

CMSC 435/634: Introduction to Graphics

Final Exam

December 16, 2002

Instructions: Clearly write your name on this sheet. Answer each problem in the space provided. If you need extra space, write “on extra sheet” in the answer space on the exam paper, clearly label the problem number on an extra sheet of paper, and staple the extra sheet to the exam when you hand it to me.

You may use a calculator to assist you in simple arithmetic. You may also use any notes you have written on both sides of a single 8.5 x 11 inch sheet of paper. No other notes or books are allowed.

You have 120 minutes. The exam consists of four parts worth a total of 120 points, and one extra credit part worth at most 20 points. Parts and subparts are all marked with the number of points they are worth.

Strategy: Read all parts of each problem before you start answering it. The work for some problems is split across several questions. You may find that later questions will guide the method you use to solve the problem. You may even find that later questions will jog your memory.

Since the total number of points and amount of time for the test are equal, if you find yourself spending more than about one minute per point on one section, you may want to move on and come back to that section later.

If something isn't clear, ask.

Good luck

Name: _____

1 Odds and ends

(20 points total)

1.1 If project 5 (driving around the mountain) were part of a possibly fictitious video game, what do you imagine the title would be? **(1 point)**

1.2 Name something related to graphics that Rob Cook did. **(1 point)**

1.3 Name one visibility algorithm other than z-buffering and ray tracing and provide a short one-sentence description of how it works. **(2 points)**

1.4 Describe the RGB color (.5,1,1). Describe the CMY color (.5,1,1). **(2 points)**

1.5 In the HSV color space, what do H, S and V stand for? Describe what H, S and V mean. **(6 points)**

1.6 Mark the color systems that are **not** physically based (so the same values may represent different colors on different devices)? **(4 points)**

- C M Y
- C M Y K
- H L S
- H S V
- L u v
- R G B
- x y Y
- X Y Z

(1 point)

1.7 What do we use a BRDF for?

1.8 What is Perlin noise?

(1 point)

1.9 Name one use for texturing other than just mapping image colors onto a surface.

(1 point)

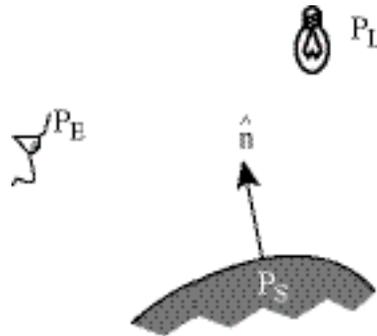
1.10 Either name or describe one line clipping algorithm.

(1 point)

2 Lighting

(25 points total)

We want to compute the illumination for a point on the surface shown in this diagram:



2.1 Lighting Vectors

(12 points)

2.1.1 Draw, on the diagram above, all of the vectors you will need to compute the diffuse and Phong specular contribution from this light.

2.1.2 For each vector in your diagram, write the exact equation you would use to compute it in terms of P_E , P_L , P_S , \hat{n} , and your other vectors.

2.2 Write the equation for the diffuse and specular components in terms of $P_{S,E,L}$, \hat{n} , a specular exponent, e , and/or your computed vectors.

(9 points)

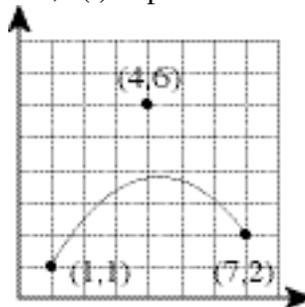
2.3 Name two other components you might include in computing the color of surface point P_S , besides diffuse and specular.

(4 points)

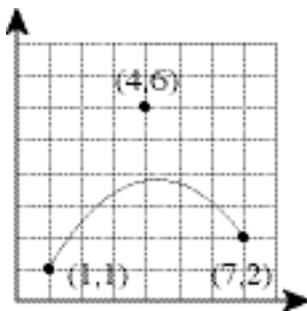
3 Quadratic Bézier

(25 points total)

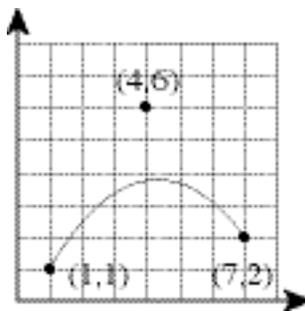
This problem concerns the quadratic Bézier curve shown below, with the indicated control points. This curve, $s(t)$ is parameterized from $t=0$ at $(1,1)$ to $t=1$ at $(7,2)$.



