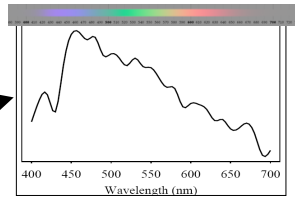
CS4405

Visual Perception

Colour Science

- Colour is characterised by the wavelength content of the light
  - Most light sources produce contributions over many wavelengths
  - Short wavelengths produce a blue sensation
  - Long wavelengths produce a red one

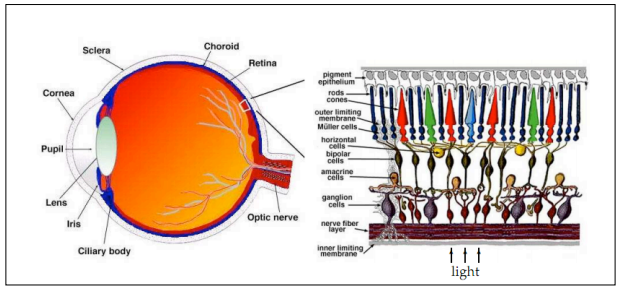
Relative power in each wavelength interval for typical outdoor light on a sunny day



Human Vision

- The lens focuses an image onto the retina (upside-down and left-right reversed)
- The retina consists of an array of rods and three kinds of cones
- The rods come into play when light levels are low and produce an image in shades of grey
- The three kinds of cones are most sensitive to red (L), green (M), and blue (S)

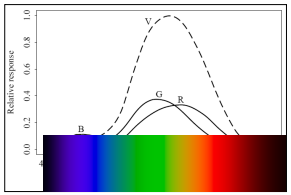
The Eye



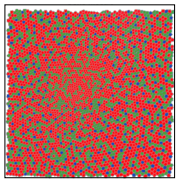
http://webvision.med.utah.edu/book/part-i-foundations/simple-anatomy-of-the-retina/

Spectral Sensitivity of the Eye

- The eye is most sensitive to light in the middle of the visible spectrum
- The sensitivity is also a function of wavelength
  - Blue sensitivity is much smaller
- The luminous-efficiency function (V) is the sum of the response curves for L (Red), M (Green), and S (Blue)



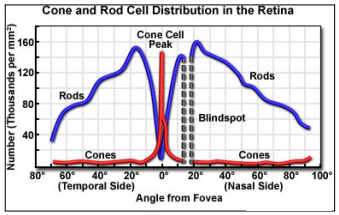
Cone Distribution

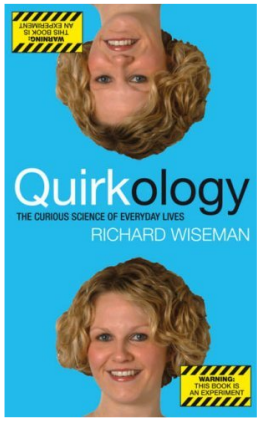


Red (L) cones (64%), Green (M) cones (32%), and Blue (S) cones (2%)

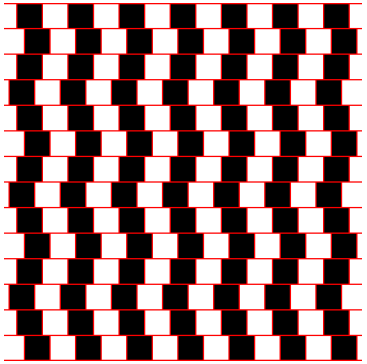
The 6 to 7 million cones provide the eye's colour sensitivity and they are much more concentrated in the central yellow spot known as the macula

The rods are more numerous (120 million) and are more sensitive than the cones however, they are not sensitive to colour




Quirkology
THE CURIOUS SCIENCE OF EVERYDAY LIVES
RICHARD WISEMAN
WARNING:
THIS BOOK IS
AN EXPERIMENT


RICHARD WISEMAN
THE CURIOUS SCIENCE OF EVERYDAY LIVES
Quirkology

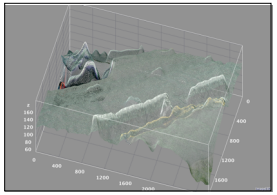


CS4405

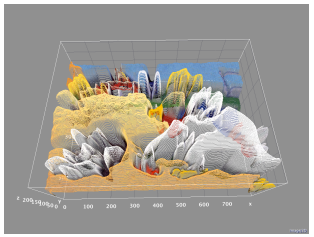
Natural Images

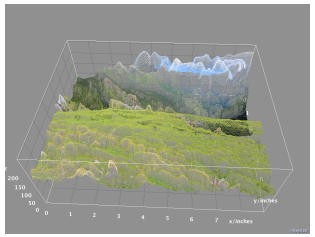
Natural Images

- Useful image contents change relatively slowly across an image
  - It is unusual for intensity values to fluctuate widely in a small area



