Questions

1. Why does color lookup table (LUT) need more than 8 bits per RGB? (It typically uses 12 bits instead of 8.)

2. In the color lecture, we talked about a spectrum of light as being the sum of the spectra of RGB light emitters in the display e.g. phosphors. In the notation from that lecture, three basis spectra (the columns of $\mathbf{P}$) were weighted by values of I_{RGB}. Now that we have learned a bit about how displays work, however, we realize that there is a transformation that happens on the images in the frame buffer, namely either gamma expansion (and possible correction). How can we extend the model from the color lecture to account for this mapping?

3. A typical model for a display might say that when the RGB value at a pixel is $(0, 0, 0)$ the display will produce a zero spectrum i.e. no light comes off the display. In practice this model doesn't hold exactly. For example, displays *reflect* at least *some* light from the surrounding scene. So some light will always come off the display, even if the power of the display is turned off!

   One way to model the *reflected* component of the light from the display is to let it have a ambient spectrum $a(\lambda)$ component. How could one model the effect of this extra light coming off the display? In particular, how does it change the response of RGB photoreceptors of someone (or a camera) that is looking at the display?

4. Consider the following situation which occurs in the lecture room.

   (a) An RGB image $I_0(x, y)$ is stored in the frame buffer of my laptop.

   (b) The image $I_0(x, y)$ is sent to a projector which projects it onto a white screen.

   (c) Suppose you take out your cell phone camera and capture a JPG image $I_1(x, y)$ of the of the screen.

   Describe each of the steps involved in the transformation from $I_0(x, y)$ to $I_1(x, y)$. State your assumptions.

   Ignore geometric aspects of this problem, namely the fact that the pixels (x, y) of the frame buffer image I_0 are not identical to the pixels (x, y) of the camera image I_1.

Answers

1. The LUT typically represents a mapping that is "concave downward" like a log or a sqrt, or x^γ where $\gamma < 1$. If it only had 8 bits per RGB channel, then there would be two "input values" (8 bit per RGB) that map to the same 8 bit output value. When the display subsequently does gamma expansion, these two identical values would both remapped to the same value and would be displayed with the same physical intensity. That would not be good, since two different RGB input values would be presented with the same physical intensity.

   If the LUT has more than 12 bits per RGB, then it is much less likely that two RGB input values get mapped to the same output value.

2. Let the RGB strength of the emitted light at a pixel be $\mathbf{s}_{RGB}$. By this I mean that the emitted spectra can be expressed as $\mathbf{Ps}$ where $\mathbf{P}$ is the $N_\lambda \times 3$ matrix of RGB spectra emitted by the display and $\mathbf{s}$ is a scaling of the three spectra. This is the same as in the lecture, but now the three (RGB) values of $\mathbf{s}$ include the non-linear mapping from I_{RGB}. For example, if $T()$ is the mapping in the LUT and we have gamma expansion, then

$$\mathbf{s}_{RGB} = k_{RGB} \ (T(I_{RGB}))^\gamma.$$

3. The reflected ambient light $a(\lambda)$ contributes an *additional* component to the spectrum at each pixel. Thus, for the eye model, the LMS values would become simply:

$$\begin{bmatrix} I_L \\ I_M \\ I_S \end{bmatrix} = \mathbf{C}(\mathbf{Ps} + \mathbf{a})$$

   i.e. the ambient component of light reflected from the monitor leads to a translation in LMS space.

4. Assume the RGB pixel values $I_0(x, y)$ are used to index into the LUT, for gamma correction. There are three lookups per pixel here, one for each of RGB. The RGB values read from the LUT are then sent to the projector.

   Each of the RGB elements in the projector emits a spectrum of light whose power at each wavelength is proportional to the sent value, raised to the power γ. This is gamma expansion. See Q2.

   The light emitted from the projector is sent through a lens which focusses the image on the screen. The screen is white, so it reflects the image without changing the spectrum. (If the screen had been colored say red rather than white, then it would reflect more light at the longer wavelength end than the shorter wavelength end, thus changing the shape of the spectrum).

   The screen acts as a diffuse reflector (not glossy) and there is also some ambient added component. See the previous question. The camera then maps the spectra reflected off the screen in the usual way – as described in lecture 24.