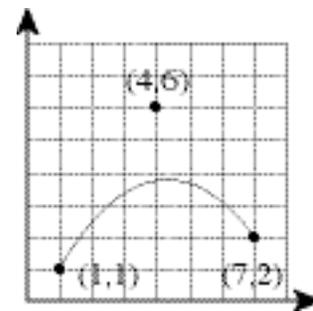
3.1 Evaluate points on the curve graphically using the deCasteljau algorithm. Draw your answers on the diagrams below. (9 points)



find $s(1/3)$



find $s(1/2)$



find $s(2/3)$

3.2 Bernstein Basis (16 points)

3.2.1 Write out the three Bernstein basis functions for quadratic Bézier curves, $B_0^2(t)$, $B_1^2(t)$, and $B_2^2(t)$

3.2.2 Evaluate the three basis functions at $t=1/2$

3.2.3 Use these as weights for the control points to numerically evaluate $s(.5)$

4 Transformation Hierarchies

(50 points total)

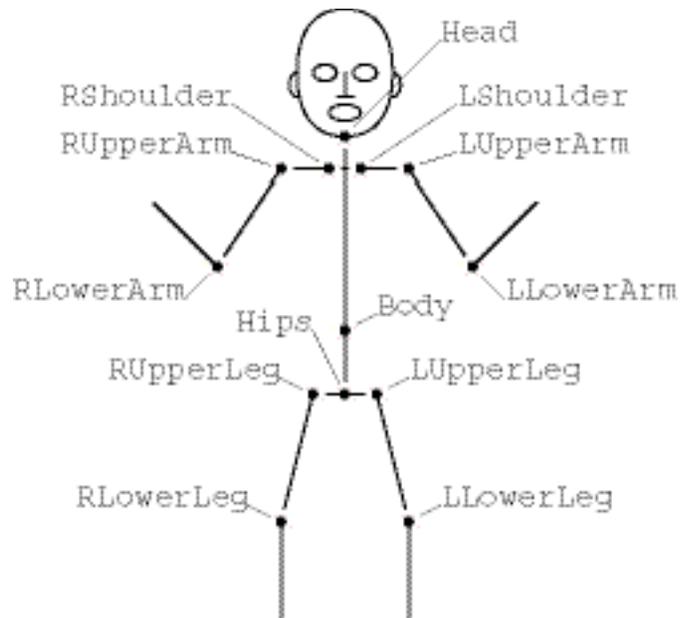
This stick figure is defined by 13 coordinate systems as indicated. The origin of each space is indicated by a dot and the geometry connected to the dot is drawn in that space. These coordinate systems are arranged in a hierarchy based at Body, and connected in the natural way down to the hands, feet and head.

For each space, we have a transformation matrix that tells us how to get there **from the system above it in the hierarchy**. For example:

Hips_from_Body,

RUpperLeg_from_Hips,

LUpperLeg_from_Hips, etc. See question 4.4 for a full list.



4.1 Draw the full tree of transformations rooted in the Body coordinate system.

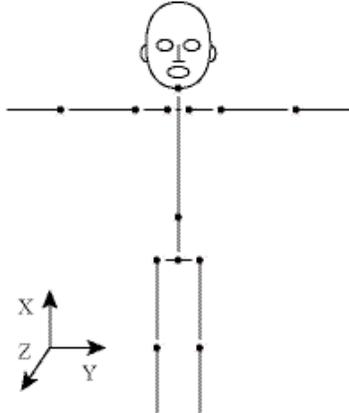
(10 points)

