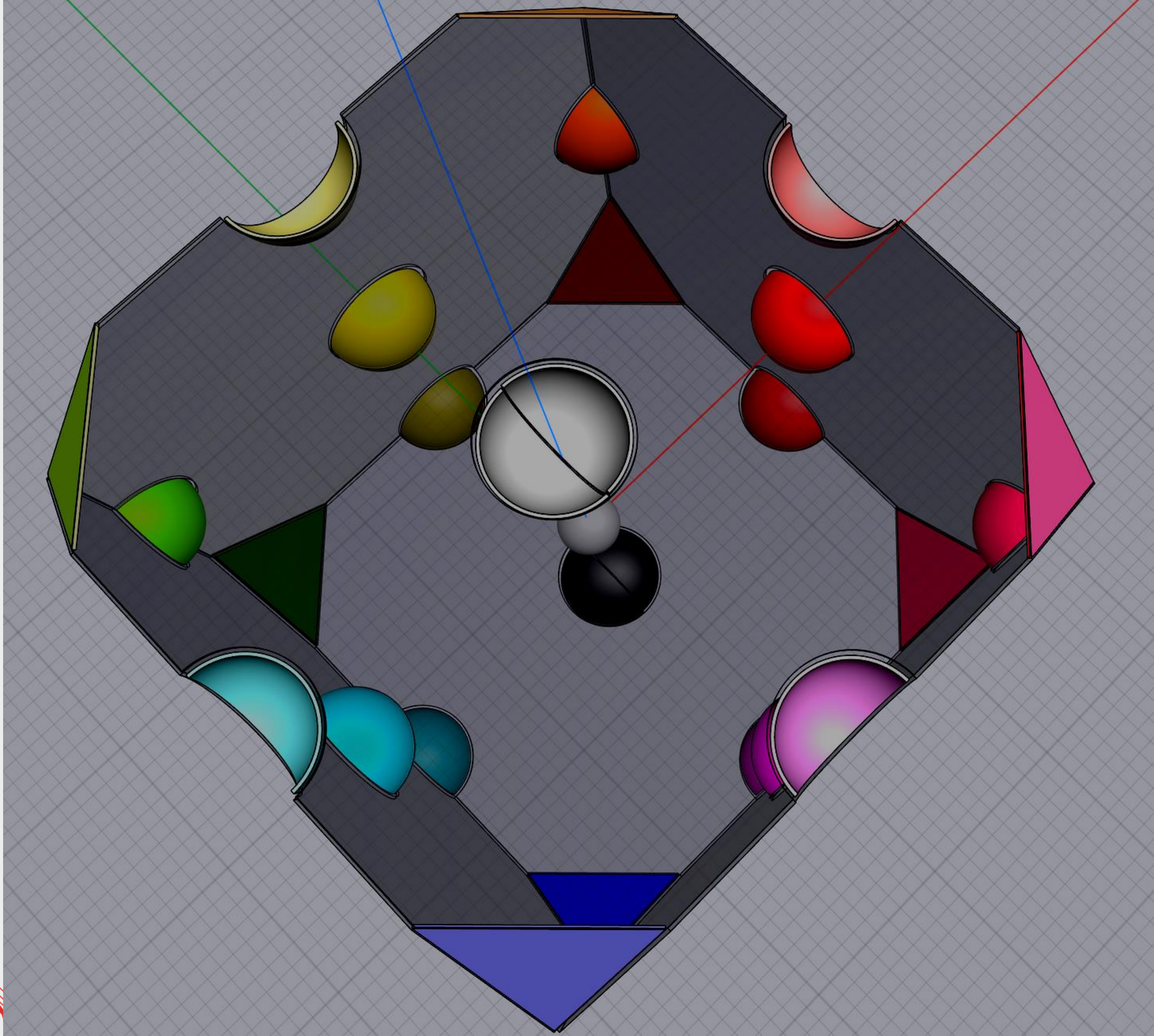
Naming Vectors

Continuing, "r" (18) is towards you, and circles around all the way to y (25). Then, pointing down is z (26).



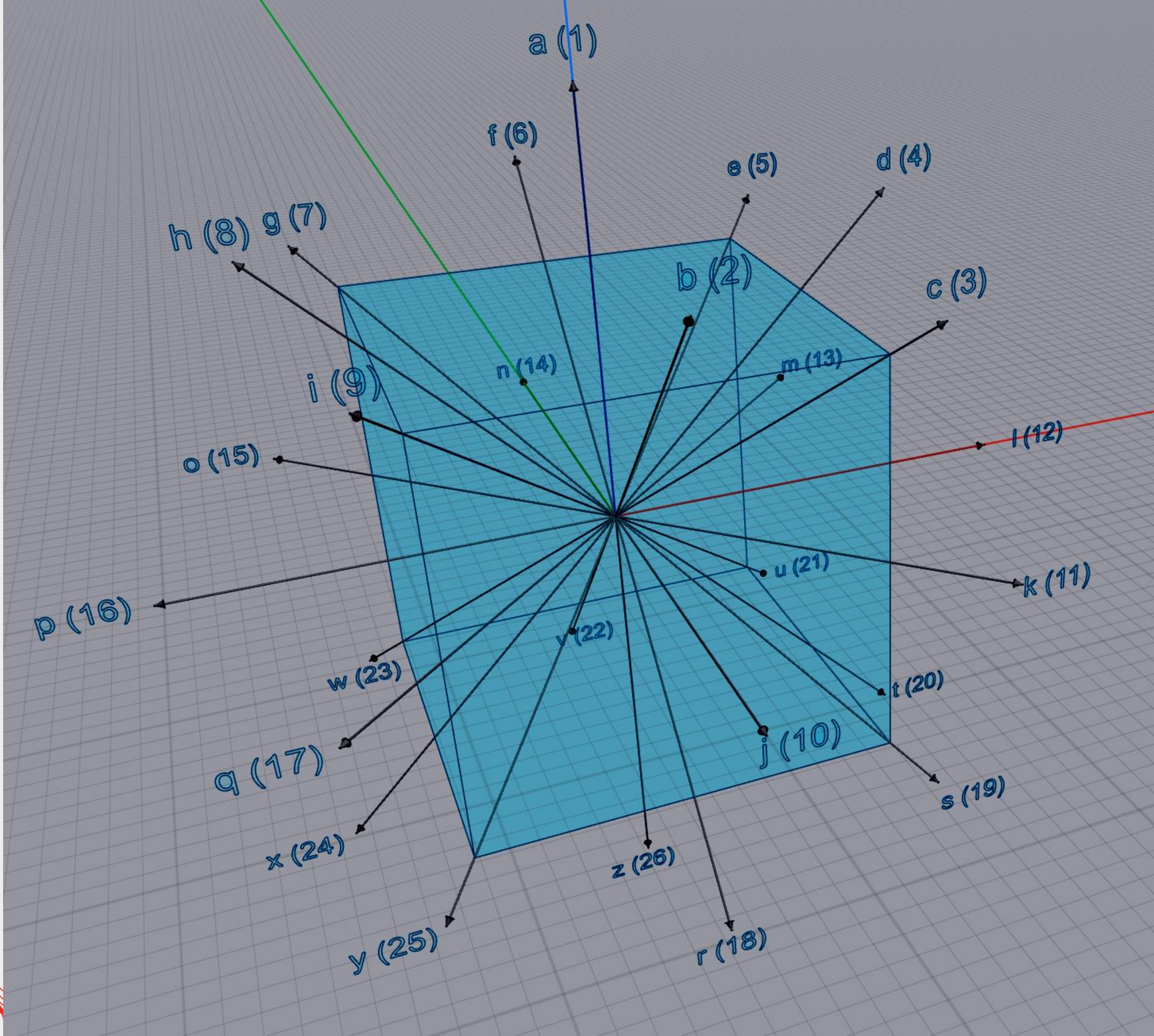
Infinity of Vectors?

Euclidean geometry divides space into 6 axes (+/- x, y, z). We divided space into 26 vector orientations, using a cube as a guide. If you prefer square degrees, you would have 41,253 unique orientations from the origin outwards. In theory, there are an infinity of vectors from origin outwards. Human consciousness can differentiate upwards of 200 million vector orientations!



