Homework 1: Drawing Pixels, Visual Perception and Colour Perception

Received: Monday, 5 October 1998
Due: Monday, 19 October 1998

Directions

Please provide short written answers to the questions in the space provided. If you require extra space, you may staple additional pages to the back of your assignment. Feel free to talk over the problems with classmates, but please answer the questions on your own.

Name: ____

Problem 1 True or False

(a) Because Sketchpad ran on a calligraphic display, flickering got worse as more objects were created.

(b) Every colour known to mankind can be represented on a PC monitor.

(c) The colour gamut of a printer can change depending on whether you look at its output in natural sunlight or fluorescent light.

(d) Diffraction is the bending of light when passing between media of different densities.

(e) The critical fusion frequency for a particular display is directly proportional to the persistence of the phosphors in the display.

(f) In a CRT, the red electron gun emits electrons with a frequency in the range of 600–700nm.

(g) Two colours with identical coordinates in CIE colour space are metamers.

(h) Two colours with identical coordinates in CIE colour space have precisely the same spectra.

(i) The main purpose of double–buffering is to be able to display graphics at a higher frame rate.

(j) Without adaptation, the human eye would be useless in all but a small set of lighting conditions.

Problem 2 A certain computer system runs at 170 MIPS (Millions of Instructions Per Second). Its graphics system displays a resolution of 1280×1024 with 24 bit colour and a refresh rate of 76hz (non-interlaced) on a monitor with a 20 inch diagonal.

(a) Assuming pixels are square, how many dots per inch (DPI) are displayed?

(b) How much time can the display controller spend drawing a single pixel?

(c) The previous question ignores the *retrace interval*, the time needed to reposition the electron beams before drawing of pixels begins (see, for example, page 41 of the textbook). If the display spends a combined 12 percent of its time retracing, how much time can now be spent drawing a single pixel?

(d) Some careful measurements determine that it takes about 10300 instructions for the CPU to render a 3D polygon to the framebuffer. How complex a scene (in terms of the number of rendered polygons) can this system display reliably at 60 frames per second?

(e) There is no colour table on this system — that is, the framebuffer holds 24 bits of information for each pixel. How much memory is required to hold the frame buffer?

Problem 3 One property of a monitor is its gamma value γ, the extent to which electron beam intensity maps nonlinearly to the intensity of light. Specifically, the greyscale value (from 0 to 255) stored in the colour table is translated linearly into a voltage, which corresponds to some electron beam intensity $N \in [0, 1)$. But because of the nonlinearity of the monitor's response, the beam intensity ends up being visible as a glowing phosphor with intensity N^γ.

(a) Suppose every pixel on the screen is set to 50% grey. Then, using sophisticated calibration equipment, I measure the brightness of the screen image and determine it to be 20% grey (*i.e.*, one fifth the brightness of white). Estimate the value of γ for this monitor.

(b) Suppose we have a framebuffer holding 4 bits per pixel, corresponding to 16 grey levels from black to white. Give a colour table that maps these 16 grey levels to 24 bit RGB colour values in a way that corrects for a monitor with $\gamma = 2.7$.

Problem 4 A square greyscale image can be thought of as a function f from the unit square $I^2 = [0,1] \times [0,1]$ to an intensity value in the range $[0,1]$. For any point $(x,y) \in I^2$, $f(x,y)$ gives the brightness of the image at that point.

Recalling that Mach bands appear at C^0 or C^1 discontinuities in intensity, which of the following image functions might be expected to exhibit Mach bands? (Note: all of these image functions are independent of y. In other words, any vertical slice of the image will be of uniform brightness.) If Mach bands are present, indicate for which values of x they occur.

