Name:________________________________

This is closed book exam. You may not use electronic devices, notes, books or other written materials.

Good luck!

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1. The VR/AR Spectrum (10 Points)

a) Put the following VR technologies in the order of increasing immersion by assigning them the numbers 1, 2, 3 and 4. 1 being the least immersive, 4 the most immersive. (4 points)

_____ 360 degree stereoscopic video on Merge VR viewer
_____ VR application on Oculus Rift
_____ 360 degree monoscopic video on smart phone
_____ VR application on Oculus Go

b) Name and explain two differences between Virtual Reality and Augmented Reality devices. (4 points)

c) What is the difference between Augmented Reality and Mixed Reality? (2 points)
2. Human Color Vision (10 Points)

a) How many different types of rods and cones are in the retina? (2 points)

b) Describe one difference between rods and cones (besides that there are different amounts of types). (2 points)

c) What is the tristimulus theory, and how does it help us in Computer Graphics? (2 points)

d) Can a computer monitor produce all the colors our eyes can distinguish? Why/why not? (2 points)

e) The diagram below shows the the x-y plane of the CIE color space. Mark and label one plausible location each for the red, green, and blue basis colors. Indicate the color gamut for the color basis you have shown. (2 points)
3. Stereo Imaging Techniques (10 Points)

a) The owner of a movie theater wants to start showing 3D movies and is torn between anaglyphic, active and passive stereo. Name one advantage and one disadvantage for each of them which it has compared to the other two. (6 points)

Anaglyphic:

Active Stereo:

Passive Stereo

b) Briefly describe how an autostereoscopic display with a barrier screen works. Additionally, draw a sketch with a few light paths from screen pixels to right and left eyes, and where they pass through the barrier screen. (2 points)
c) Many stereo imaging techniques suffer from **ghosting**. Briefly describe what ghosting is. (1 point)

d) Name an example for a 3D display which completely **avoids** ghosting? (1 point)
4. VR Display Characteristics (10 Points)

Briefly define the following terms in the context of VR displays and estimate the values for the Oculus Rift. (2 points each)

a) Field of View (FOV):

b) Field of Regard (FOR):

c) Spatial Resolution:

d) Total number of pixels per eye:

e) Refresh Rate:
5. Interior Design (10 Points)

You have been hired as a consultant by a successful furniture company to help them design an application for interior design (i.e., to help people lay out new furniture in their house) using VR or AR. During this process you need to make the following decisions.

a) Name **two** benefits that VR has over AR for this application. (2 points)

b) Name **two** benefits that AR has over VR for this application. (2 points)

c) Of all the existing and currently available VR and AR devices, which one would you recommend that the company design their application for initially? Give **three** reasons for your decision. (3 points)

d) What are the **three** most important features you recommend that the interior design application that runs on the device you recommended in part c) needs to have? (3 points)
6. CAVE vs HMD (10 Points)

a) Name three advantages of CAVEs over HMDs (0.5 points each)

b) Name three advantages of HMDs over CAVEs (0.5 points each)

c) Write down the sequence of matrix transformations from object space to canonical view volume and briefly describe each one for HMDs and CAVEs: (6 points)

HMDs:

CAVEs:
7. VR Rendering Optimization (10 Points)

a) Describe the Asynchronous Time Warp (ATW) by answering the following questions.

Why is it done? (2 points)

At what rendering stage is it done? (1 point)

How does it work? (3 points)

b) Describe two ways in which the Asynchronous Space Warp (ASW) differs from ATW. (4 points)
8. Virtual CAVE System (10 points)

Bob is trying to simulate a 360-degree CAVE system on an Oculus Rift HMD using OpenGL. He created four virtual CAVE screens, where user will stand in the center surrounded by four textured quads, as shown in the figure below:

![The virtual cave scene in top-down view](image)

Bob wants to render a skybox of the CSE courtyard to the CAVE screens in stereo, but he encounters some problems and asks you for help.

a) Render to Texture: Bob understands that custom frame buffer objects would be a good way to render the skybox to the CAVE screens, but he cannot figure out how to use FBOs correctly. He wrote down this pseudocode with place holders: (4 points)

```c
for_each_eye {
    for_each_screen {
        ___
        ___
        ___
        ___
        ___
    }
}
```
What is missing is the five function calls needed for the core loop above. Put the function calls below in the correct order and fill in the letters A through E (i.e., the abbreviations of the function calls as given below) in the above pseudo code.

A. P = GetOffAxisProjectionMatrix();
B. BindFrameBufferToDefault();
C. BindMyFrameBuffer();
D. DrawQuad();
E. DrawSkybox(P);

b) Now Bob is implementing the GetOffAxisProjectionMatrix() function. The off-axis perspective matrix is constructed from the formula below. Explain the role of each matrix in this formula. (3 points)

\[ P' = PM^T T \]

c) Bob notices that the images rendered on the four screens are roughly correct but not aligned to each other. Name two things Bob might be doing wrong, and briefly explain how they would cause alignment problems. (2 points)
d) Finally, Bob is able to render the skybox correctly on the CAVE screens. However, he now has the problem that the skybox rotates when he turns his head. For example: when he starts out looking straight ahead where he sees Atkinson Hall (see figure below), and then rotates his head by 90 degrees to the left, he sees the CSE building.

What could he be doing wrong? (1 point)