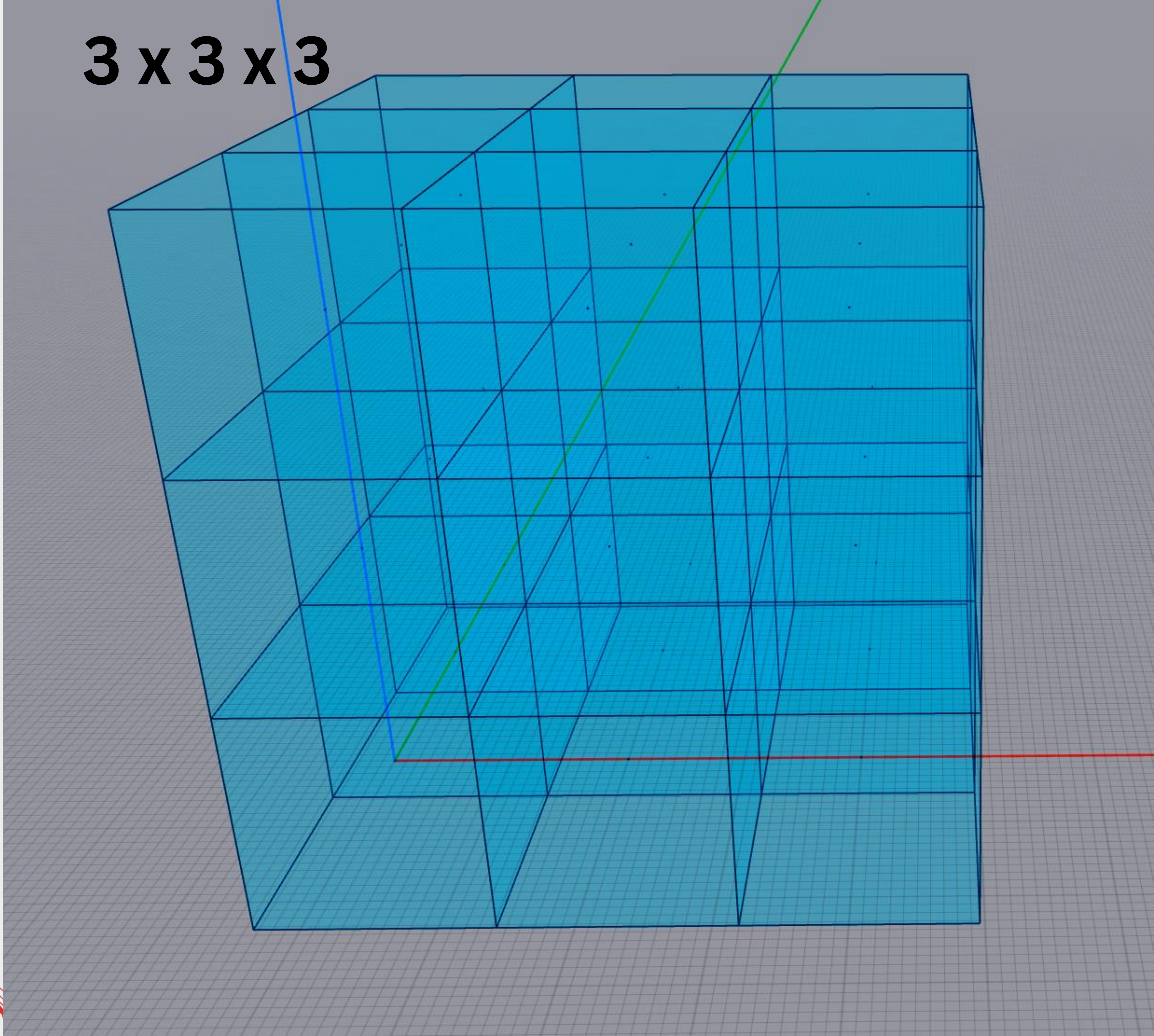
26 Handles

All 26 handles, or vector orientations, are depicted here. If we split the cube into 3x3x3 voxels (27 voxels), we could label each voxel with this same lettering or numbering system (center cube could be "origin," "." or "zero"). We could then subdivide again and again and reach 7 trillion voxels in 9 iterations. Any voxel within perception could be addressed with a "word" merely 9 letters long.



27 Voxels (Base-3)

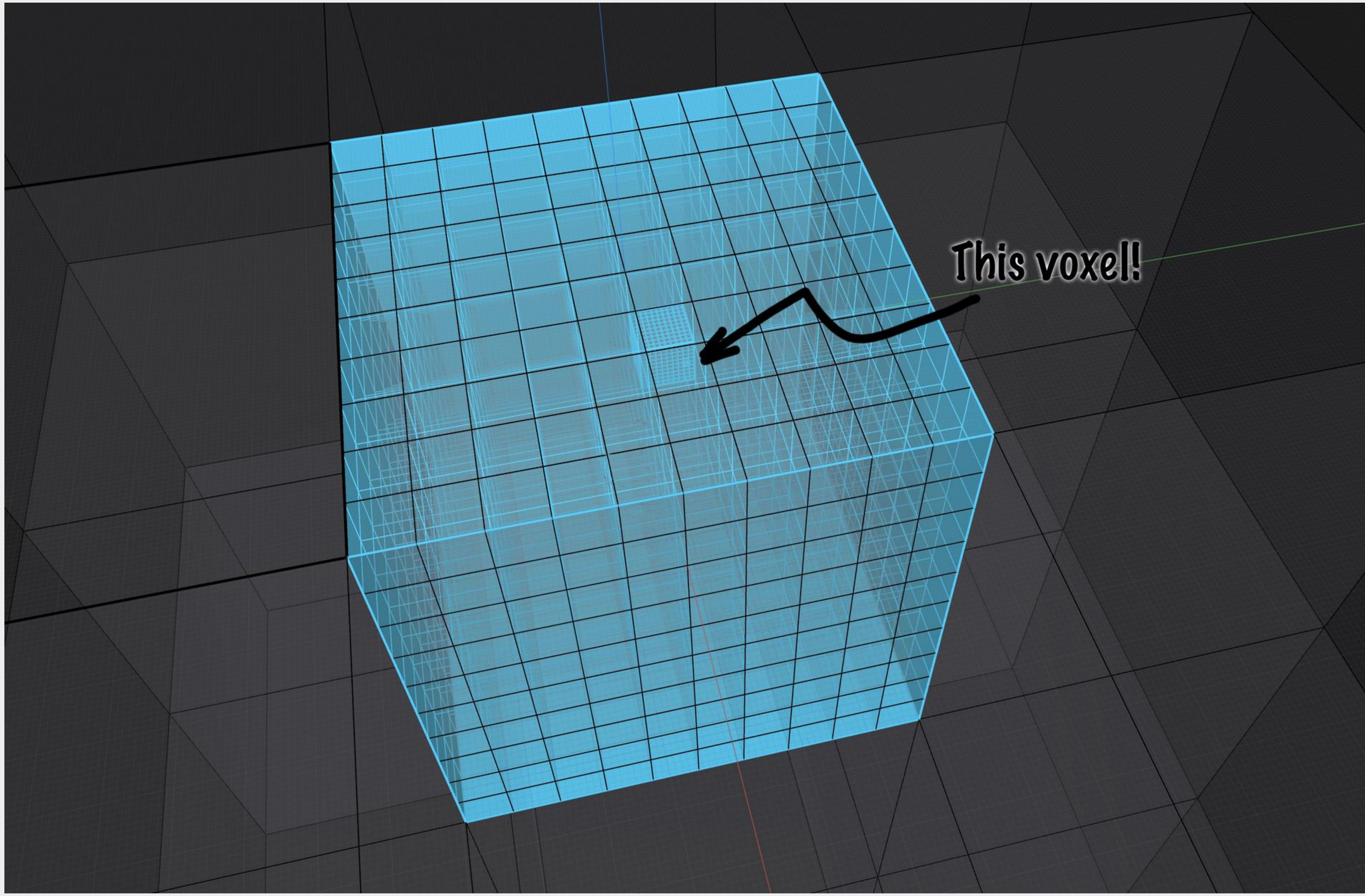
Here is a single subdivision of the cube of perceptual space into 27 large sub units or voxels. Each of these could be subdivided into 27 smaller voxels. You could specify which large voxel first, then the nested one within that, then the next smallest voxel. After 9 iterations, you could address any voxel in human experience with a "word" like "bjjrtsvar."



1,000 Voxels (Base-10)

