Problems and Solutions for Photorealistic Rendering

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Introduction

- The ultimate goal: **physically-based visual plausibility**
- Can we generate scenes that **appear realistic** through better simulation of both **light transport** and **the human eye**?

Approach the problem in three stages:

1. Realistic model of light transport
2. Realistic model of the eye
3. Appropriate conversion from our eye model to a digital image

On the nature of light

- Most effects we wish to render can be described using ray optics
- Light interactions occur in the spectral domain
- Basic operations: absorbtion, fluorescence, phosphorescence
- However, our eyes perceive light in a 3 dimensional space
- **metamers**: Two unique spectra with the same visual appearance

What advantages does spectral rendering provide?

- Accuracy!!

  Many operations are impossible with only 3 dimensional colour

1. Handling metamers correctly under absorbtion and transmission and under different illuminants

2. Materials which shift power along the spectrum (fluorescence)

3. Handling wavelength-dependent changes in light direction: refraction and dispersion

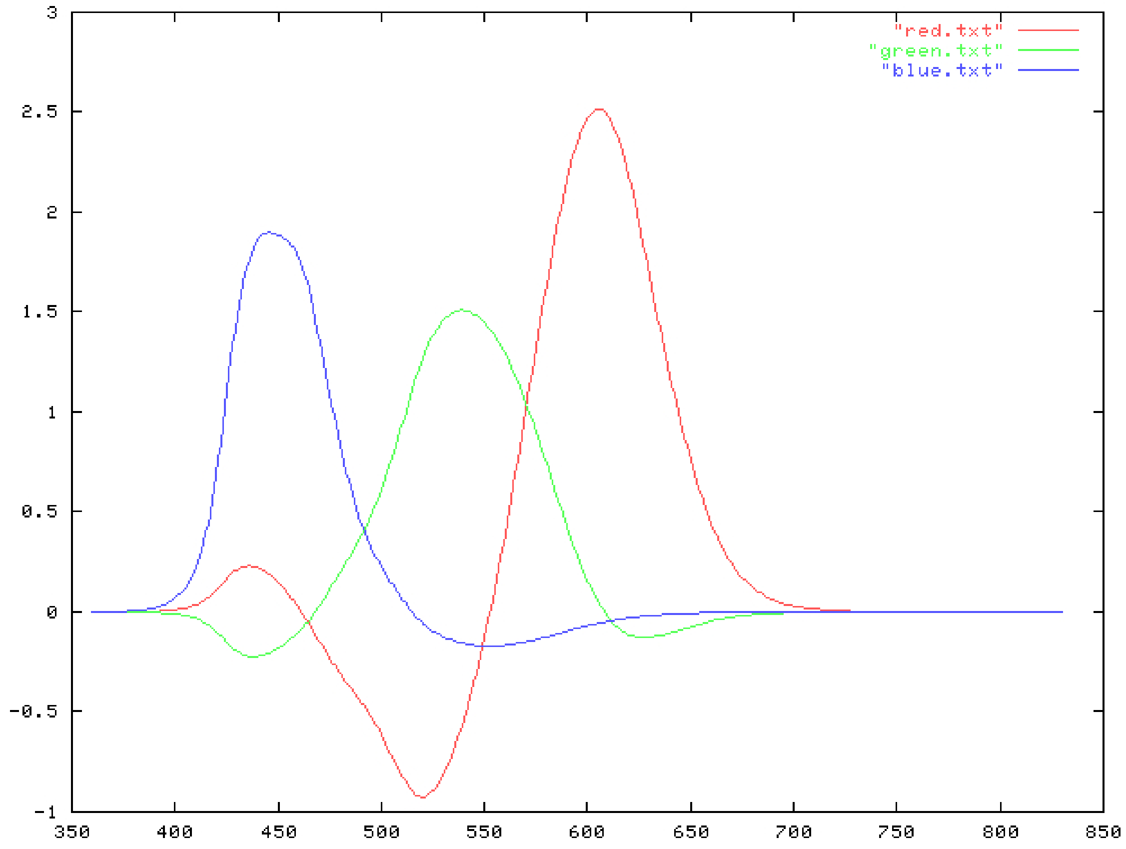
Conversions to and from spectral representations

- Converting from a power distribution to a three-dimensional space is no big deal

$$X = k \int \Phi(\lambda)\bar{x}(\lambda)d\lambda$$
$$Y = k \int \Phi(\lambda)\bar{y}(\lambda)d\lambda$$
$$Z = k \int \Phi(\lambda)\bar{z}(\lambda)d\lambda$$

- Converting the other way is annoying

RGB spectral representation



Implementation options for spectral rendering

- Increase the number of basis functions
- Choose a small number of stratified wavelengths and render the full scene for each
- Randomly sample by wavelength

Stratified Wavelength Clusters (Evans and McCool 1999)

