Exam Instructions (Read Carefully)

1. Sign the first page of the exam with your Signature in the space provided on the upper left immediately.
2. Continue reading the instructions, but do not open the exam booklet until you are told to do so by a proctor.
3. Print your Name and Student Identification Number on every page in the space provided at the top of each page before you start the exam.
4. Cheating is an academic offense. Your signature on the exam indicates that you understand and agree to the University’s policies regarding cheating on exams.
5. Please read the entire exam before answering any of the questions.
6. There are three questions on this exam, each worth the indicated number of marks. Answer as many questions as you can.
7. Write all of your answers on these pages. If you need more space, there is blank space at the end of the exam. Be sure to indicate when a question is continued, both on the page for that question and on the continuation page.
8. Interpret the exam questions as written. No questions will be answered by the proctors during the exam period.
9. The exam is closed book. There are no aids permitted except for a calculator.
10. You have 45 minutes in which to work. Budget your time wisely.
11. In the event of a fire alarm during the exam, enter the four-character code provided by the proctor(s) in the space on the upper right, then gather your belongings and exit the room, handing your exam to a proctor as you exit.
12. No one will be permitted to leave the exam room during the last ten minutes of the exam.

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<tr>
<th>Question</th>
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<th>Maximum</th>
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Question #1 [30 marks total]
This question tests your knowledge of OpenGL display techniques that were used in Assignment 1. The following diagram was discussed in lecture and in tutorials as a basis for describing the various OpenGL function calls that are required to render the colour cube and other objects in the 3D scene. Refer to this diagram for all parts of this question.

The nodes in the diagram correspond to one or more OpenGL function calls, as indicated.

“N1” corresponds to OpenGL calls that deal only with setting the parameters of the synthetic camera.

“N2–4” correspond to other OpenGL calls that deal with all other object manipulation and modeling transformations.

“N5” corresponds to OpenGL calls that are specific to drawing the Monitor RGB colour cube.

“N6” corresponds to OpenGL calls that are specific to drawing the labeled CIE XYZ axes.

“N7” corresponds to OpenGL calls that are specific to drawing the 3D CIE tristimulus curve.
(a) [18 marks] For each of the following OpenGL functions, indicate the **single most likely** node (N1, N2, N3, N4, N5, N6, or N7) in which the function would be used with the parameters (if any) that are specified. Write your answers in the spaces provided to the left of each item.

[2 marks each, all-or-nothing.]

_N7_  glBegin( GL_LINE_STRIP );
_N5_  glBegin( GL_POLYGON );
_N5_  glColor3f( ... );
_N1_  glMatrixMode( GL_PROJECTION );
_N3_  glMultMatrixf( &XYZtoRGB[0][0] );
_N4_  glMultMatrixf( &PlanarProjection[0][0] );
_N2_  glMultMatrixf( &Rotation[0][0] );
_N1_  glOrtho( ... );  or  gluOrtho2D( ... );
_N1_  gluLookAt( ... );

(b) [12 marks] For each of the following data files or other sources of information, indicate the **single most likely** node (N1, N2, N3, N4, N5, N6, or N7) in which the information would be used. Write you answers in the spaces provided to the left of each item.

[2 marks each, all-or-nothing.]

_N7_  /ugrad0/cs414/data/tristimulus.data
_N2_  The rotation matrix computed by the VTrackball widget.
_N3_  The matrix that you computed using MATLAB.
_N4_  The matrix

\[
\begin{pmatrix}
1 & 0 & 0 & 0 \\
0 & 1 & 0 & 0 \\
0 & 0 & 1 & 0 \\
1 & 1 & 1 & 0
\end{pmatrix}
\]

that was given in lecture, the tutorials and the newsgroup.
_N1_  The aspect ratio computed by your program’s callback function when the user resizes the window.
_N1_  The new values for near and far clipping planes if you implemented Option B.
Question #2 [30 marks total]
This question tests your knowledge of the CIE colour systems.
The following table, which is a subset of the data in the file

/ugrad0/cs414/data/tristimulus.data
gives the CIE XYZ tristimulus values for various wavelengths. All entries are for the same amount of
power (i.e., the energy of the light is the same for all wavelengths).