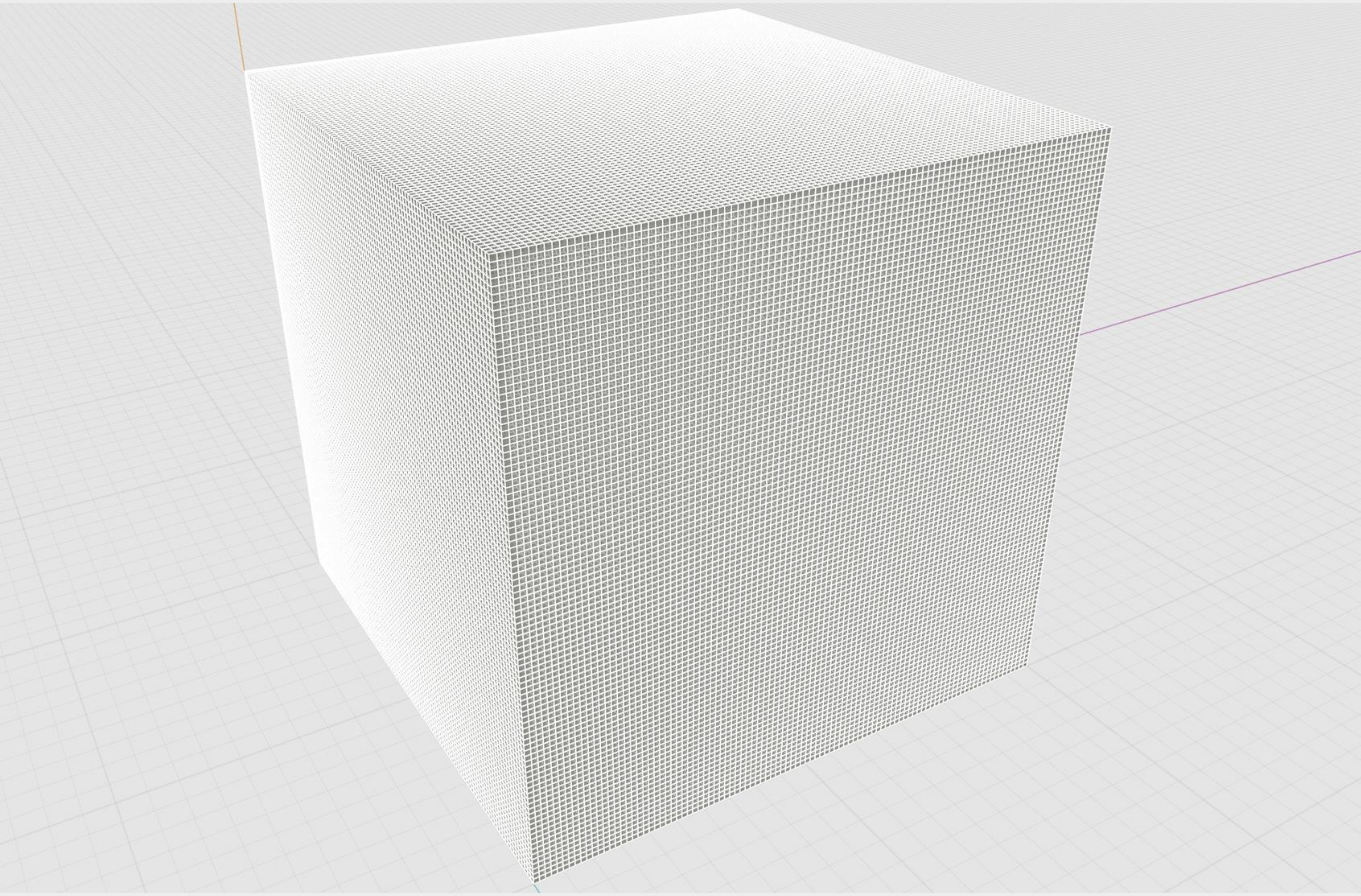
10 x 10 x 10

If the brain used a base-10 subdivision, this would be 10x10x10 voxel subdivision, or 1,000 voxels per division. A larger "alphabet" (with 1,000 characters!) would need to be used to write the addresses, but each voxel could be reached with a 4- or 5-letter long word, as opposed to the 9-letter word for 3x3x3 subdivision (base-3 subdivision).



A Million Voxels (Base-100)

100 x 100 x 100

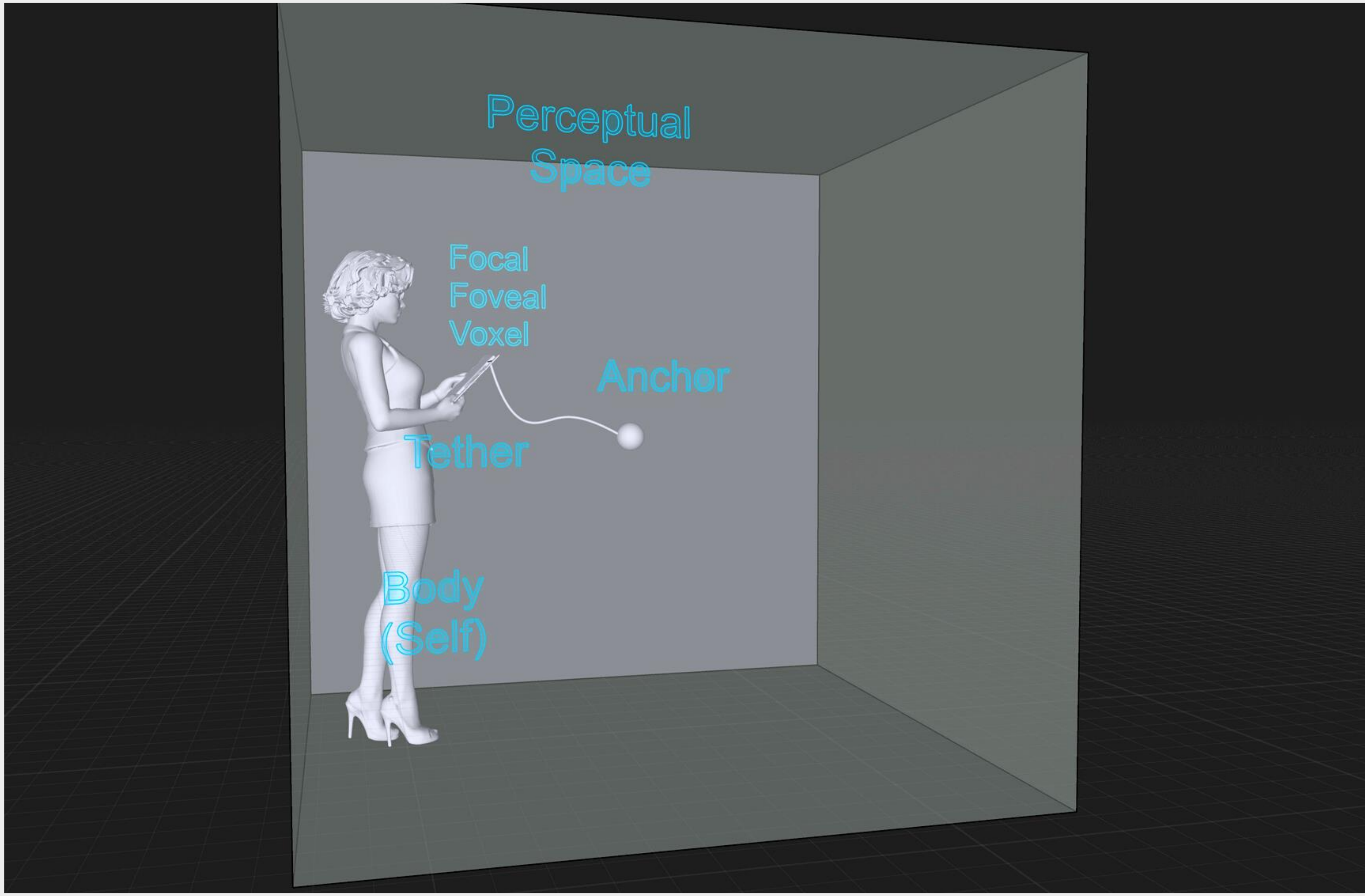


The brain has over 1 trillion voxels of discrimination, but this 100x100x100 cube represents a "primitive consciousness" that can discriminate a million voxels. A "million letter alphabet" could let you specify any voxel within human consciousness in essentially 2 letters.

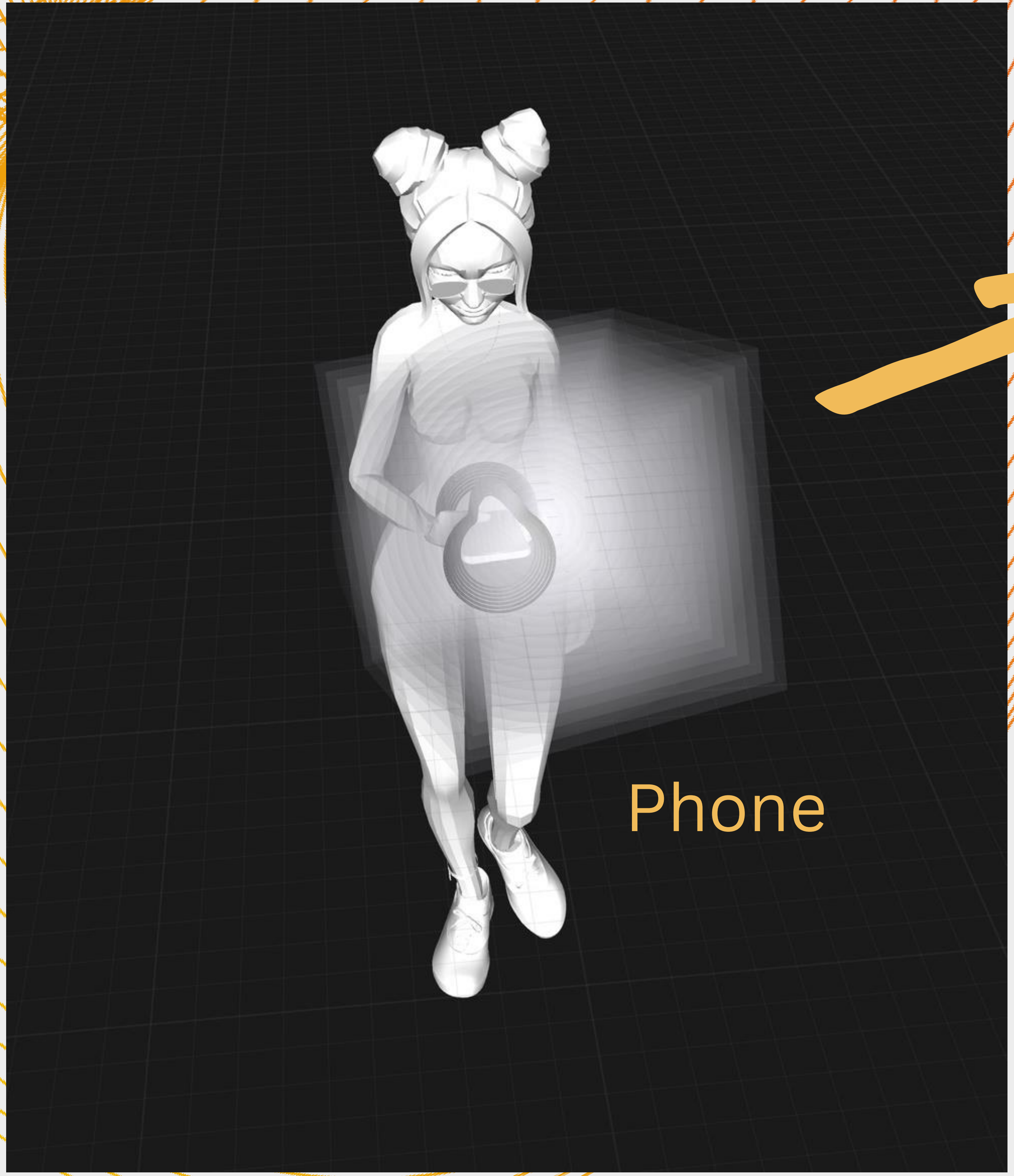
A Trillion Voxels? (Base-10,000)

