Administrivia

- Project proposal presentation (ppp)--moved to Mar 3.
- Assignment 3 is out
Syllabus Notes

• Transition day (finish physics based vision)

• A few things today may be found in §6---if you are interested in color, I recommend reading §6 (lots of overlap with color from CS433/533).

• Filters is next. We will do §7.1, in less detail §7.1-7.4, §7.5 and §7.6, and mention some of §7.7.

• Then onto edge detection. We will touch on much of §8.
Shape from shading (review)

• Under strong assumptions, pixel brightness can give clues about surface normals, which can be integrated to get shape.
  – Under-constrained! (Only have one piece of data per pixel, but we need 2 or 3 (if we need to estimate albedo as well).
  – Can impose regularization (smoothness) and consider boundary conditions
  – Normals are not shape, but they can be related to the partial derivatives of the shape as a function--the surface is given by (x,y,f(x,y))
  – The partial derivatives must satisfy integrability constraints--random normals do not come from a continuous surface!
Photometric Stereo (review)

• Add constraints on the normals by considering image taken under different lights

\[ I_i(x, y) = V_i \cdot g(x, y) \]  \hspace{1cm} \text{(Lambert's law)}

• Combining the conditions given by each light, i, we get

\[ i = Vg \]

• More real application--if you have different colors of light in different directions (not so weird, consider the sky and sun), then you can do something which resembles photometric stereo with one image.
Example figures
Dealing with shadows

\[
\begin{bmatrix}
I_1^2(x, y) & I_1(x, y) & 0 & \ldots & 0 & V_1^T \\
I_2^2(x, y) & 0 & I_2(x, y) & \ldots & \ldots & V_2^T \\
\vdots & \vdots & \vdots & \ddots & \ddots & \ddots \\
I_n^2(x, y) & 0 & \ldots & 0 & I_n(x, y) & V_n^T \\
\end{bmatrix}
\]

| Known | Known | Known | Unknown |
Recovered reflectance
Recovered normal field
From Normals to Shape

From $g$ we can get the normal $\hat{n} = \frac{g}{|g|}$

It is natural to represent surface as a depth map $(x, y, f(x, y))$

But what is the relationship between that and the normals?
If we represent surface as a depth map \((x, y, f(x, y))\)

The surface normal is the gradient of a function whose level set is our surface

Such a function is \(g(x, y, z) = z - f(x, y)\)

So \(\hat{n} \ (\nabla f_x, \nabla f_y, 1)\)

Alternatively take the cross product of \(\nabla f_x \) and \(\nabla f_y \)

From \(\hat{n} \ (\nabla f_x, \nabla f_y, 1)\) we get \(f_x = \nabla \frac{n_x}{n_z}\) and \(f_y = \nabla \frac{n_y}{n_z}\)
From Normals to Shape

So, if have the normals, we can estimate the derivatives of \( f(x,y) \)

Since we proclaim that our estimates of \( f_x \) and \( f_y \) are be the derivatives of a an actual differentiable function, \( f(x,y) \) we can further check (or constrain) that \( f_{xy} = f_{yx} \).

We can now recover the surface height at any point by integration along some path, e.g.

\[
f(x, y) = \int_0^x f_x(s, y)\,ds + \int_0^y f_y(x, t)\,dt + c
\]
Surface recovered by integration
Color (very briefly)

Color is a sensation

Usually there is light involved, and usually there is a relationship between the world and the colors you see.

Your brain has a big effect on the colors you see.

We will focus on what colors mean to a camera which is much simpler.

Color for a camera (R,G,B) is a very limited sampling of spectral light energy (why three values?)
The colors of the rainbow

- Light is electromagnetic radiation, occurring at different wavelengths (or photon energies)
- The radiation around us is a mix of these
- Visible portion is about 400 to 700 nm
- Certain applications may require modeling some UV also.
- Light is specified by its spectrum recording how much power is at each wavelength.
Sunlight
Two disparate source spectra

Fig. 4.1. Wavelength composition of light from a tungsten-filament lamp (typified by CIE ILL A (Sect. 4.6)). Relative spectral power distribution curve. Color temperature: 2856 K

Fig. 4.2. Wavelength composition of light from a daylight fluorescent lamp. Typical relative spectral power distribution curve. Correlated color temperature: 6000 K. (Based on data of Jerome reported in [Ref. 3.14, p. 37])
Radiometry for colour

- All definitions are now “per unit wavelength”
- All units are now “per unit wavelength”
- All terms are now “spectral”
- Radiance becomes spectral radiance
  - watts per square meter per steradian per unit wavelength
- Radiosity --- spectral radiosity
Case study

- Dielectric surface, well approximated by a specular part and a Lambertian body part.
Specular surfaces

• Important point: The specular part of the reflected light usually carries the color of the **light**
• Technically, this is the case for dielectrics--plastics, paints, glass.
• Important exception is metals (e.g. gold, copper)
Dielectric Specularities
Metallic Specularities
Recall Image Formation (Spectral)

\[(R, G, B) = (380, 480, 780)\]
Recall Discrete Version

Represent the light by a vector, \( L \)

Consider a matrix \( R \) whose rows are the discretized version of the response functions.

Let \([\,\,\,] \) be a vector of camera responses (i.e., \((R,G,B)')\)

Then

\([\,\,\,]=R^*L\)
From previous slide

\[ R = R L \]

R is **not** full rank (typical values are 3 by 101 or 3 by 31)

First key observation is that you cannot recover \( L \) from \( p \)
(\( L \) is spectra, \( p \) is RGB)

Second observation---many spectra can have the same RGB.

(This is the essence of color reproduction)
Color for recognition

• It seems natural to use color (as opposed to grays in a B&W image) to recognize things--why?
Color for recognition

• It seems natural to use color (as opposed to grays in a B&W image) to recognize things--why?
  – Color has more information than grays
  – Grays in a B&W image are subject to shading
  – Light varies greatly in intensity--less so in chromaticity
  – Chromaticity is color without magnitude. For example
    • \( r = R / (R+G+B) \) and \( g = G / (R+G+B) \)
  – BUT the ambiguity between what part of the signal is due to light and what part is due to the world remains.
The Computational Colour Constancy Problem

(Same scene, but different illuminant)