Natural and Graphic Images

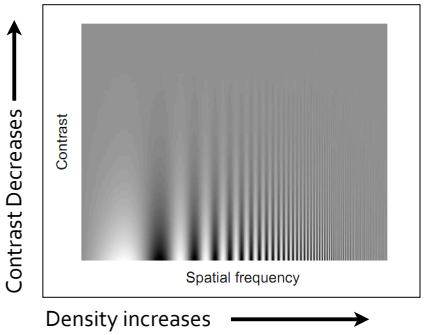




Human Visual System

- Psychophysical experiments indicate that humans are much less likely to notice the loss of very high spatial frequency components (fine detail) than the loss of lower frequency components
  - The spatial redundancy can be reduced by largely reducing the high spatial frequency contents
- Visual acuity (accuracy in distinguishing closely spaced lines) is much greater for grey (intensity only) than for colour

Spatial Frequency and Contrast



Where is the line above which you can't see any difference between the stripes (everything is grey)?

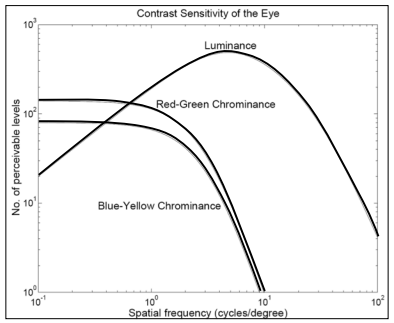
This contrast threshold depends on the spatial frequency

This line is highest somewhere in the middle and then drops again as you go to higher spatial frequencies

Human Eye Colour Sensitivity

The differences of L and M cones form a red-green (RG) system

The differences of S cones with a combination of L and M cones form a blue-yellow (BY) system



http://mvr.mcgill.ca/Fred/Papers/Mullen&Kingdom_2002.pdf

JPEG

- JPEG was developed by the Joint Photographic Experts Group and accepted as an international standard (ISO/IEC IS 10918-1) in 1992
- JPEG intended to be used for photographs and paintings of realistic scenes with smooth variations of tone and colour
- JPEG is a lossy image compression method

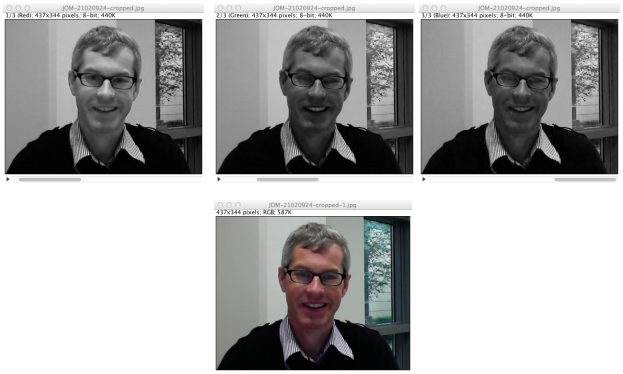
Lossy Compression

- Lossy compression schemes discard data in order to increase the amount of compression
  - Trade-off between data size and quality
- Often use domain-specific knowledge
- JPEG uses information about the way the Human Visual System processes natural images
  - It is not the ideal format for images with large areas of solid colour or a very limited number of distinct colours

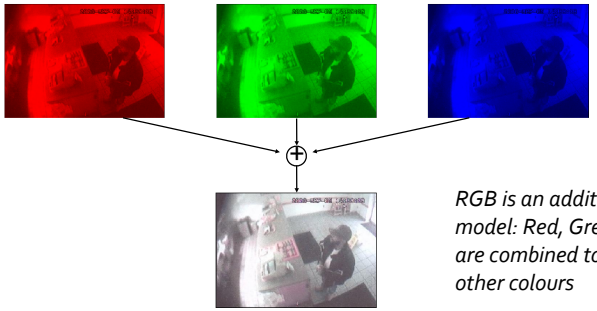
JPEG

- JPEG is designed so that the loss factor can be tuned by the user to tradeoff image size and image quality
- JPEG is designed so that the loss has the least effect on human perception
  - Optional colour-space conversion (for best results)
  - Chroma sub-sampling
  - Transform coding

RGB



RGB Colour Space



RGB is an additive colour model: Red, Green and Blue are combined to produce other colours

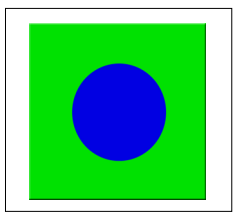
RGB Colour Space Limitations

The main limitation of the RGB representation is that apparent luminance is perceived differently for different colours

Same R, G, B values

The human eye is more sensitive to luminance (brightness) than chrominance (colour)

Same luminance – but which looks 'brighter'?