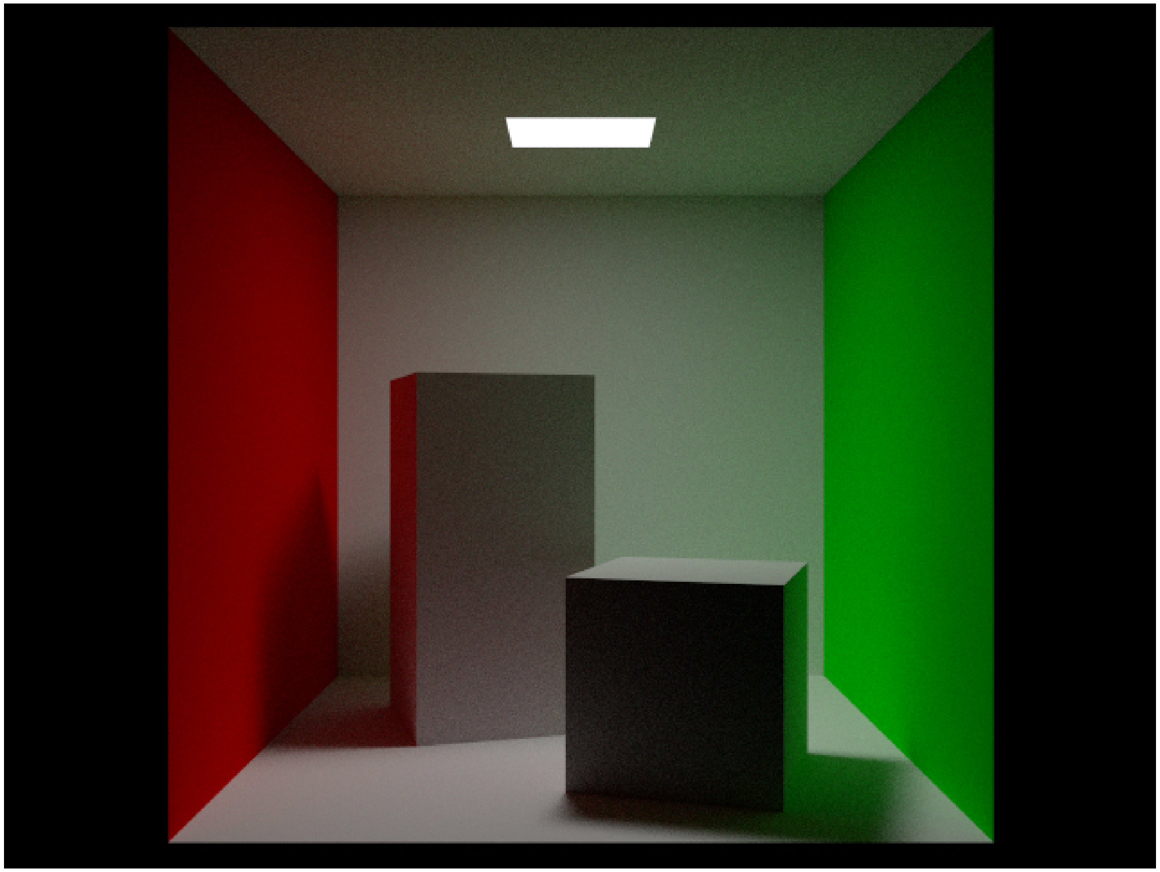
- Apply monte-carlo sampling on the spectrum of each output pixel
- Randomly sample a set of wavelengths per path, trace them together
- Wavelengths sampled from the cdf of a random light source

$$Q_i = \int \int \int W_{ij}^{Q}(\lambda, \bar{x}, \hat{\omega}) L(\lambda, \bar{x}, \hat{\omega}) d\bar{x} d\hat{\omega} d\lambda$$

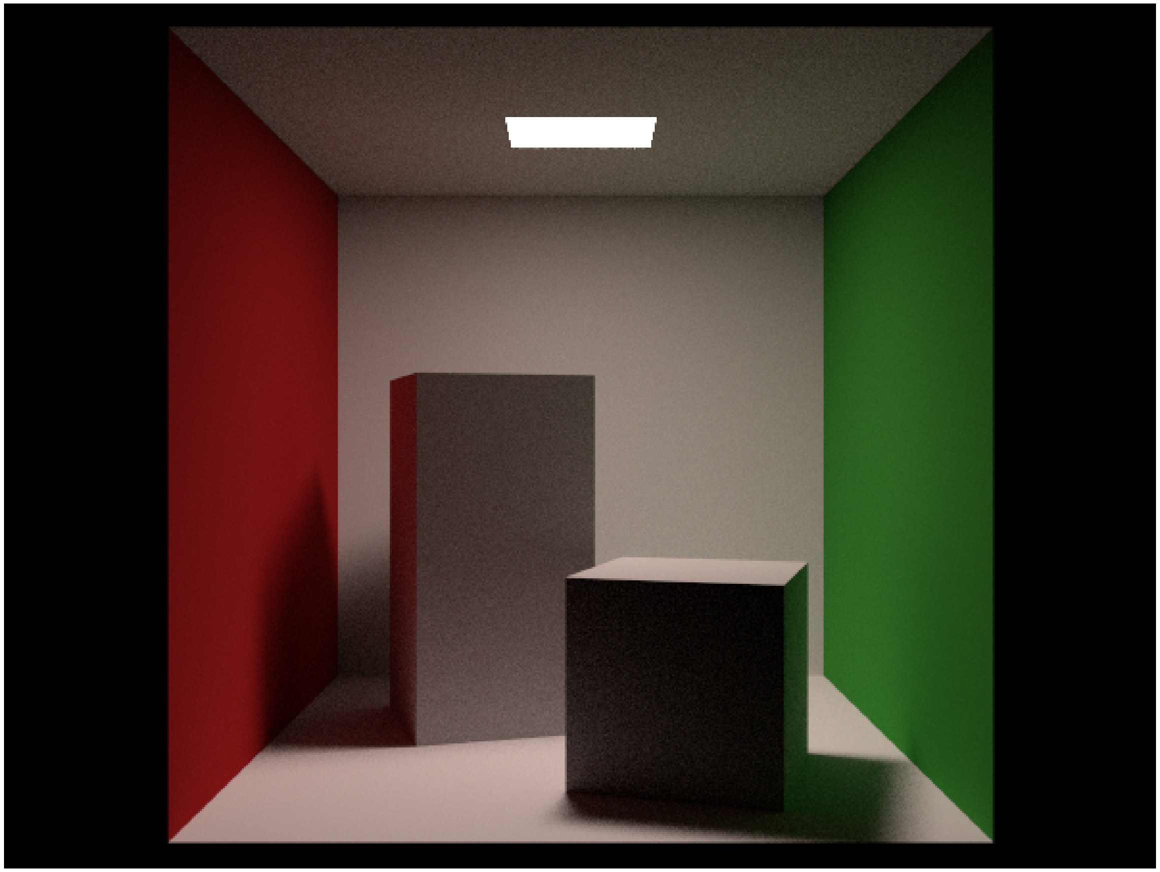
Sampling...