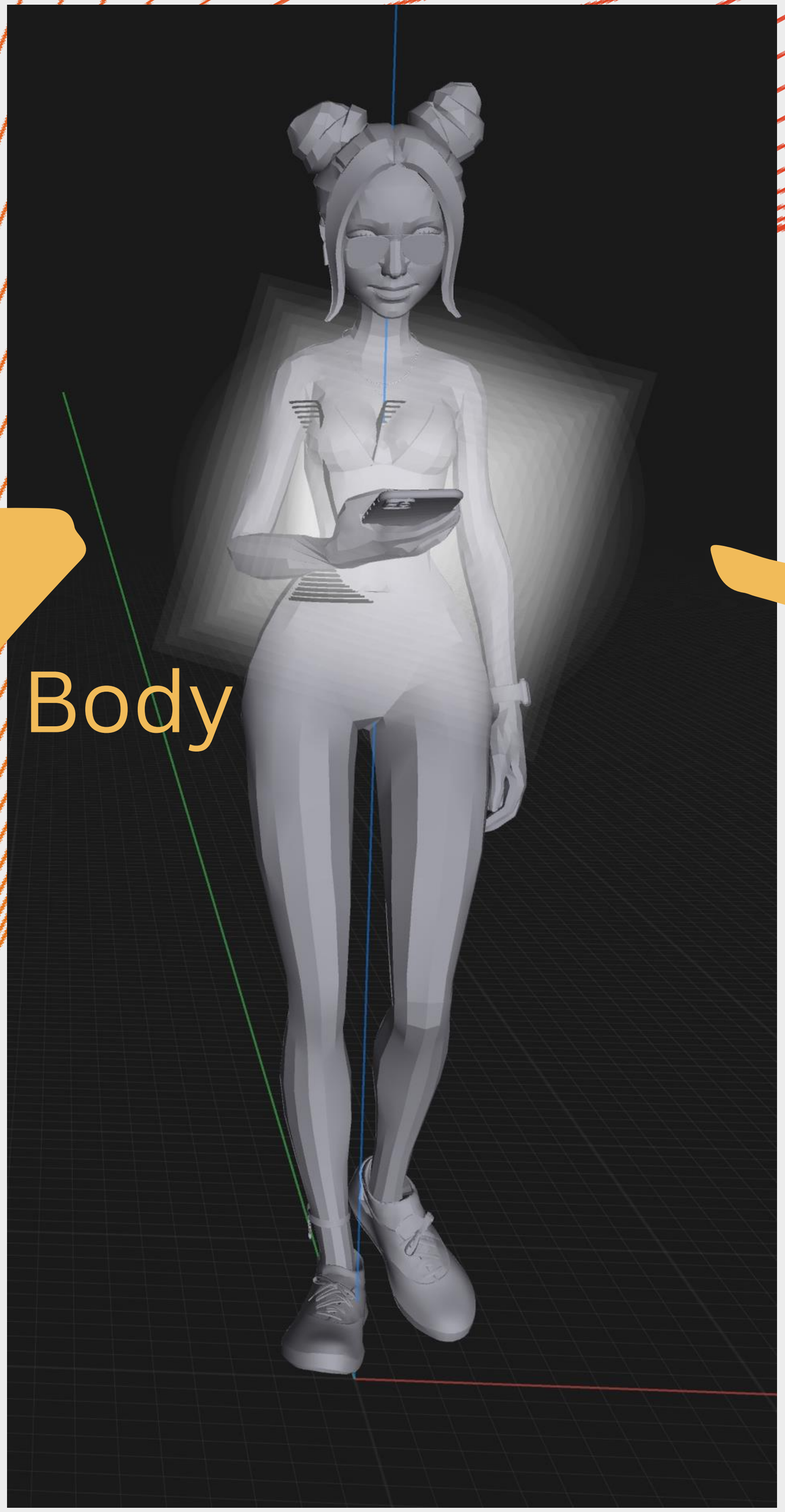
10,000 x 10,000 x 10,000

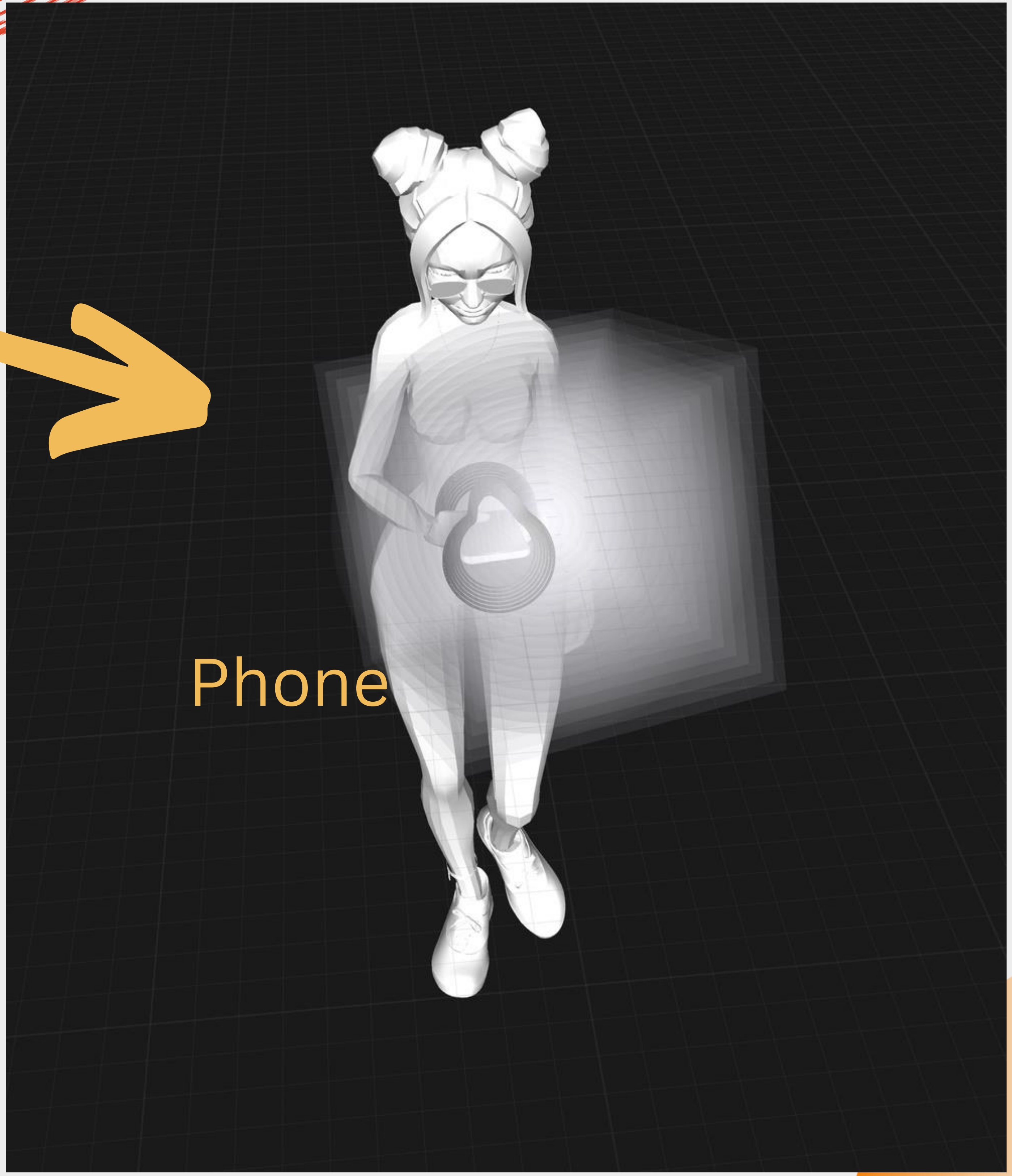
If the brain had an alphabet with a trillion letters, then any one voxel could be specified with a single letter. But what if, instead of using letters, it uses randomly selected sparse subsets of neurons? Statistically, this is entirely possible with fairly few neurons and with much redundancy (only 10% even need to fire if robustness built in) and little chance of overlapping false positives.



