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Exam is open notes and open book. **You are not allowed to use the Internet.**

You are not allowed to talk to anyone (e.g., your classmates).

If you need clarification for any question, I will be online from 12-1 pm at the link below. I will not respond to any question at other times or through other means (email, etc.). I will admit students to my zoom on a first come first served basis, so there may be some delay before I admit you.

<https://pdx.zoom.us/j/7370850474>

Each Question is 3 Points. Be brief in your answers.

Once you are done, upload your response to canvas by the deadline. Late submissions will receive a grade of zero.

- 1) Consider a triangle with (x,y,z) coordinates as (0,2,-6), (1,3,-4), and (-1,-3,-9). Consider a perspective projection of triangle coordinates onto a vertical plane at $z = -3$ (i.e., a plane parallel to the x-y plane and located at $z = -3$). What would be the coordinates of the projected triangle?

Answer:

Coordinates of the projected triangle are (0, 1, -3), (3/4, 9/4, -3) and (-1/3, -1, -3)

- 2) Let the matrix below be used for perspective projection in VR chain of transformations pipeline. If there are any problems, discuss the problems that may arise?

$$\begin{bmatrix} n & 0 & 0 & 0 \\ 0 & n & 0 & 0 \\ 0 & 0 & n & 0 \\ 0 & 0 & 1 & 0 \end{bmatrix}$$

Answer:

The problem is that with perspective projection all objects are going to be superimposed on one another on the $z = n$ plane. That is not a good method because we are losing the information about which object is in front of the other object during the transformations.

- 3) Let the focal distance of VR lenses be f . At what distance would visual display be typically placed with respect to f and why?

Answer:

- The lens is placed at its focal length. A virtual image (and enormous) is formed behind it. A real image is formed on your retina.
- Visual display/Screen of the VR headset would typically be placed at a distance ' f ' from the lens, where ' f ' is the focal length of the lens.
- This is to ensure that the virtual images are properly focused on the viewer's eyes.
- If the visual display is placed too far away from the focal distance, the viewer might have to strain their eyes to focus on the content, leading to discomfort and eye strain. On the other hand, if the

display is placed too close to the focal distance, the virtual images might appear blurry or out of focus.

- 4) Consider a user that is fixated on a virtual object while wearing a VR headset. Let the display frame rate be 60 frames per second (fps) and assume the display illuminates instantaneously for each frame and keep it until next frame arrives. What would be the impact if the user yaws her head and how the problem can be mitigated while maintaining 60 fps?

Answer:

User's might perceive undesired motion of the object due to illusions as the position of an object slips on the retina. The virtual object slides under the retina and is fixed for 16.67 milliseconds when the user rotates their head while using a VR display at 60 frames per second. The image display can be fixed for 2ms, then turned off, to resolve this issue. Low persistence is the result of the eye's photoreceptors being able to capture the image and the brain perceives the image. Flickering begins at a low persistence of 60 FPS, but this problem can also be solved by raising the frame rate to 90 FPS. By implementing these improvements, the user can have a good experience.

- 5) What is the main drawback of the painter's algorithm for the purpose of image rendering? Propose a solution to address the problem?

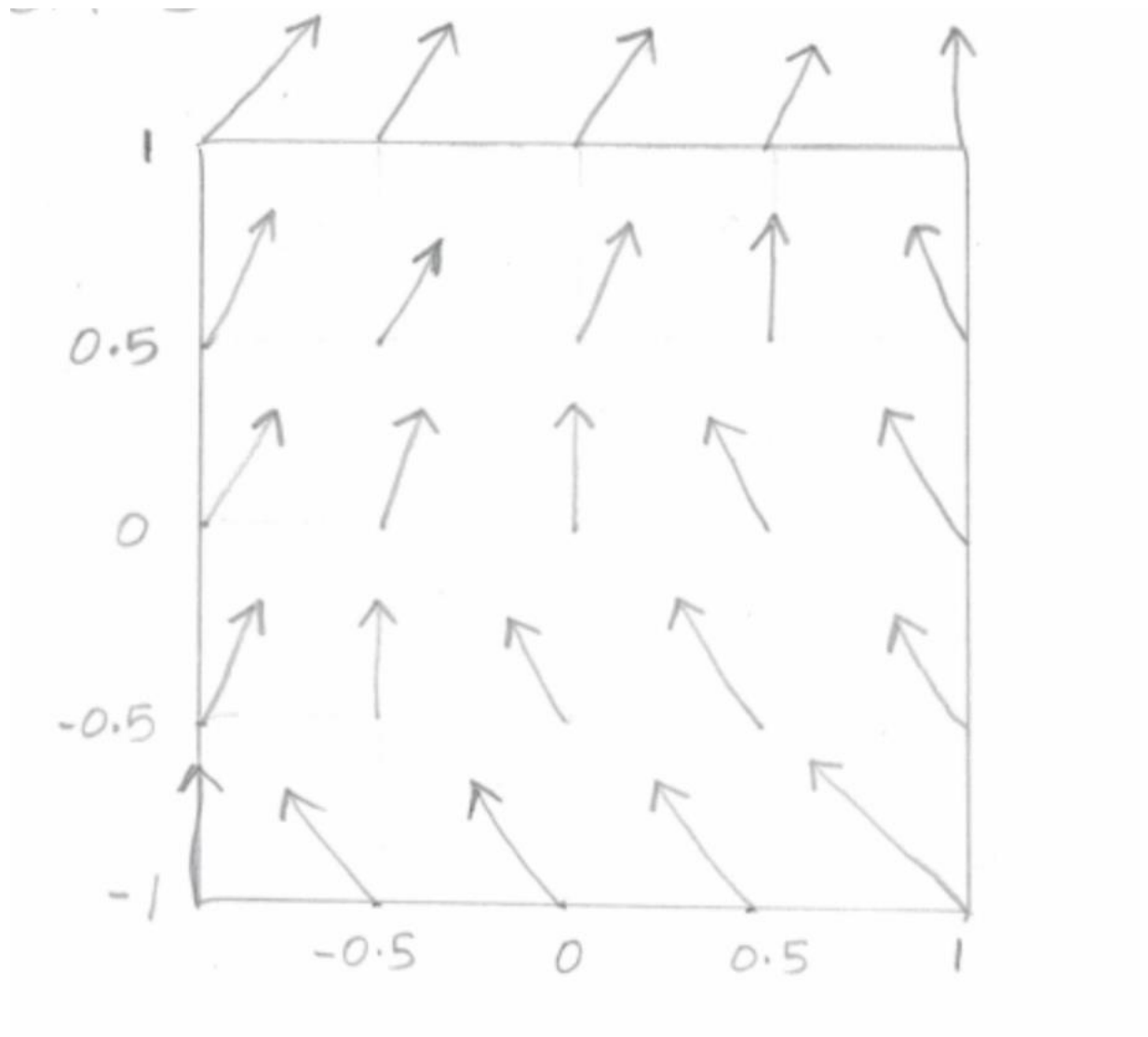
Answer:

- In Painter's algorithm we paint triangles from farthest away to closest, here we sort the triangles by their depths that is z value. Closer objects paint over the top of farther away objects.
- Main drawback of painter's algorithm is the possibility of existence of depth cycles, where it cannot provide the order of overlapped images correctly.
- To address this problem, we can maintain a depth buffer also called z-buffer, and store the depth on a pixel-by-pixel basis and which have normalized value either 0 or 1 (being farthest point)
- Initialize the depth buffer and frame buffer such that for all pixel positions (x,y) $\text{depthBuff}(x,y) = 1$, $\text{frameBuff}(x,y) = \text{Background Color}$ and process each triangle one at a time.

- 6) Draw the vector field associated with $(x,y) \rightarrow (-x+y, 2)$. Let x and y each be in the range of -1 to 1.

Answer:

The vector field associated with $(x,y) \rightarrow (-x+y, 2)$



- 7) You are given a device and asked to come up with a mechanism to track its orientation. What steps would you take?

Answer:

IMUs and Cameras are used in modern devices for tracking. IMU (Inertial Measurement Unit) contains 1 accelerometer (for measuring linear acceleration), 1 gyroscope (for measuring angular velocity) and 1 magnetometer (used as heading reference) per axis, so in total 9 of them per IMU.

For tracking 2D orientation we typically use the gyroscope of the IMU. Tracking 3D orientation is built upon the 2D tracking principles. Measuring angular velocity using it gives the orientation of the object. In practice the measured and estimated velocities are different. This is attributed to the difference in actual orientation and estimated orientation. This happens due to the drift error.

$\text{Drift error} = \text{Actual orientation} - \text{Estimated orientation}$

With constant angular velocity as time progresses the drift increases i.e. error increases.

Orientation, $\Theta(t) = \int (\text{Angular velocity})$
i.e. Angular Velocity = Derivative ($\Theta(t)$)

To effectively track the orientation with low errors we need to address below issues

Calibration – The output of low quality sensors are calibrated to mimic the output of high quality sensors through modeling

Integration – Sensor outputs that are recorded in discrete time intervals need to be integrated over time for actual orientation.

Registration – Also the initial orientation that is used for all future estimations needs to be determined through additional sensor or procedures.

Drift Error – This grows over time so needs to be compensated.

8) Describe the parallax effect and its connection to distance estimation?

Answer:

Parallax effect refers to the apparent motion of an object because of change in a user's viewpoint that gives the perception of distant objects moving slower and objects near to the eye moving faster and thus parallax can be used to determine the distance. So, the amount of displacement gives an estimation of the distance.

9) Which sense organ is responsible for sense of balance? How do existing/futuristic VR systems track and affect it?

Answer:

Vestibular Organ (Inner Ear) is responsible for sense of balance. In current VR systems not all sense organs are accounted for properly, say for example the vestibular organ. Thus user may experience a conflict between real and virtual world like user might actually be sitting on a chair but VR experience involves walking. This would cause a height mismatch between the 2 worlds causing mental fatigue to user.

The vestibular system is usually neglected which leads to mismatch of perceptual cues. In current VR systems, there is no engineered device that renders vestibular signals to a display that precisely stimulates the vestibular organs to values as desired. Some possibilities may exist in the future with galvanic vestibular stimulation, which provides electrical stimulation to the sense organ. However, it may take many years before such techniques are sufficiently accurate, comfortable, and generally approved for safe use by the masses.

10) Describe a VR interaction mechanism that does not have a counterpart in the physical world?

Answer:

- Teleportation, where user can quickly get to a new location without having to traverse physically.
- For teleportation, user can determine the desired location by simply pointing a virtual laser pointer and pressing a key. If places are not visible, they can be selected using a pop-up menu or voice commands or text-based search. It is easy to experiment with google cardboard.

- Teleportation reducesvection and VR sickness because there will be no conflict of stimuli with organs. However, with teleportation we don't get to learn spatial arrangement and dimensions of the environment.