- If there are many light sources, must find appropriate weights and add this to our estimate
- Fluorescence: extending the possible range of wavelengths required
- Dealing with refraction: degradation of frequencies in path

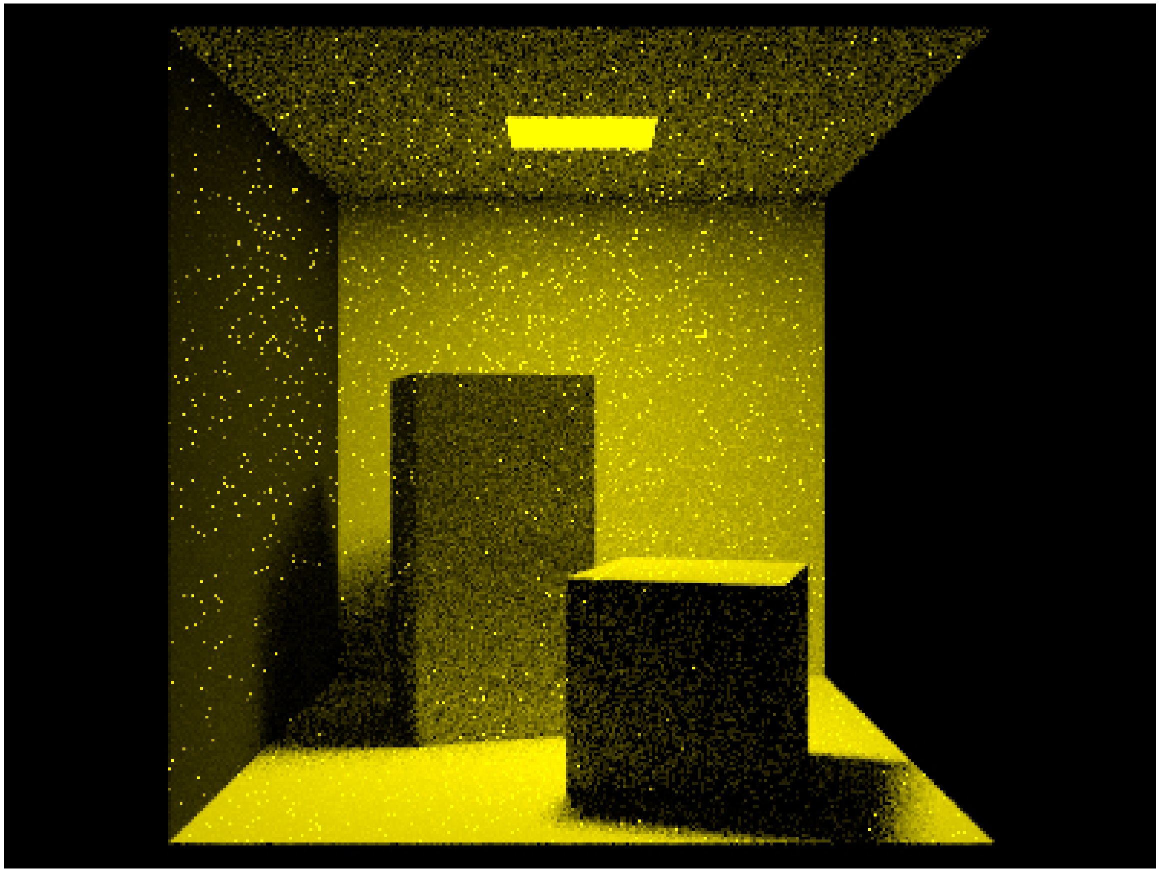
Cornell box: RGB version



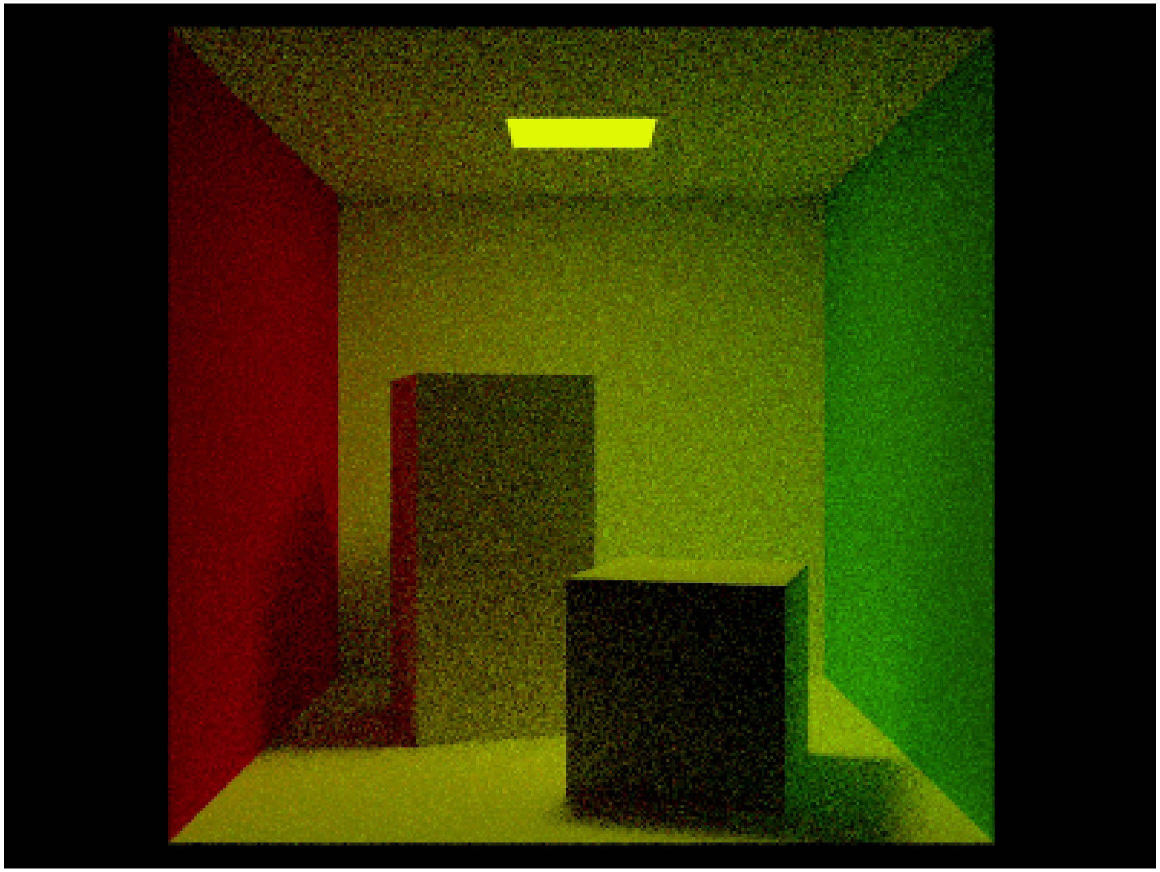
Cornell box: SWC version



A scene under a yellow illuminant



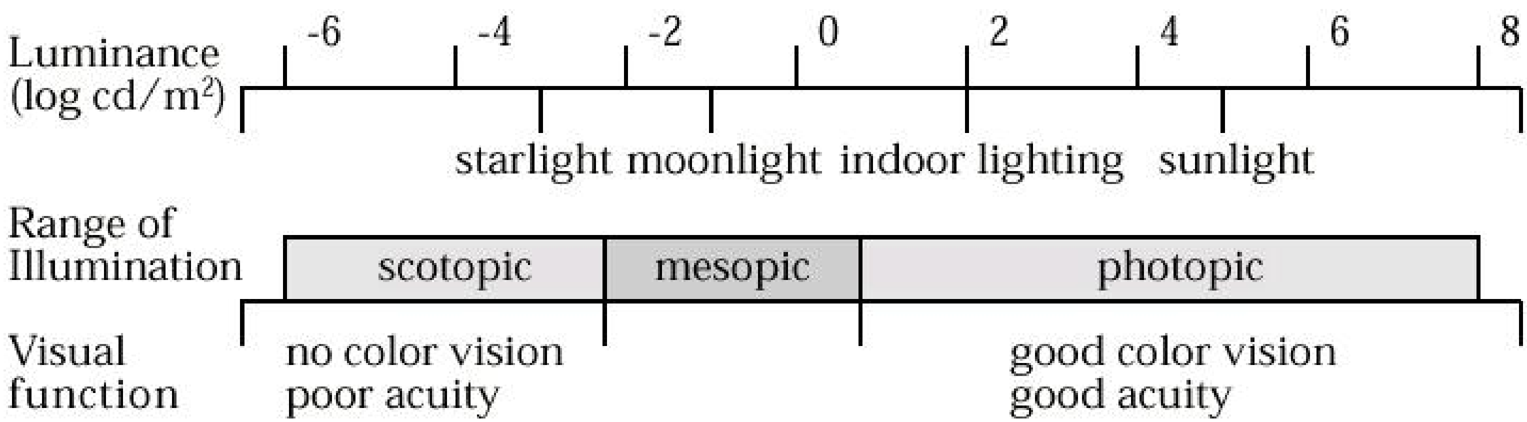
The same scene using XYZ



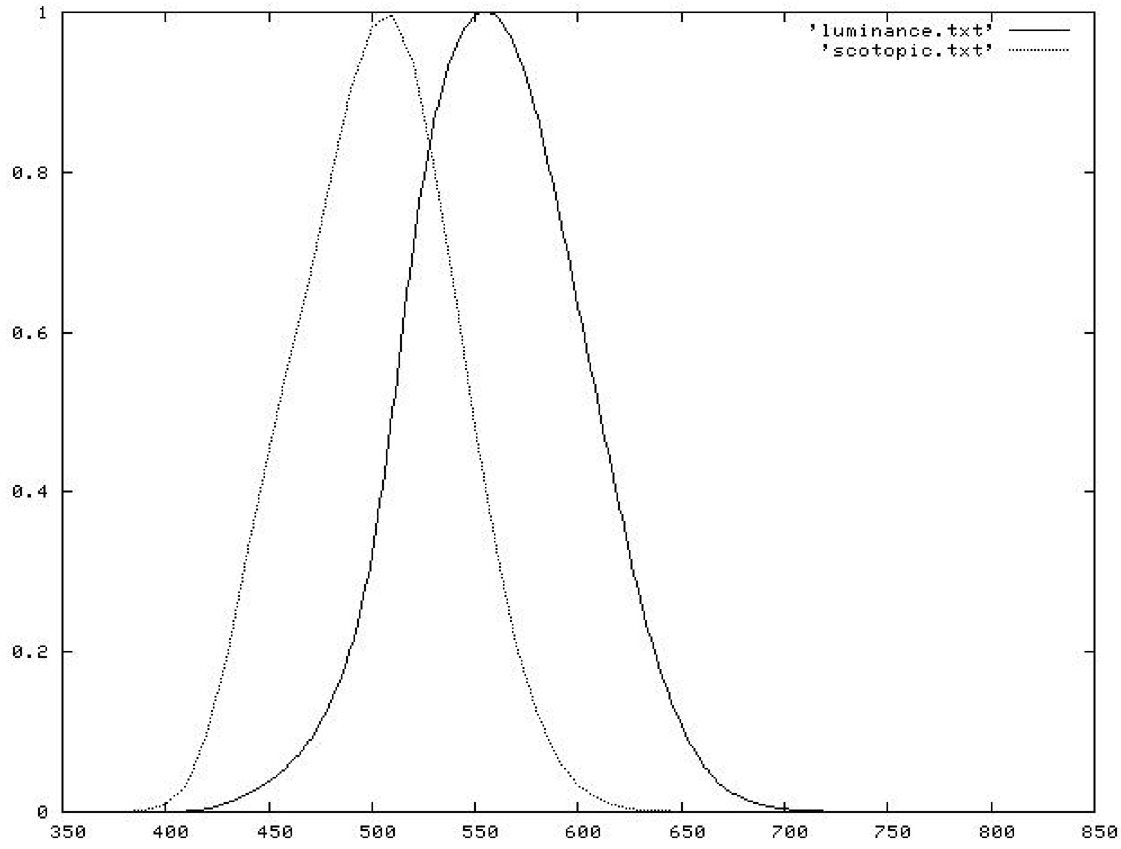
Model of the eye

- There are four types of receptors: three types of cones, and rods
- Visual mode also plays a factor: photopic, mesopic and scotopic.
- Model is defined as an image in $\log XYZV'$ and a visual mode value s.