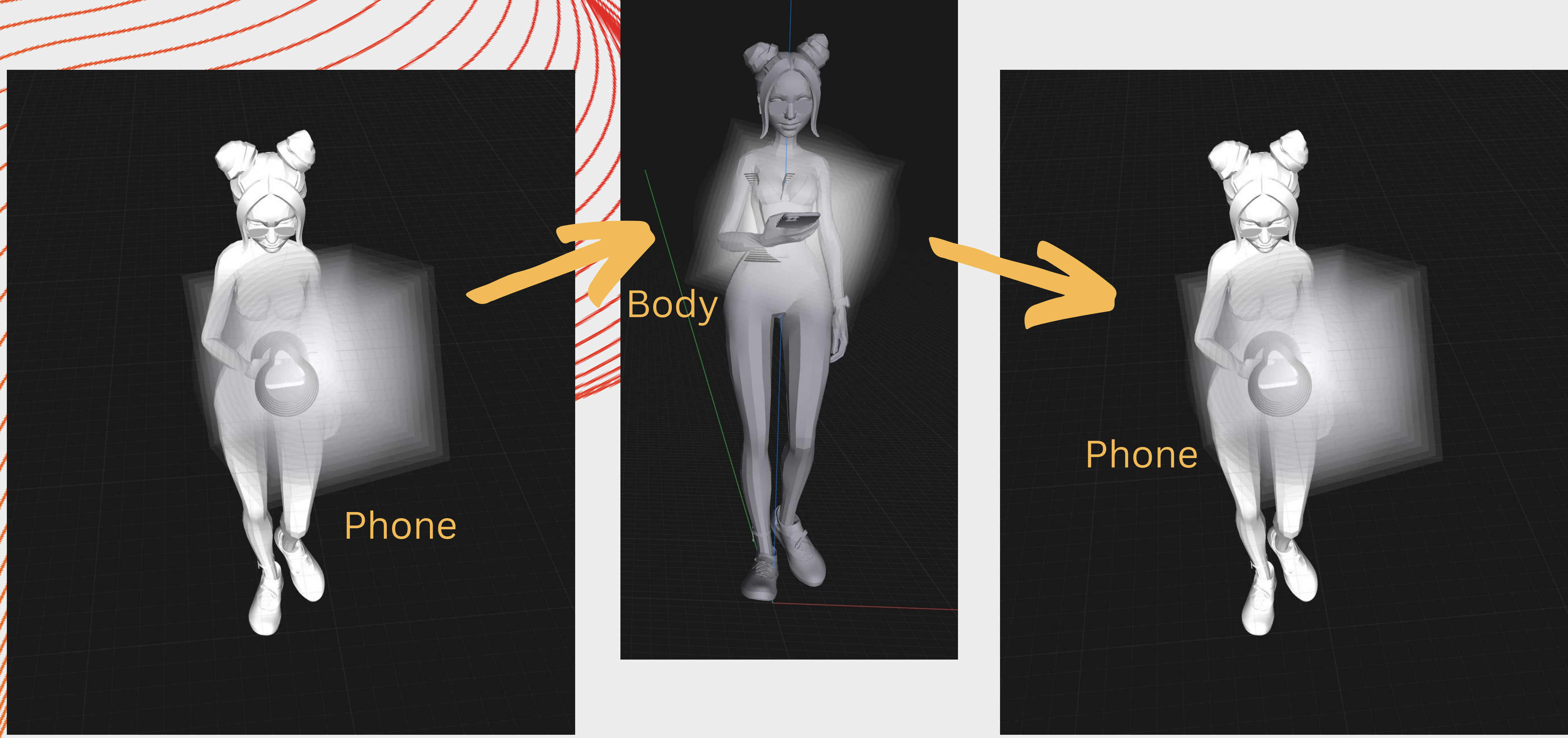
Moving Attention Spatially







Reference Frames



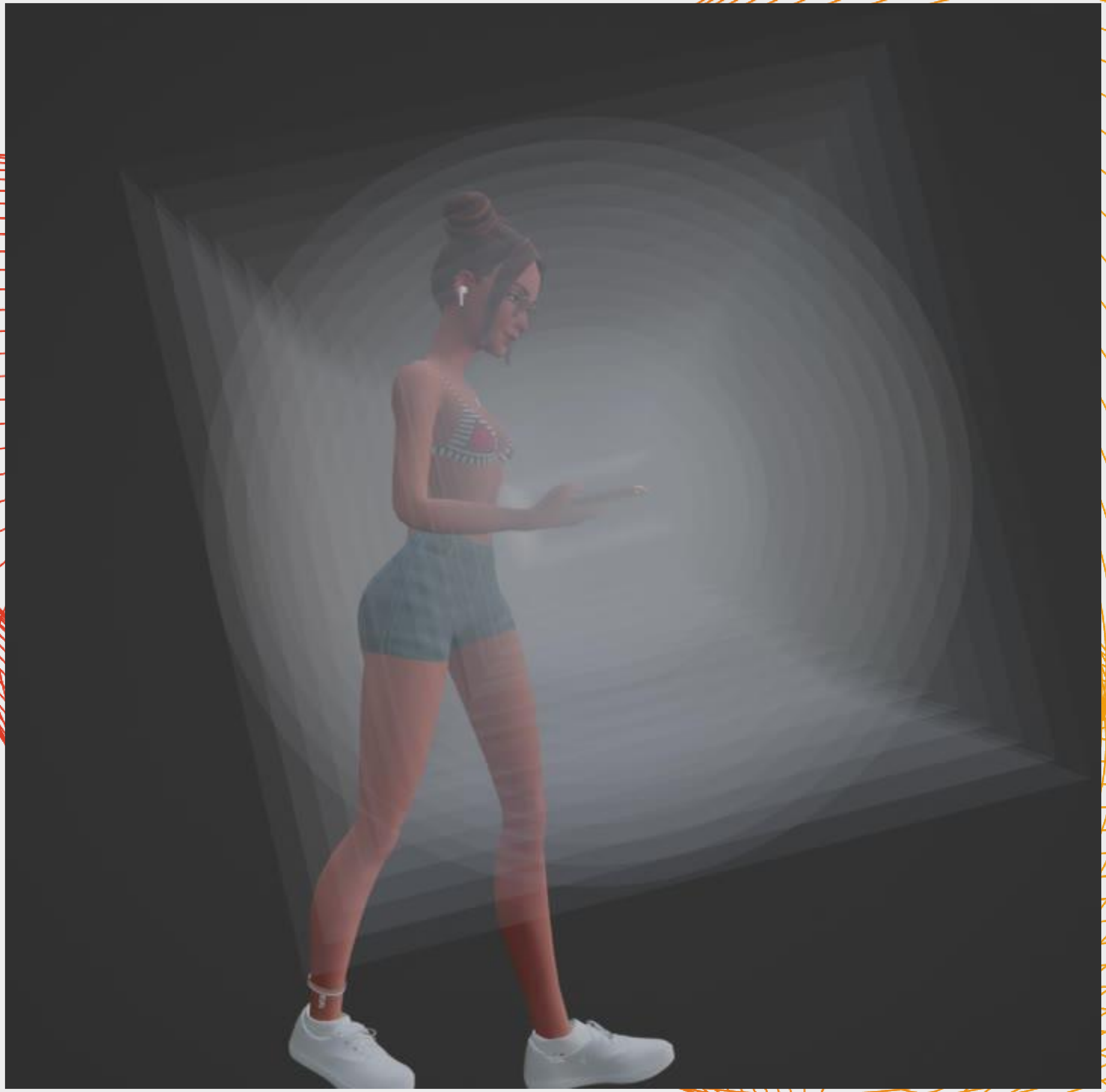
While it may seem as though the bank moves when we shift our attention, it is important to consider the equivalence of reference frames. From the bank's reference frame, it remains stationary while changes occur in what it is "painting" (which voxels selected).

What if we were to think of the bank as the brain, with its distributed and encoded representation of information? In this view, the stable perception of the world could be a result of the consistent painting of the schema. The bank would seem to move as "thing-painted" changed. This raises interesting questions about the relationship between the mental representation of the world and the external reality that it corresponds to.

Color Opponency

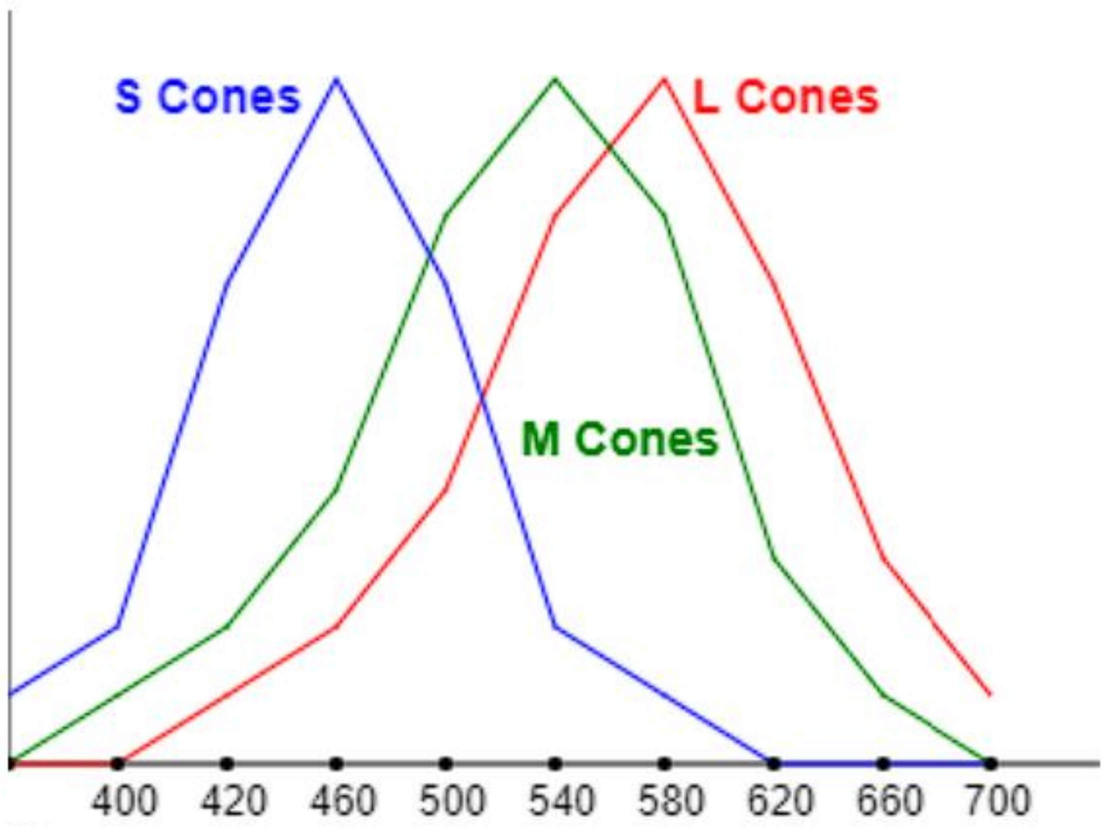
Color opponency refers to the way in which the human visual system processes and perceives colors. It is based on the principle that there are certain pairs of colors that are perceived as opposite to each other, and that these pairs of colors cannot be perceived together at the same time.