(a) $f(x,y) = x$

(b) $f(x,y) = \begin{cases} 0 & : \quad x \leq \frac{1}{2} \\ 1 & : \quad x > \frac{1}{2} \end{cases}$

(c) $f(x,y) = \max(\sin(4\pi x), 0)$

(d) $f(x,y) = e^{-|x-\frac{1}{2}|}$

Problem 5 A certain graphics system has a framebuffer that can hold 6 bits per pixel and uses a colour table to transform those 6 bits into a 24 bit displayed colour. Assume that the monitor used with this system has $\gamma = 1.0$, *i.e.*, we don't need to worry about gamma correction.

(a) How many shades of grey could this system display on the screen at once?

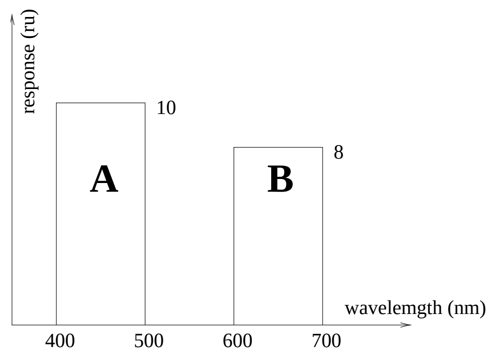
(b) In class, when building a colour table for three–bit colour indices, we found that a "good" choice of colours was associated with a natural division of the three bits into red, green and blue information. What is a "good" choice of colours to place in the colour table in *this* case? Give a short function (in pseudocode or some programming language) that takes a six bit index as input and prints the red, green and blue intensities (in the range 0–255) that should be associated with that index.

(c) With the above colour table, how many shades of grey can be displayed? That is, how many entries in the colour table defined by your answer to **(b)** correspond to greys?

(d) Now suppose that for some reason, green is strictly more important than red, and red is strictly more important than blue. That is, we'd like to be able to display more distinct shades of green than red, and more distinct shades of red than blue. Now what's a "good" choice of colours? Provide a revised function mapping six bit indices to 24 bit colours.

(e) How many shades of grey can be displayed using this new colour table?

Problem 6 A new species of shrew was recently discovered in the tropical rain forests of southern Poland with a rather unusual visual system. The Plonge Shrew (as it is called) has exactly two kinds of photoreceptors, type A and type B. These photoreceptors are distributed evenly around its retinas. The response curves of these cones are as follows:



(a) Unfortunately, the Plonge Shrew is a rather reticent creature, who runs for cover at the slightest hint of light. In order to photograph this elusive animal, you need to see it without it being aware of your light. What colour of flashbulb could you use to illuminate the shrew without its knowledge?

(b) Given the following spectral intensity curves, indicate which pairs, if any, represent metamers from the shrew's point of view.

(i) $f(\lambda) = \frac{\lambda}{10}$

(ii) $f(\lambda) = \begin{cases} 22\frac{2}{9} & : \quad 0 \leq \lambda \leq 585 \\ 15\frac{5}{13} & : \quad 585 < \lambda \leq 1000 \end{cases}$

(iii) $f(\lambda) = \frac{\lambda^3}{10000}$

(iv) $f(\lambda) = \frac{10000}{\lambda}$

(v) $f(\lambda) = \begin{cases} 15\frac{1}{4} & : \quad 0 \leq \lambda \leq 562 \\ 31\frac{3}{4} & : \quad 562 < \lambda \leq 1000 \end{cases}$

(c) One of the shrew's favorite fruits is the phig. Phigs have a spectral sensitivity of $f(\lambda) = \lambda$.

Under which pairs of lighting conditions mentioned in **(b)** would phigs appear exactly the same?

Problem 7 Answer each question with a few sentences. These are somewhat open–ended, and you are encouraged to come up with creative answers.

(a) Monitors typically employ phosphors with extremely low persistence. However, it is possible to manufacture phosphors with much higher persistence. Why might a display made with these phosphors be useful? Describe a potentially beneficial use of a display with high persistence phosphors.

(b) Evolution has provided us with three "flavours" of cones, each suitable for detecting light within a particular range of colours. Why only three? Why might it be beneficial to have more kinds of cones? If there are benefits, then what reasons might there be for only having three?