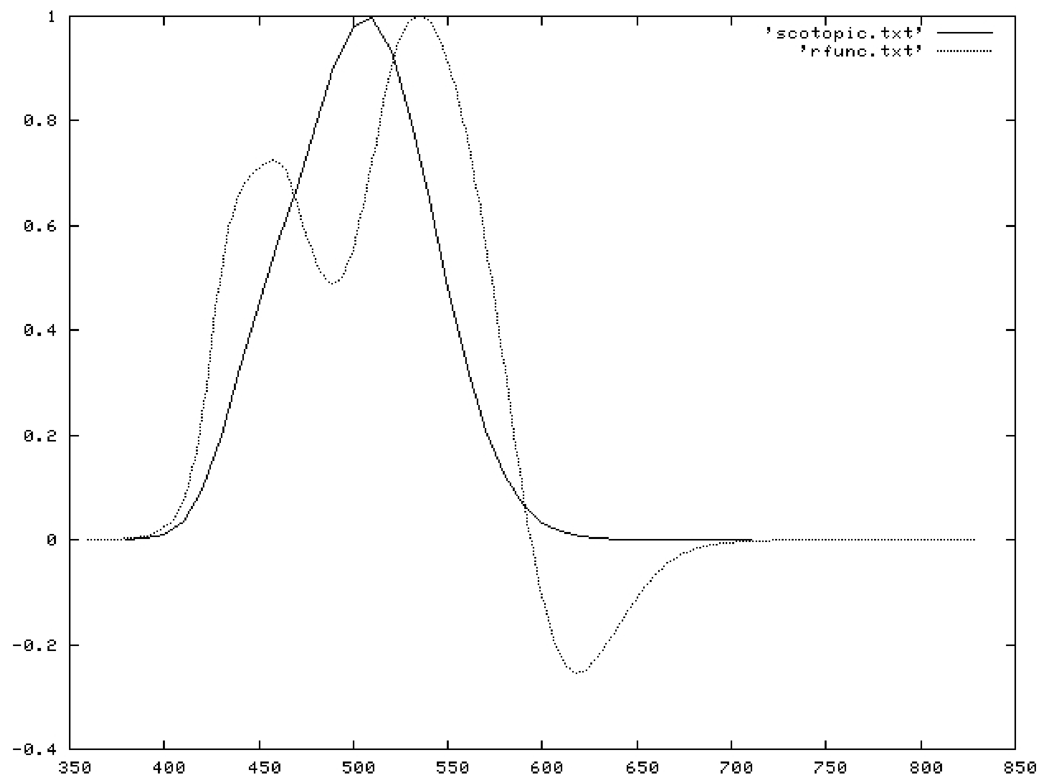
Why V' and s: Scotopic vision



Scotopic luminous efficiency is a shift of the photopic



An approximation for V'



From Pattanaik 1998: $R = -0.702X + 1.039Y + 0.433Z$

Effects gained from a model of the eye

1. Glare

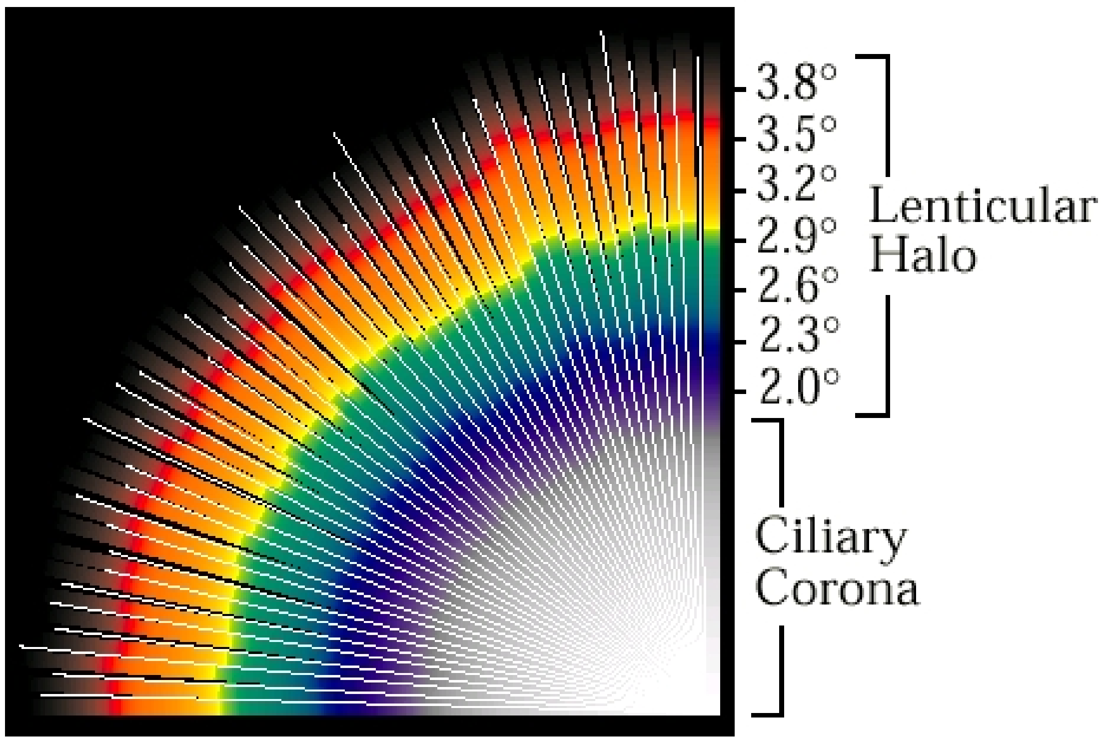
2. Chromatic adaptation and dynamic range compression

3. Night-Vision

A model for glare

- Increase perceived dynamic range by modeling how high intensity sources perceived by the eye
- Caused by scattering of light as it enters the cornea and the lens

What's up with glare, anyway?



A model for glare

- Luckily, we can calculate glare maps for each of $XYZV'$ individually
- Also, glare only depends on the angular size of the bright object, and can be precalculated for a given scene

Chromatic adaptation and dynamic range compression

- Chromatic adaptation occurs when the eye adjusts to the colour of the illuminants in the scene
- Not as interesting for generated images. more useful for image processing
- The eye can adapt to images with a high dynamic range

Dynamic range methods

- Linear compression, other approximations (Schlick)
- Local scaling methods (Chiu)
- Multi-layer bandpass filtered images (Ferwerda, Ward, Pattanaik)