4.2 Write the chain of transformation matrix multiplies to get from the LLowerArm coordinate system to the Head coordinate system. For transformations moving down the hierarchy, use the transformation name (e.g. the matrix to get from the Body coordinate system to the Hips coordinate system is `Hips_from_Body`). For transformations moving up the hierarchy, use the inverse (e.g. the matrix to get from the Hips coordinate system to the Body coordinate system is `Hips_from_Body-1`). **(10 points)**

4.3 Write pseudo-code for the necessary transformation stack and drawing operations for the body and both legs (but not the arms or head). Use terms like `draw(Body)` to draw all geometry in the Body space, `xform(Hips_from_Body)` to transform from Body space to Hips space, `push` to push a copy of the current transformation matrix onto the transformation stack (equivalent to `glPushMatrix`, but shorter to write), and `pop` and to pop the top matrix off of the matrix stack (equivalent to `glPopMatrix`). Assume that when entering your code we are in the Body coordinate system. You should be back in the Body coordinate system when your leaving your code. **(15 points)**

4.4 We want to place this stick figure into a pose similar to your position right now, **(15 points)** while taking this exam.

Draw a sketch of your intended pose and describe the relative transformations necessary to position the stick. For reference, here is the stick man in his rest pose, with zero rotation at every joint so every local coordinate system aligns with the world coordinate system. To describe the position, for each transformation listed below, briefly describe the rotation axis and angle relative to the coordinate system above it in the hierarchy. You need not say anything about the translations also included in each transformation – the translation distances are fixed by the lengths of each body segment.



Head_from_Body	
RShoulder_from_Body	
LShoulder_from_Body	
RUpperArm_from_RShoulder	
LUpperArm_from_LShoulder	
RLowerArm_from_RUpperArm	
LLowerArm_from_LUpperArm	
Hips_from_Body	
RUpperLeg_from_Hips	
LUpperLeg_from_Hips	
RLowerLeg_from_RUpperLeg	
LLowerLeg_from_LUpperLeg	

5 Extra credit

(20 points total)

5.1 The program I used to draw the diagram for problem 3 includes a cubic Bézier curve-drawing tool, but no quadratic splines.

(10 points)

The quadratic curve I wanted is given by this equation (for control points $q_{0,2}$):

$$s(t) = [q_0 \ q_1 \ q_2] \begin{bmatrix} 1 & -2 & 1 \\ 0 & 2 & -2 \\ 0 & 0 & 1 \end{bmatrix} \begin{bmatrix} t \\ t^2 \\ 1 \end{bmatrix}$$

But the cubic curve I had to use is given by this equation (for control points $c_{0,3}$):

$$s(t) = [c_0 \ c_1 \ c_2 \ c_3] \begin{bmatrix} -3 & 3 & -1 \\ 0 & 3 & -6 \\ 0 & 0 & 3 \\ 0 & 0 & 1 \end{bmatrix} \begin{bmatrix} t \\ t^2 \\ t^3 \\ 1 \end{bmatrix}$$

Since every quadratic curve is also a cubic curve with a 0 coefficient on the t^3 term, I knew I could reproduce the exact curve if I could just find the right locations for the four cubic Bézier control points. This process is called degree elevation. Write out a matrix equation to compute cubic Bézier control points from quadratic Bézier control points. It's not necessary to actually compute any matrix multiplications or inverses.

5.2 In recent SuperBowl games the commentators have occasionally gone back to see a freeze frame replay of a critical play from other angles. They appear to have the ability to pan around the football or player to view the play from any position, for example to see if the football was in bounds or out of bounds when it crossed the goal line. No, they didn't have a helicopter circling the field at the critical moment; this is accomplished through image-based rendering using the video images from the existing cameras. **(10 points)**

5.2.1 Assuming six cameras spaced around the field, what additional information beyond the video images would you need from the cameras or commentators to be able to do this?

5.2.2 Outline a procedure to achieve this effect, from video images and other information to image-based rendering on your TV screen.