The classic example of color opponency involves three pairs of colors: red/green, blue/yellow, and black/white. In each pair, one color is considered to be "opponent" to the other. This means that when one color is perceived, the brain suppresses the perception of its opponent color, creating the illusion of color contrast.



Color Opponency

Wavelength Responsiveness of L, M, and S Cones



Color Examples

Wavelength Responsiveness of L, M, and S Cones

Cones	Peak Sensitivity	Range of Responsiveness
L Cones	~560 nm	~450-650 nm
M Cones	~530 nm	~450-630 nm
S Cones	~420 nm	~380-500 nm

Color Opponency

Color	Wavelength Range (nm)	Frequency Range (THz)
Red	630-740	400-480
Yellow	570-590	510-530
Green	495-570	530-610
Blue	450-490	610-670

Color opponency occurs due to the activity of three types of cone cells in the retina that are sensitive to different wavelengths of light. These cones are commonly referred to as "long-wavelength" (L), "medium-wavelength" (M), and "short-wavelength" (S) cones, and they are responsible for our perception of color.

The L cones are most sensitive to long wavelengths of light, which are in the red portion of the spectrum. The M cones are most sensitive to medium wavelengths, which are in the green portion of the spectrum. The S cones are most sensitive to short wavelengths, which are in the blue portion of the spectrum.

Color opponency occurs because the activity of certain cones can inhibit the activity of others, creating an opponent relationship. Specifically, the red/green opponent system is thought to occur between L cones and M cones. When L cones are stimulated, they inhibit the activity of M cones, and vice versa. This creates the perception of a red-green color opponent system.

Similarly, the blue/yellow opponent system is thought to occur between S cones and the combined activity of L and M cones. When S cones are stimulated, they inhibit the activity of L and M cones, which creates the perception of a blue-yellow color opponent system.

Finally, the black/white opponent system is thought to be mediated by rod cells, which are responsible for our ability to see in low-light conditions. Rod cells are not sensitive to color, but they can inhibit the activity of both L and M cones, creating the perception of black-white opponent processing.

Color Processing

Role of V4 in color processing:

- Schein, S. J., & Desimone, R. (1990). Spectral properties of V4 neurons in the macaque. Journal of Neuroscience, 10(10), 3369-3389.

- Christof Koch: Lecture 9: Seeing the World in Color (2012) YouTube. YouTube. Channel: Allen Institute. Available at: https://www.youtube.com/watch?v=ELj26VUBOPQ&list=PLCEC78997E3E2DAB4&index=9 (Accessed: March 21, 2023).

Color Representation

Essentially nothing is apparently known about how color is actually "made" or "printed" within perception. This is unfortunate, as most of the "printed" conscious experience is the printing of colors.

However, it is important to note that most of the meaning within consciousness can still be conveyed entirely devoid of color, using only shapes/locations. Color appears to be an added feature of surfaces that we're already consciously aware of.

It might involve the coactivation of specific sets of neurons in V4, somehow linked to their intended locations.

The Bank's Dewey Decimal System

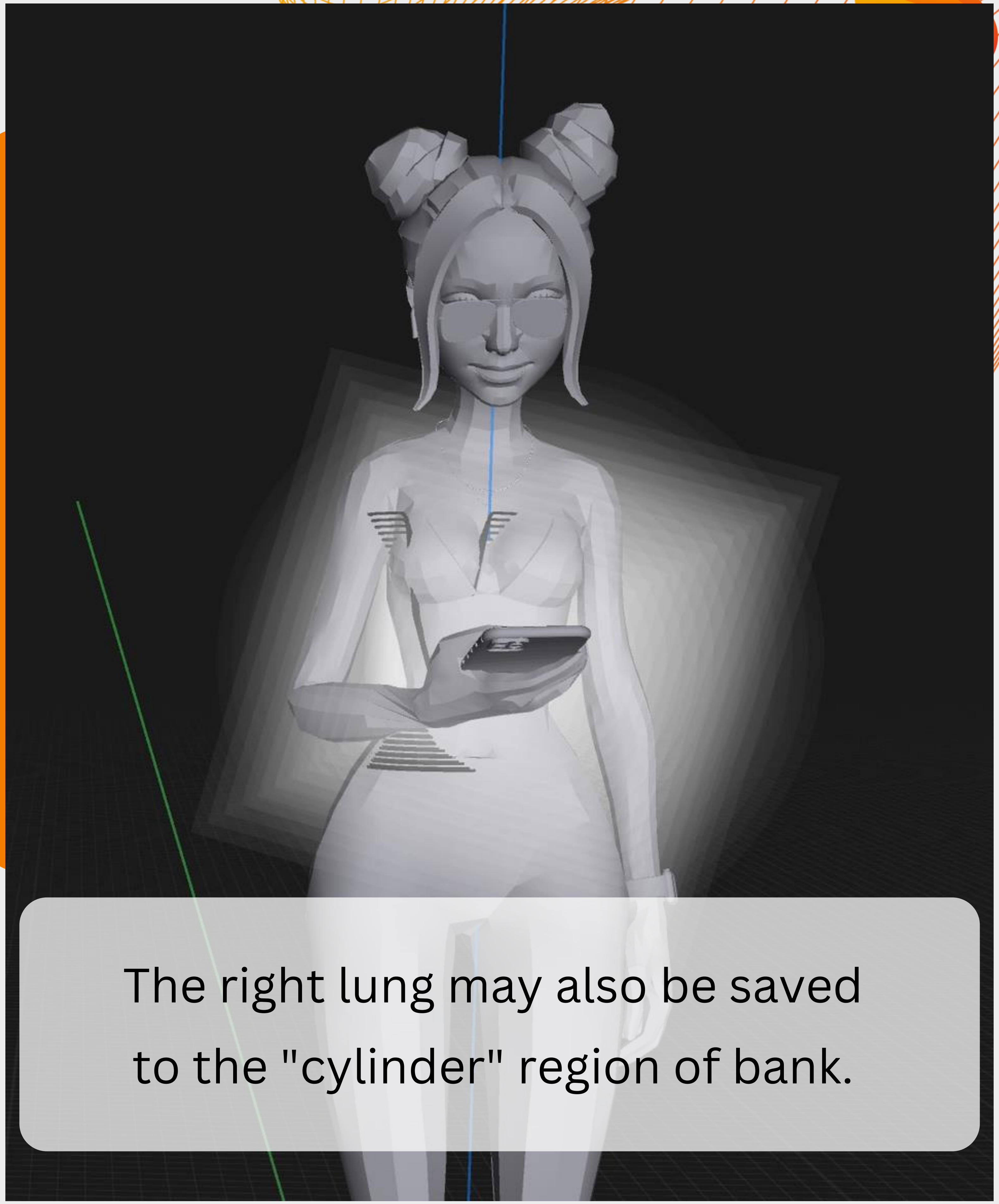
Not only is the brain orderly in separating body, hearing, and sight into regions (parietal, temporal, occipital lobes, respectively), and in keeping a retinotopy of spatial layout of neurons (in V1), and in having regions dedicated to specific purposes (FFA for faces, FG for objects, PPA for scenes) - it also appears to store a category of shapes (sharing a common shape, function, or abstraction) ***in the same spatial vicinity*** within the bank.

Phones are proposed to be saved to the "cylinder" region of bank.

The Bank's Dewey Decimal System: Triggering

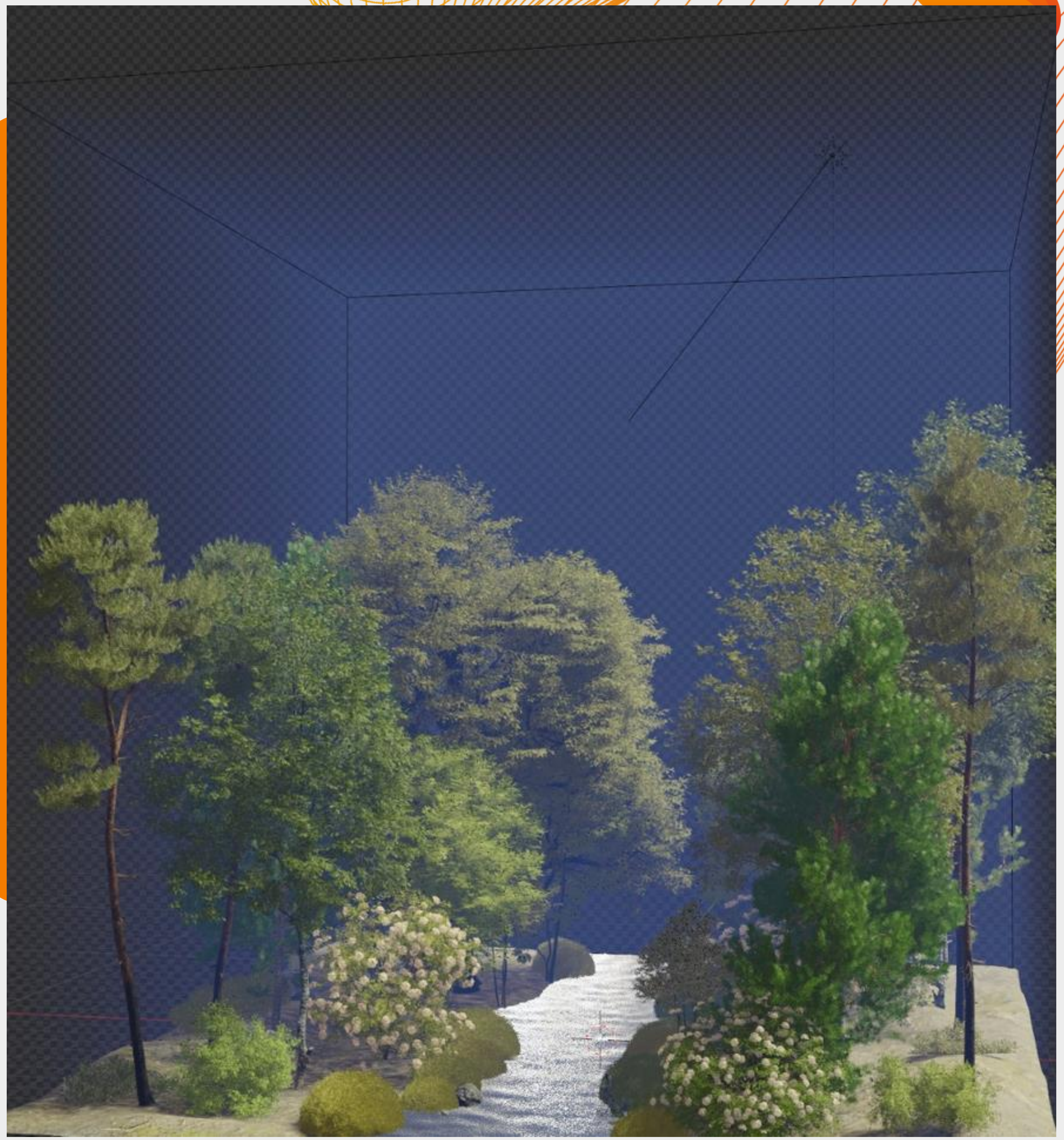
The bank system may also involve the brain's neural mechanisms for triggering neural ensembles of similar shapes by proximity and geometric similarity. This means that the bank can automatically trigger a sense of familiarity with an object, face, or scene.