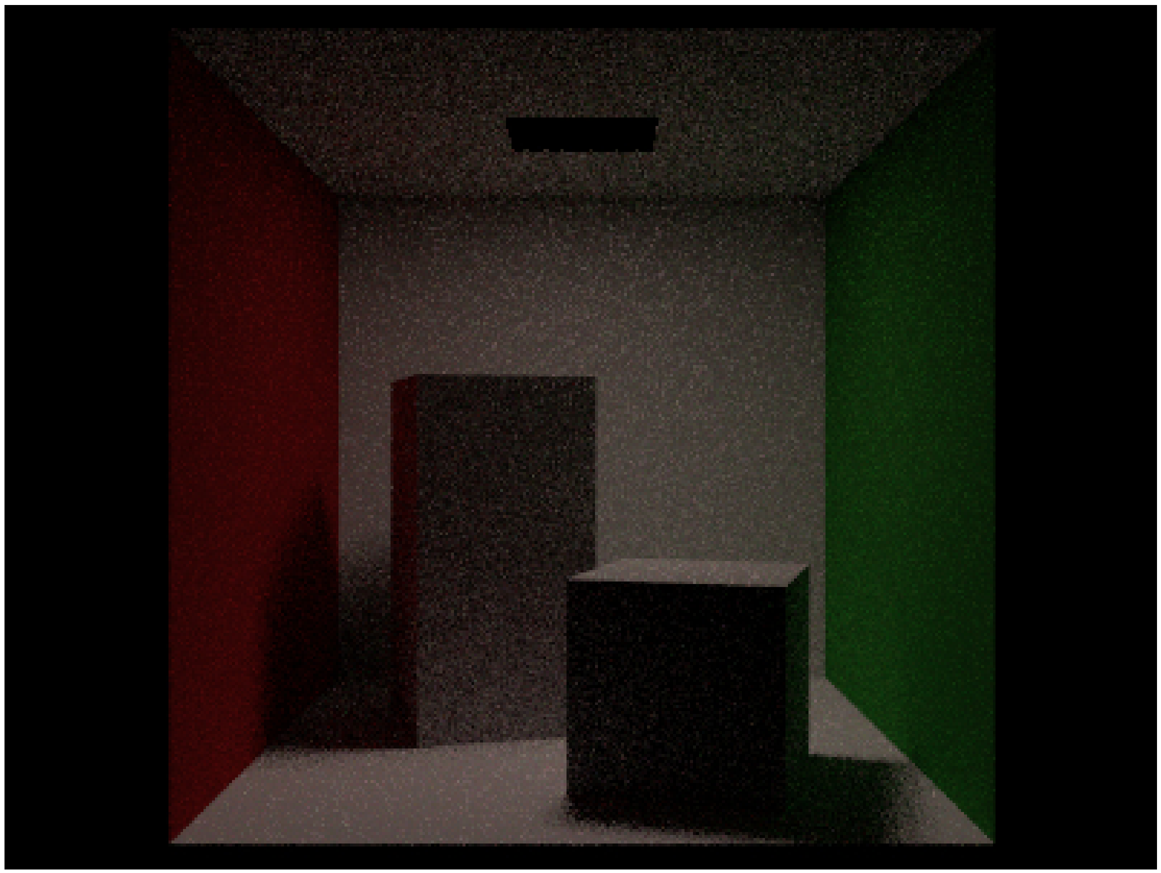
Night Vision

- The usual mapping for scotopic vision in tone mapping is to blur images in low light situation to simulate the loss of acuity

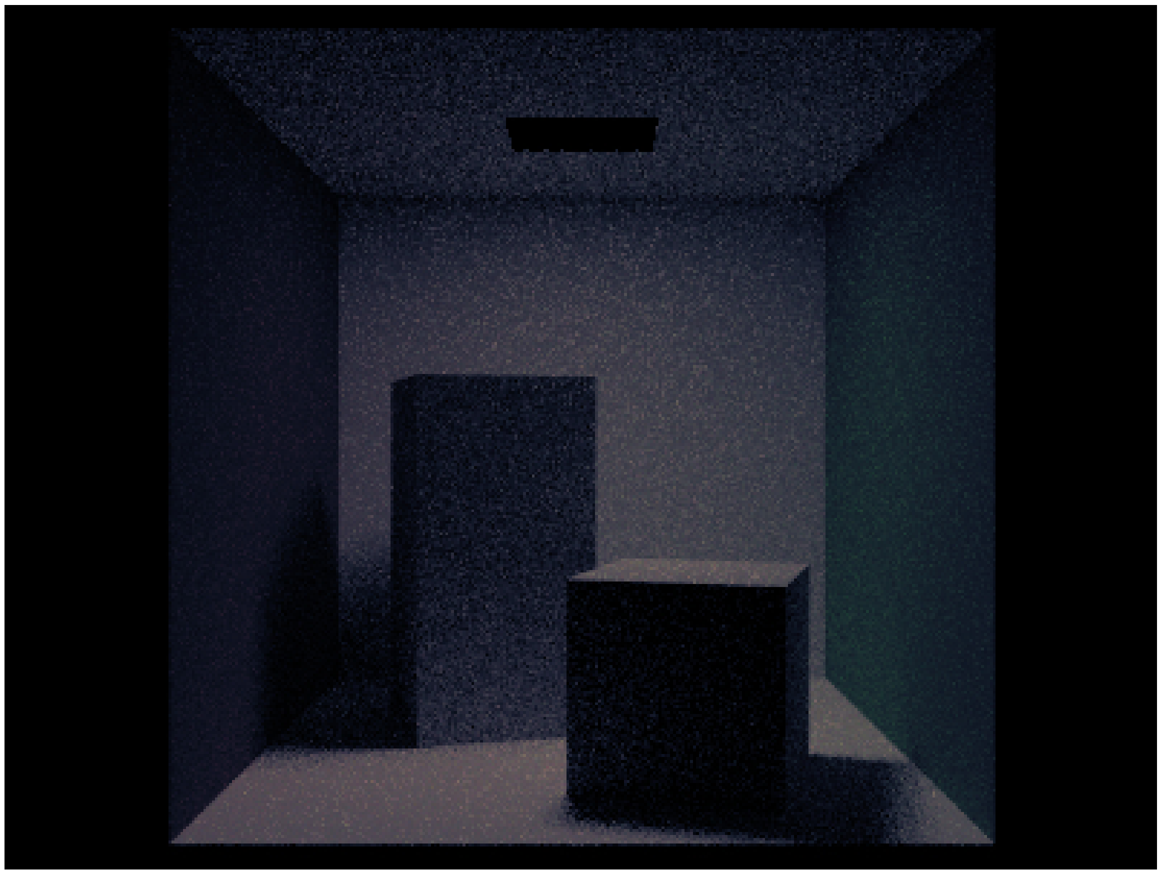
- Jensen et al (Siggraph 2001) argues that the scene should also shift to become more blue, but there is a lack of empirical data to simulate this 'accurately'