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CMSC 435/634: Introduction to Graphics

Final Exam

May 12, 2004

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Good luck

Name: _____

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1 Odds and ends

(30 points total)

1.1 What was your favorite assignment?

(1 point)

1.2 What is this equation for?

(3 points)

$$L_o(\hat{\mathbf{v}}) = \int_{\Omega(\hat{\mathbf{n}})} f_r(\hat{\mathbf{v}} \leftarrow \hat{\mathbf{l}}) L_i(\hat{\mathbf{l}}) \hat{\mathbf{n}} \cdot \hat{\mathbf{l}} d\omega(\hat{\mathbf{l}})$$

1.3 What are each of these terms in 1.2?

(3 points)

$L_o(\hat{\mathbf{v}})$	
$L_i(\hat{\mathbf{l}})$	
$f_r(\hat{\mathbf{v}} \leftarrow \hat{\mathbf{l}})$	

1.4 Name one graphics fact about Rob Cook.

(1 point)

1.5 Write out the 4x4 matrix for glScale3f(2,3,4);

(2 points)

1.6 Name two kinds of *shaders* other than *surface shaders* that can be written in the RenderMan shading language.

(2 points)

1.7 Name one advantage and one disadvantage of the A-buffer over the Z-buffer. **(4 points)**

1.8 Draw the stages of a graphics pipeline. **(4 points)**

1.9 What is the CMYK color (0.75, 0, 0.5, 0.25) in RGB (show the formula you used for the conversion?) **(3 points)**

1.10 What are the other (more intuitive) names for the hither and yon clipping planes? **(2 points)**

Hither _____

Yon _____

1.11 Match up each of these texturing methods with the thing the texture affects. **(5 points)**

Bump Map _____

Light intensity

Displacement Map _____

Normal

Environment Map _____

Reflection color

Gloss Map _____

Specular coefficient

Shadow Map _____

Surface Position

2 Shading

(35 points total)

- 2.1 What are the two directions in a BRDF (Bidirectional Reflectance Distribution Function)? (4 points)
- 2.2 Which of these make physically plausible BRDFs? (4 points)
- Diffuse
 - Phong
 - Blinn-Phong
 - Cook-Torrance
- 2.3 For each of the above that you said was **not** physically plausible, which property or properties of physical BRDFs does it violate? (6 points)
- 2.4 Name one real surface or object that exhibits anisotropic shading (1 point)
- 2.5 Draw a diagram of the surface microstructure as assumed by a microfacet BRDF model. Include all relevant vectors. (8 points)

2.6 What is each of these microfacet BRDF terms intended to model? When is it greatest? When is it smallest?

(12 points)

2.6.1 Fresnel Reflectance

2.6.2 Facet Distribution

2.6.3 Shadowing

2.6.4 Masking

3 Antialiasing

(30 points total)

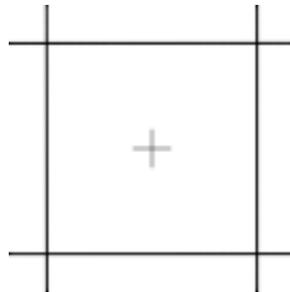
- 3.1 Describe in a couple of sentences what aliasing is and where it is seen in graphics. **(4 points)**
- 3.2 What are the tradeoffs between uniform supersampling, jittered supersampling and exact area sampling **(6 points)**
- 3.3 Give an example of temporal aliasing. **(3 points)**
- 3.4 Would you ever use image antialiasing (e.g. supersampling) and texture antialiasing (e.g. mipmapping) at the same time? Why or why not? **(5 points)**
- 3.5 How many texels are combined when using trilinear mipmapping? **(2 points)**

3.6 The squares shown below represents a pixel centered at integer coordinates (i,j) . **(10 points)**
The pixel center is the small cross in the middle, and the square shown goes from $(i-.5, j-.5)$ to $(i+.5, j+.5)$.

If you find yourself needing to use a random number function in any of the questions below, use `drand48()`, which returns a uniformly distributed random number in the range $[0,1)$.

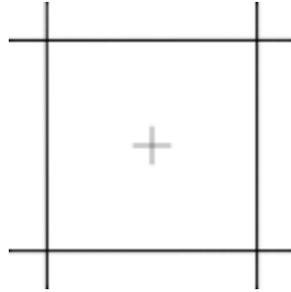
3.6.1 What are the four expressions for the sample locations in a 4-sample uniform supersampling pattern?