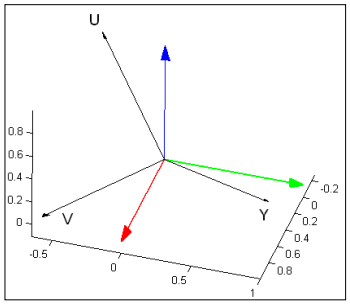


YUV Colour Space

- The YUV is an additive colour model obtained by a linear transformation of the RGB space
- The luminance component (Y)
  - Indicates the apparent brightness of the colour
- Two chrominance components (U and V)
  - Indicate how far from grey the colour is in the blue and red directions respectively

YUV Colour Space

The YUV space can be visualised by looking at the directions of pure Y, U and V vectors in the orthonormal RGB space



RGB to YUV

- There are various schemes to convert RGB to YUV
- JPEG uses a variant of YUV called YCbCr
  - Y, Cb and Cr are integer quantities over a full 8-bit range (0-255)

$$
\begin{aligned}
Y &= 0.299\,R + 0.587\,G + 0.114\,B \\
Cb &= -0.1687\,R - 0.3313\,G + 0.5\,B + 128 \\
Cr &= 0.5\,R - 0.4187\,G - 0.0813\,B + 128
\end{aligned}
$$

http://www.jpeg.org/public/jfif.pdf

YCbCr to RGB

```
R = Y                      + 1.402 (Cr-128)
G = Y - 0.34414(Cb-128) - 0.71414 (Cr-128)
B = Y + 1.772  (Cb-128)
```

http://www.jpeg.org/public/jfif.pdf

Exploiting HVS Limitations

- Treat luminance and chrominance differently
- Cb and Cr can be sampled at lower rate than Y due to their narrower bandwidth
- Cb and Cr can be quantised more coarsely due to their lower contrast sensitivity

Chroma Sub-sampling

- Chroma sub-sampling is the practice of encoding images by implementing less resolution for chroma information than for luminance information
  - Taking advantage of the human visual system's lower acuity for colour differences than for luminance
- JPEG records the Y value for each pixel in the image but only records a single (Cb,Cr) pair for a group of pixels (chrominance sample)
- Need a structure for deciding how to sample the chrominance

Example (Quality = 50)

Original (TIFF)
5.8MB

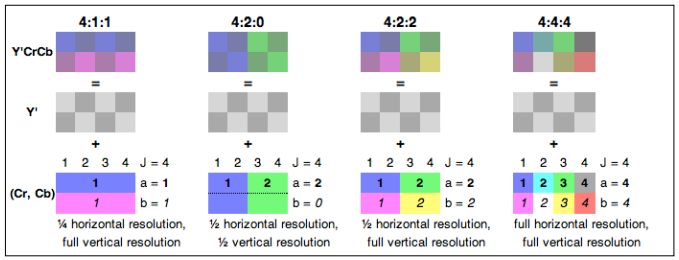
JPEG Not Sub-sampled
248KB

JPEG Chroma Sub-sampled
208KB

Sub-sampling Schemes

- The subsampling scheme is usually expressed as a three part ratio J:a:b that describes the number of luminance and chrominance samples in a conceptual region that is J pixels wide and two pixels high
  - **J**: horizontal sampling reference (width of the conceptual region usually 4)
  - **a**: number of chrominance samples (Cr, Cb) in the first row of J pixels
  - **b**: number of (additional) chrominance samples (Cr, Cb) in the second row of J pixels

Sub-sampling Examples



Commonly used in JPEG

Example: Photoshop

Method	JPEG Quality	Preset	Chroma Subsampling
Save As	12	Maximum	None
Save As	11		None
Save As	10		None
Save As	9		None
Save As	8	High	None
Save As	6		4:2:0
Save As	7		None
Save As	5	Medium	4:2:0
Save As	4		4:2:0
Save As	3	Low	4:2:0
Save As	2		4:2:0
Save As	1		4:2:0
Save For Web	100	Maximum	None
Save For Web	90		None
Save For Web	80	Very High	None
Save For Web	70		None
Save For Web	60	High	None
Save For Web	51		None
Save For Web	50		4:2:0
Save For Web	40		4:2:0
Save For Web	30	Medium	4:2:0
Save For Web	20		4:2:0
Save For Web	10	Low	4:2:0

JPEG Compression