- Their method of hue mapping shifts the chromaticities of the colours and also shifts the luminance towards the scotopic luminous efficiency

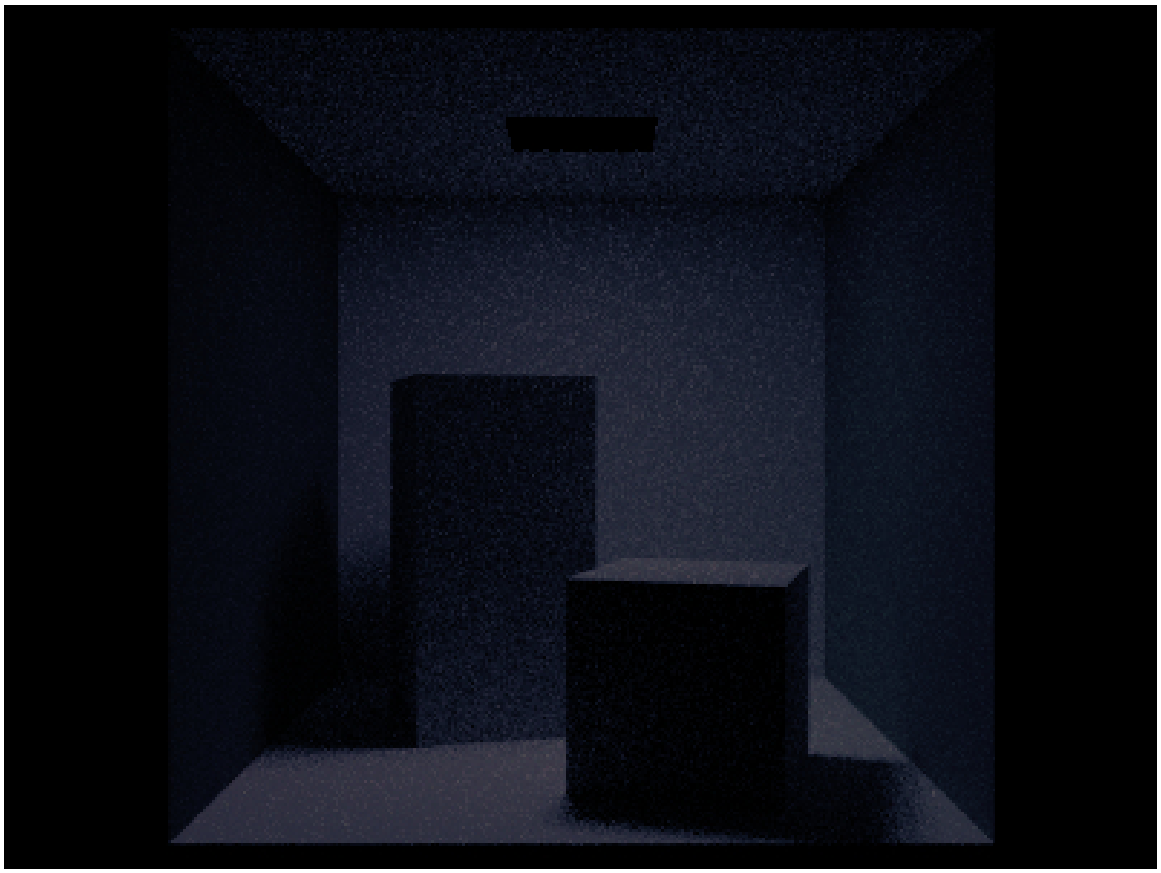
Cornell box at night



Cornell box at night: mapped



Cornell box at night: more blue as we get darker



Converting for a display device

- Unfortunately, many of the above steps have already required data about the display device!
- Still need to gamut map and gamma correct

Our final processing Pipeline

1. Process input colours to spectra
2. Render using SWC to $XYZV'$
3. Compute visual function information
4. Apply a digital glare filter
5. Filter the image for chromatic adaptation, acuity, and dynamic range
6. Apply subjective night-vision mapping
7. Gamut-map and gamma correct for digital display