3.6.2 Draw a sample of the locations produced in the pixel below.



3.6.3 What are the four expressions for the sample locations in a 4-sample jittered supersampling pattern?

3.6.4 Draw a sample of the locations produced in the pixel below.



4 NPR

(25 points total)

- 4.1 What is NPR an abbreviation for? What is it? (2 point)
- 4.2 Name three important characteristics of the Gooch and Gooch cool-warm shading technical illustration method. (3 points)
- 4.3 Write an equation for the cool-warm blend in terms of C_{cool} and C_{warm} , $\hat{\mathbf{n}}$ and $\hat{\mathbf{l}}$. (6 points)
- 4.4 Name four controllable features of a pen-and-ink stroke. (8 points)
- 4.5 Why might you choose an image-based painting algorithm over an object-based one? (3 points)

4.6 Why might you choose an object-based painting algorithm over an image-based one?

(3 points)

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December 21, 2004

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Good luck

Name: _____

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1 Odds and ends

(25 points total)

1.1 Which assignment was your favorite?

(1 point)

1.2 What is *gamma correction*? What is the gamma correction equation?

(4 points)

1.3 Why would you ever want to use a rendering technique that is not interactive?

(3 points)

1.4 How long is the cross product of two vectors, \vec{a} and \vec{b} . What direction does it point?

(3 points)

1.5 Name one graphics fact about Ivan Sutherland.

(1 point)

1.6 Define *Implicit Modeling*.

(2 points)

1.7 What was the major difference between Ken Perlin's *Image Synthesizer* and Rob Cook's *Shade Trees*? **(3 points)**

1.8 What do each of these stand for? **(5 points)**

1.8.1 RGB

1.8.2 CMY

1.8.3 CMYK

1.8.4 HSV

1.9 Write out the 4x4 matrix to rotate θ counterclockwise around the y axis. **(3 points)**

2 Illumination

(35 points total)

2.1 What is the difference between *global illumination* and *local illumination*?

(5 points)

2.2 BRDFs (Bidirectional Reflectance Distribution Function)?

(10 points)

2.2.1 What are the two directions in a BRDF?

2.2.2 List three conditions that all physical BRDFs must obey.

2.3 Refraction

(10 points)

2.3.1 Given the refraction of an incident ray, \mathbf{v}_i , to a transmitted ray, \mathbf{v}_t , and the refraction equation, $\eta_i \sin \theta_i = \eta_t \sin \theta_t$, draw a picture showing the relevant vectors, θ_i and θ_t .

2.4 Write an equation for θ_t at total internal refraction.

2.5 Phong and Blinn-Phong Shading

(10 points)

2.5.1 Write out the Phong Shading equation and draw a picture showing all of the relevant vectors.

2.5.2 Write out the Blinn-Phong Shading equation and draw a picture showing all of the relevant vectors.

3 Scan Conversion

(30 points total)

- 3.1 What major advantage do the Bresenham or midpoint line drawing algorithms have over the DDA algorithm? **(5 points)**
- 3.2 The Bresenham algorithm was originally developed in 1962 for drawing lines with integer endpoints on a Calcomp vector plotter connected to an IBM 1401. Much has changed since then. Which of the algorithm's original advantages are no longer relevant, and which still hold? **(10 points)**
- 3.3 Which line algorithm do we use to walk down the edges in the concave polygon scan conversion algorithm? **(3 points)**

3.4 Write high-level pseudo-code for this polygon scan conversion algorithm. You may consider operations like "set up sorted edge table" or "set up active edge table" as single steps in the algorithm. You need not show their implementation.