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<th>X</th>
<th>Y</th>
<th>Z</th>
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<td>0.000386916</td>
<td>0.0679741</td>
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<td>700</td>
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</table>
For the following questions, use the data in the table on the previous page to compute your answers. You need only compute two significant digits in your answers. Show all of your work.

(a) [2 marks] In what units are the wavelength in the table measured?
   nanometers OR $10^{-9}$ meters

(b) [2 marks] For what wavelength in the table does the light have the highest luminance?
   560nm
   [2 marks for exact, 1 mark for anything else in the range 520–600.]

(c) [3 marks] The “Purple Line” runs between the “bluest” and the “reddest” pure spectral colours. What are the tristimulus values of the “bluest” colour in the table?
   At $\lambda = 400$, $X = 0.0143197$, $Y = 0.000386916$, $Z = 0.0679741$
   [1 mark for each of $X$, $Y$ and $Z$.]

(d) [6 marks] What are the three chromaticity values of the “reddest” colour in the table?
   At $\lambda = 700$, $X = 0.0113522$, $Y = 0.0041$, $Z = 0.0$, so $X+Y+Z = 0.0155$.
   $x = X/(X+Y+Z) = 0.7324$, $y = Y/(X+Y+Z) = 0.2645$, $z = Z/(X+Y+Z) = 0.0$
   [2 marks for each of $x$, $y$ and $z$ with partial marks if approach looks correct.]

(e) [6 marks] Assume that a colour P along the Purple Line is an equal mixture of the “bluest” light in the table with the “reddest” light in the table (assume P is half of each) What are the XYZ tristimulus values of the colour P?
   
   $X = (0.0114+0.0143)/2 = 0.0128$
   $Y = (0.0041+0.0004)/2 = 0.0023$
   $Z = (0.0000+0.0679)/2 = 0.0340$
   [2 marks for each of $X$, $Y$ and $Z$ with partial marks if approach looks correct.]

(f) [6 marks] What are the three chromaticity values of the color P that was defined in Part (e)?

   $X+Y+Z = 0.0128+0.0023+0.0340 = 0.0491$
   $x = X/(X+Y+Z) = 0.0128/0.0491 = 0.2607$
   $y = Y/(X+Y+Z) = 0.0023/0.0491 = 0.0468$
   $z = Z/(X+Y+Z) = 0.0340/0.0491 = 0.6925$
   [2 marks for each of $x$, $y$ and $z$ with partial marks if approach looks correct.]

(g) [5 marks] For which wavelengths (approximately) are the standard RGB colour-matching functions all non-negative? Justify your answer!

   The functions are non-zero iff two are zero and the third is unity (one). This happens only at the three wavelengths that were used as the $R$, $G$ and $B$ colours in the matching experiments. These are approximately 460nm, 530nm and 650nm. Any values roughly in the 400’s, 500’s and 600’s are OK if there is a justification. [3 marks for only approximate wavelengths or only the justification, 5 marks for both parts of the answer.]
Question #3 (40 marks – 2 marks each)

Explain the following terms as they have been used so far in our course on computer graphics. If the term is an *acronym*, explain for what it is an acronym and its meaning, usage, or how it functions (i.e., do not just provide the full name, but also explain what the acronym identifies). Where appropriate, include explanatory diagrams or formulae in your answers.

(a) addressability

The total number of locations (for monitors) or locations per inch (for printers) at which x or y coordinates can be specified when positioning objects (or pixels) in a display. This is a one-dimensional value, which may be different for the horizontal and the vertical directions.

(b) angle of incidence [include a diagram]

The angle $\Theta_i$ between an incoming (incident) ray of light and the normal to a surface. [See Figures 14.2, 14.31 and 14.32 in the text. 1 mark each for definition and diagram.]