In an upcoming class, we will explore this triggering mechanism in more detail and how it leads to the skewering and replay of episodic memory snippets, which is an important aspect of consciousness and memory.



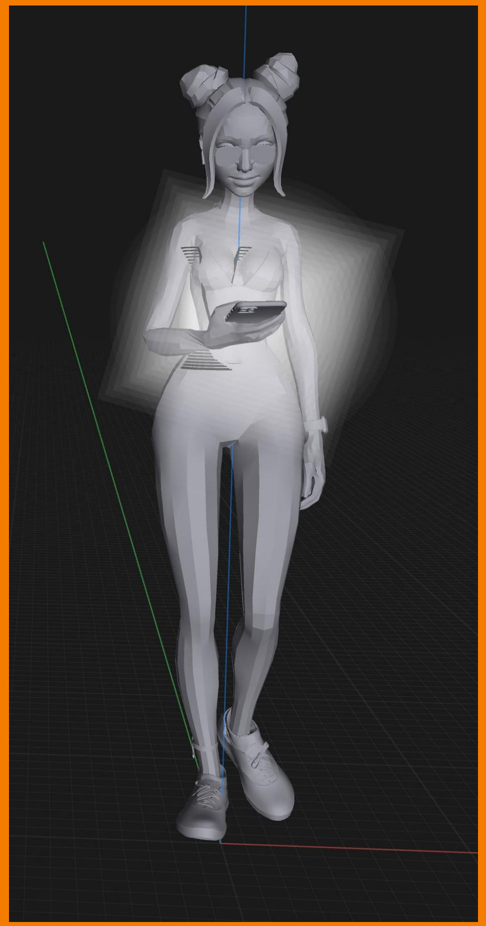
The Bank's Dewey Decimal System: Reading & FFV

Reading might offset to the cylinder region of the bank. But simply gazing outwards may default to locating the FFV (focal foveal voxel) to the centroid of the bank, allowing a large volume of bank to overlay the entire scene.



The Bank's Dewey Decimal System: Head and Torso

When you tilt your head, you often bring transient attention to the tilting. Thus, the bank comes and overlays the head, ostensibly with the cylinder to the right for internal modeling, and forward direction facing outwards. When modeling your torso, bank aligns with torso. Thus, it can interact with body schema and head direction.

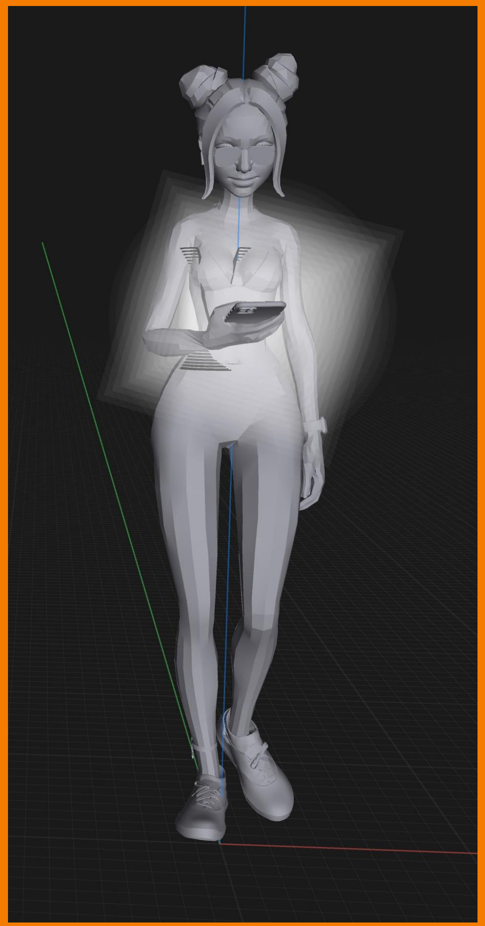


Attention to head is often segregated from attention to body, as separate inertial forces affect each. The ***vestibular system*** is tied to the **head's** position, 3D orientation relative to gravity, velocity, and acceleration. The ***motor system and certain regions of the cerebellum*** track mostly the **torso** region.

Seeing others often segregates head from torso also: Peelen, M., Downing, P. The neural basis of visual body perception. Nat Rev Neurosci 8, 636–648 (2007). https://doi.org/10.1038/nrn2195

The Bank's Dewey Decimal System: Left (& Right?) Hand

It seems likely that the left hand is mapped to the cylinder, as the "break" in the front would be as follows: left side break is thumb; right side break is edge of index, middle, ring, and pinky fingers. Human ability to use tools requires the opposable thumb, and tool use would ostensibly be mapped to this same vicinity in the bank.