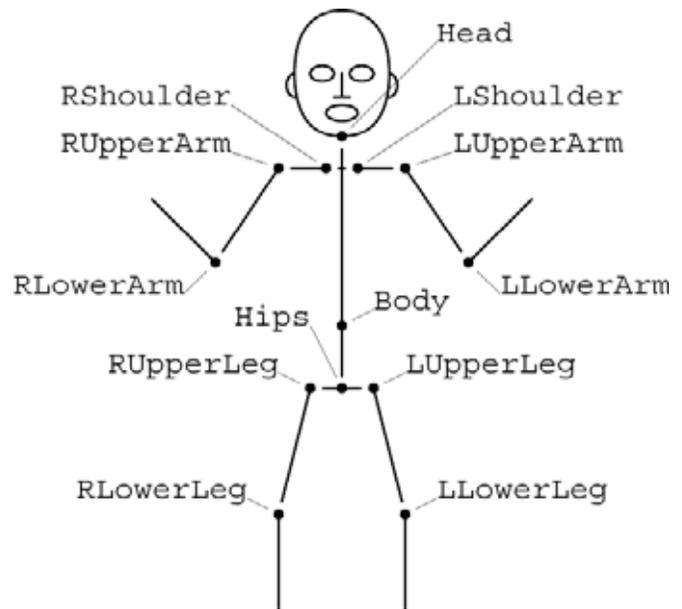
(12 points)

4 Transformations

(30 points total)

This stick figure is defined by 13 coordinate systems as indicated. The origin of each space is indicated by a dot and the geometry connected to the dot is drawn in that space. These coordinate systems are arranged in a hierarchy based at Body, and connected in the natural way down to the hands, feet and head.

For each space, we have a transformation matrix that tells us how to get there **from the system above it in the hierarchy**. For example: `Hips_from_Body`, `RUpperLeg_from_Hips`, `LUpperLeg_from_Hips`, etc.

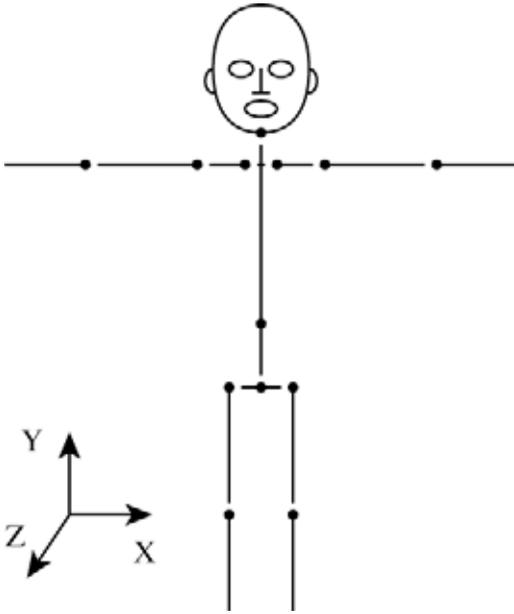


- 4.1 Write the chain of matrices to transform a point in the `RLowerArm` coordinate system to the `LLowerArm` coordinate system. (Hint: You will need to use some inverse matrices!)

(10 points)

4.2 The stick figure's rest position is shown here. You may rotate each joint by adding a single `glRotate(θ, x, y, z)` to the joint's transform. For example, adding `glRotate(90, 0, 1, 0)` to `Head_from_Body` would turn the head to point toward the right side of the page. **(20 points)**

In "`Head_from_Body rotate($90, 0, 1, 0$)`" form, list the set of rotations to position this figure in a natural pose to reach out and shake someone's hand with the other arm down.



5 Extra Credit

(20 points total)

Many paint and hardware stores now have computer paint mixing machines that can produce a paint to match anything the customer brings in that will fit in the machine. Typically these machines measure the reflected spectrum of the sample under simulated daylight, incandescent and fluorescent lights.

5.1 How many original paint colors does the machine need to be able to match the sample in all three lighting conditions? Why? **(5 points)**

5.2 Assuming the sample spectra, Q_D , Q_I and Q_F are the only thing measured on-site, what other measurements or data might you need in the machine? Write out an equation to solve for exactly how much of each original paint color you need to mix to make the match **(10 points)**

5.3 How feasible is it to match the sample's color under all lighting conditions? How many source paint colors would you need? **(5 points)**