(c) aspect ratio [include a formula]

The ratio between the height of a window (or viewport) and the height of a window (or viewport).

$$\text{aspect} = \frac{\text{width}}{\text{height}}$$

[1 mark for height/width, 2 marks for correct]

(d) callback

A function that is registered with a widget (such as the VTrackball) that will be called by the widget when certain events occur.

(e) calligraphic display

A "line drawing", "vector" or "stroke" system in which characters, points, lines and perhaps higher order curves (such as conics) can be displayed, but solid areas cannot be easily displayed.

(f) dominant wavelength [include a diagram]

The wavelength of the spectral colour that lies on the line from the white point through a particular colour and on to the boundary of the CIE chromaticity diagram. Some colours hit the Purple Line, so they do not have a dominant wavelength, so we use the complementary colour. [See figure 11.15. 1 mark each for explanation and rough diagram.]
(g) Engelbart (Douglas)

While at Stanford Research Institute he invented the mouse. [2 marks for anything related to "invented the mouse". 1 mark for vaguer stuff.]

(h) event loop

The "ping pong" pattern of interrupts (or events) and callbacks between the Window manager (or SRGP, GLUT or similar packages) and the application program in which events detected by the window manager result in callbacks to the application.

(i) frame buffer

The two-dimensional memory (or raster) in which pixels (and other values) are stored. Often a frame buffer is addressed by (x,y) pixel coordinates. [2 marks for "2D memory" or "raster" and "pixels", 1 mark for vaguer answers.]

(j) graphics pipeline [include a diagram]

The sequence of steps through which a data structure or other representation of a scene is systematically transformed to an image that is perceived by the eye and understood by the brain. Key steps are the display list (DAG), traversal of the DAG, modeling transforms, viewing transforms, clipping, perspective, scan conversion, digital-to-analog conversion, display on a monitor, and perception by the eye and brain. [See Figures 14.41-14.45 in the text for examples. 2 marks for the general idea of a set of steps and a diagram indicating some flow of information with a subset of the steps listed here. 1 mark for less complete answers.]

(k) gluLookAt()

An OpenGL function that specifies an eye point, a look-at (reference) point, and an "up" vector that is used as part of the viewing transformation. It computes an appropriate windowing matrix from this information. [2 marks for full description of arguments, or partial description plus mention of how it used. 1 mark for less.]

(l) LUT

"Look Up Table" converts colour numbers stored at each pixel to (often) 24-bit RGB values as an image is displayed from the frame buffer.

(m) nonspectral colour

A colour whose dominant wavelength would be on the Purple Line. [0 marks if the answer says "monochromatic"].
(n) odd-parity rule
When determining the interior of a (polygonal) region, a point is "inside" if a line from it to infinity (or vice versa) crosses the region boundary an odd number of times; it is "outside" if there are an even number of crossings. [See Figure 2.9 in the text.]

(o) pixel
A "picture element" that specifies the on/off, grey-scale, or colour to be displayed at the corresponding location on the monitor or paper.

(p) Snell’s Law [include a diagram and a formula]
The sine of the angle of refraction is related to the sine of the angle of incidence by the ratio between the indices of refraction of the two media.

\[ n_i \sin \Theta_i = n_r \sin \Theta_r \]

[See Figures 14.31 and 14.32 in the text. 2 marks for diagram and formula. 1 mark for just one of these. 0 marks for neither.]

(q) specular reflection [include a diagram or formula]
The "mirror-like" reflection in which the angle of incidence is equal to the angle of reflection for highly specular surfaces. [See Figures 14.2, 14.31 and 14.32 in the text.]

(r) SRGP
Simple Raster Graphics Package is a set of functions for 2D graphics. [2 marks for name and something about 2D or bitmap or pixels, 1 mark for less.]

(s) synthetic camera [include a diagram]
The analogy between 3D viewing in OpenGL (and similar packages) and a photographic camera. [See figure 6.1 in the text. 1 mark each for the description and the diagram.]

(t) window manager
Software that controls the creation and deletion, position, sizing and resizing of display windows (such as X11).