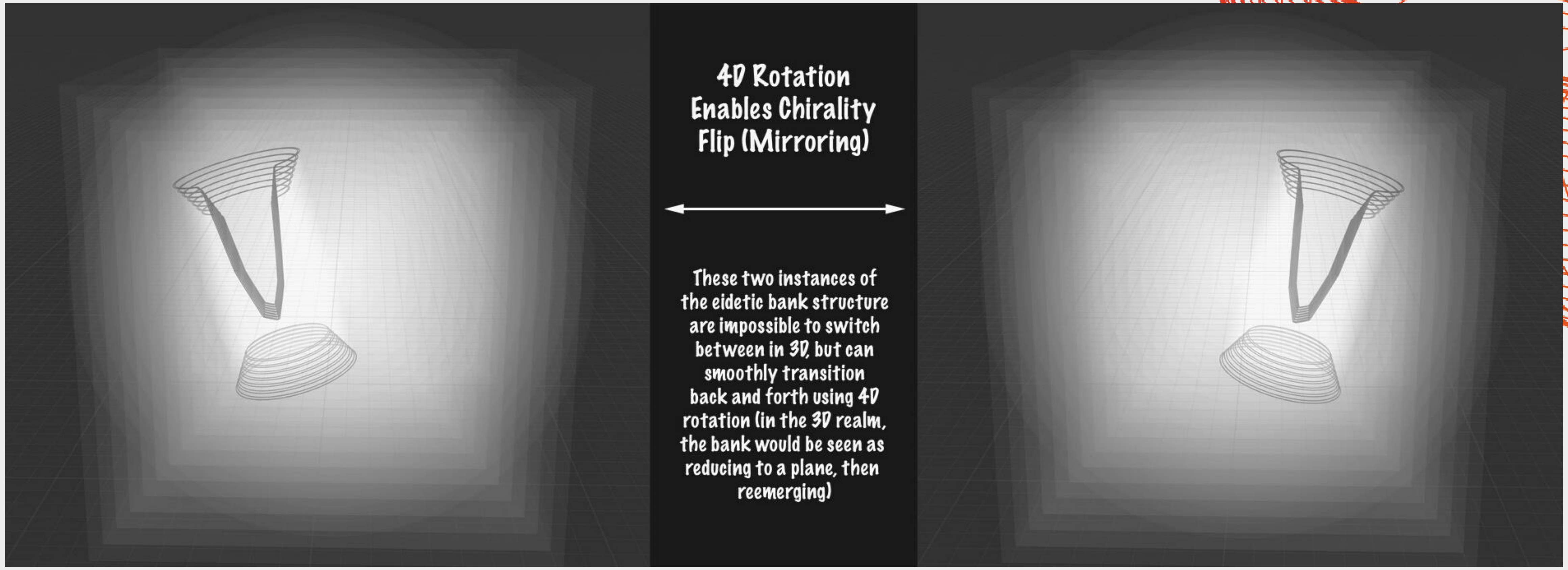


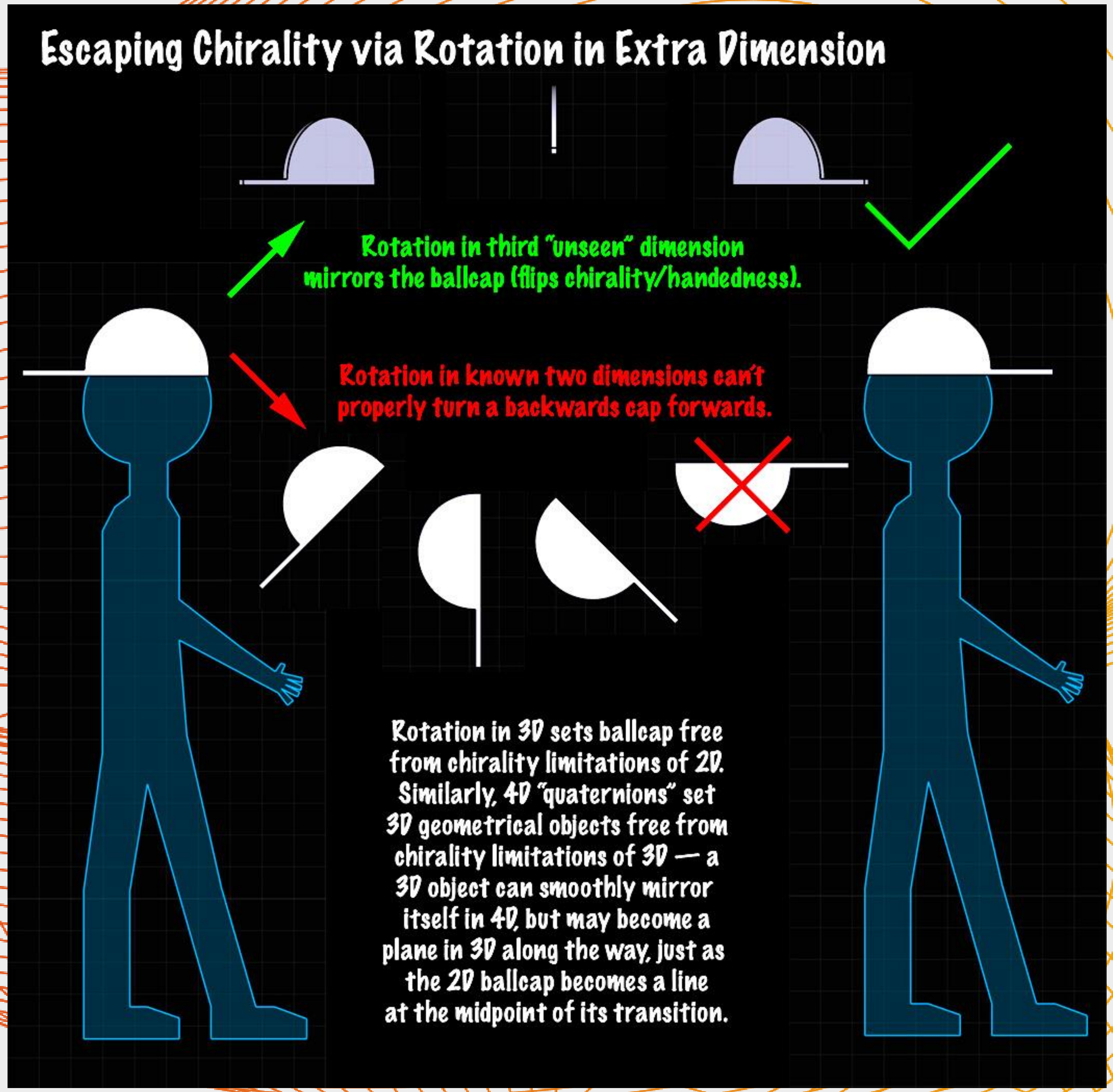
The Bank's Dewey Decimal System: Round, Cylindrical, Flat

Round surfaces can easily be stored on a sphere (will be able to represent typical rolling motion, too). Flat surfaces - including computer screens, tables, walls, floors - can easily be modeled by the face of a cube or by any plane passing through the bank. A tire could easily be modeled by the cylinder, and this would even be able to model the motion of the tire as constrained to one axis (whereas ball is unconstrained in rotation).

Chirality of Bank

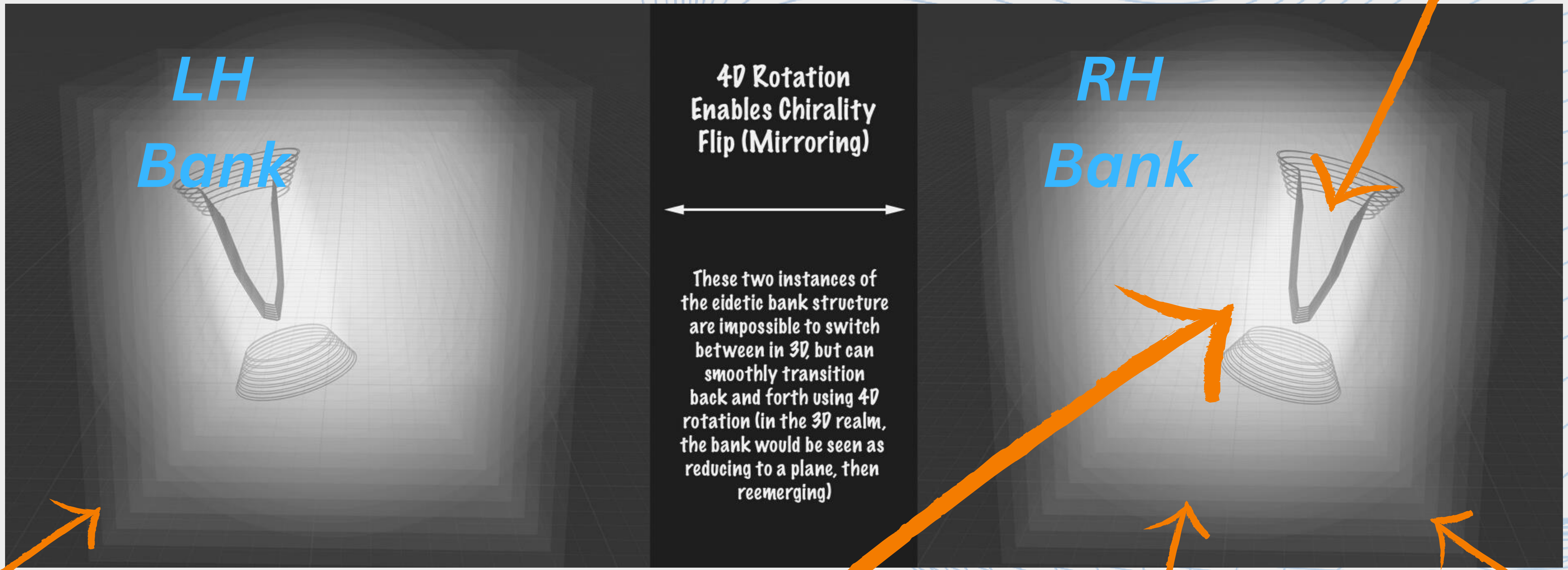
Chirality refers to the handedness of something. In 2D, a ballcap could only be rotated in that plane. To change chirality, you must rotate it in the third dimension. The bank appears to have a right-handed (as seen by viewer) and a left-handed chirality in certain settings.





Map of Bank

Left- (& right-?) handed tools, phone, wheels, cylinders, drinking glass, reading tasks (?), faces (??): ***cylinder***



Torso or head: ***entire (LH) bank***

FFV (focal foveal voxel): ***centroid of (RH) bank***

Balls: ***spheres***

Planar surfaces: ***cube face***

Shape+ Regions of Interest

- **Extrastriate Body Area (EBA)**: involved in processing the shape and configuration of the human ***body***.
- **Lateral Occipital Complex (LOC)** or **Lateral Occipital Area (LO)**: involved in ***object*** recognition, particularly with complex shapes.
- **Fusiform Face Area (FFA)**: involved in processing the identity and expression of ***faces***.
- **Parahippocampal Place Area (PPA)**: involved in processing spatial layouts and ***scenes***.
- **Occipital Place Area (OPA)**: involved in processing the layout and ***features of scenes***.
- **Transverse Occipital Sulcus (TOS)**: involved in processing the ***shapes and spatial relationships*** of objects.
- **Posterior Middle Temporal Gyrus (pMTG)** or **Human MT+**: involved in processing ***motion*** and complex visual patterns.
- **Inferior Temporal Gyrus (ITG)**: involved in processing complex shapes and objects, including ***face and body parts***.
- **Parvocellular (P) pathway**: involved in processing ***fine details and color*** information in the visual system.
- **Magnocellular (M) pathway**: involved in processing ***motion*** and ***spatial*** information in the visual system.
- **Visual Word Form Area (VWFA)**: involved in processing ***written words and letters***.

What, Where, When

The visual path splits at V1/V2 and goes into a **"where" path** to parietal cortex (which itself trifurcates and goes to hippocampus, premotor cortex, and prefrontal cortex), and a **"what" path** to fusiform/IT/LOC (and then to hippocampus, which could be thought of as a **trigger embedding/reactivation path**, as it is involved in storing and retrieving memories).

Bank Correlates?

The neural correlates for the bank are postulated to include the visual what pathway, with specific involvement of the fusiform gyrus, lateral occipital cortex, and inferior temporal lobe. However, it is likely that the network is distributed throughout the brain, including the prefrontal cortex, and may even involve the parietal cortex in instantiating shapes from memory.

The bank probably works closely with the hippocampus in triggering the most suitable "like" things to give a sense of familiarity. Novel things are initially saved most in the hippocampus and may be triggered by the cortex through repetition and dreaming. In an upcoming class, we will explore the neural underpinnings of the bank and its relationship with memory in greater detail.