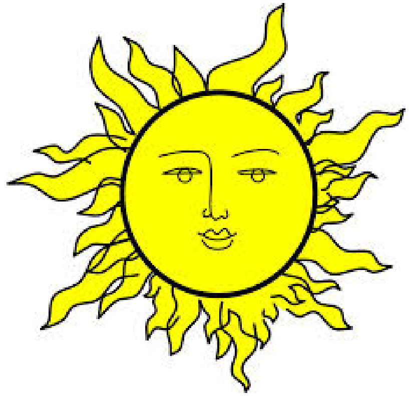
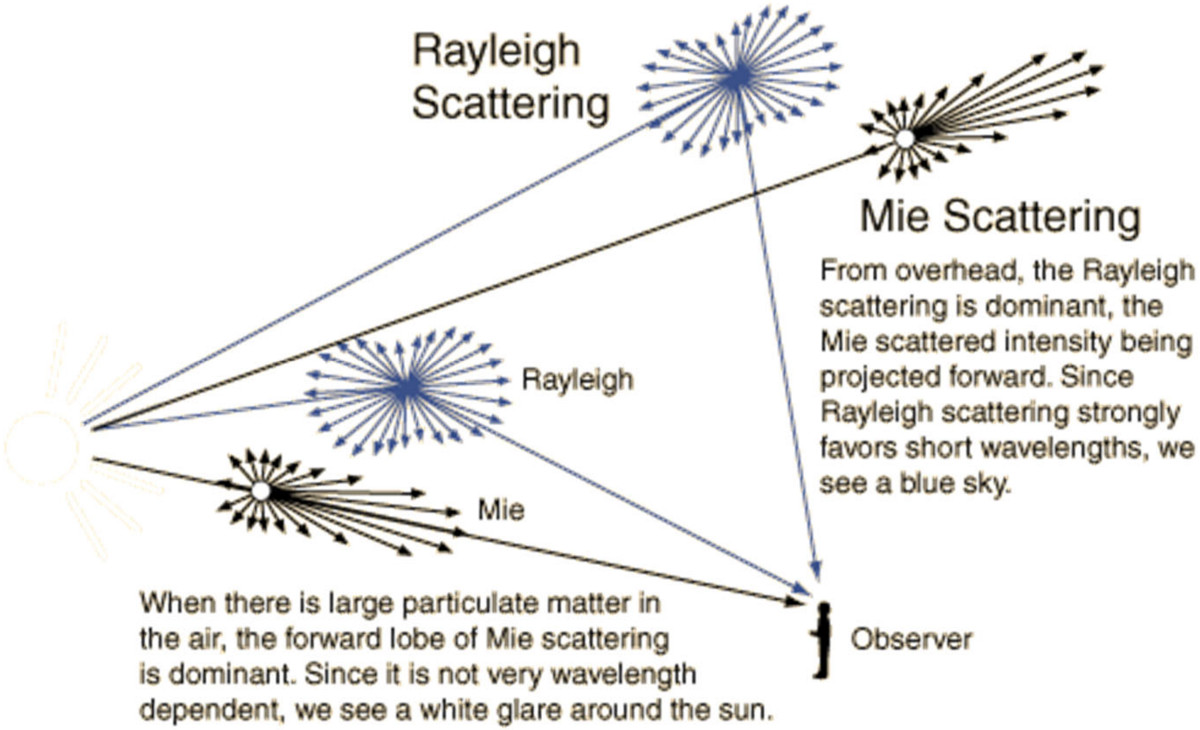
Why is the Sky Blue?

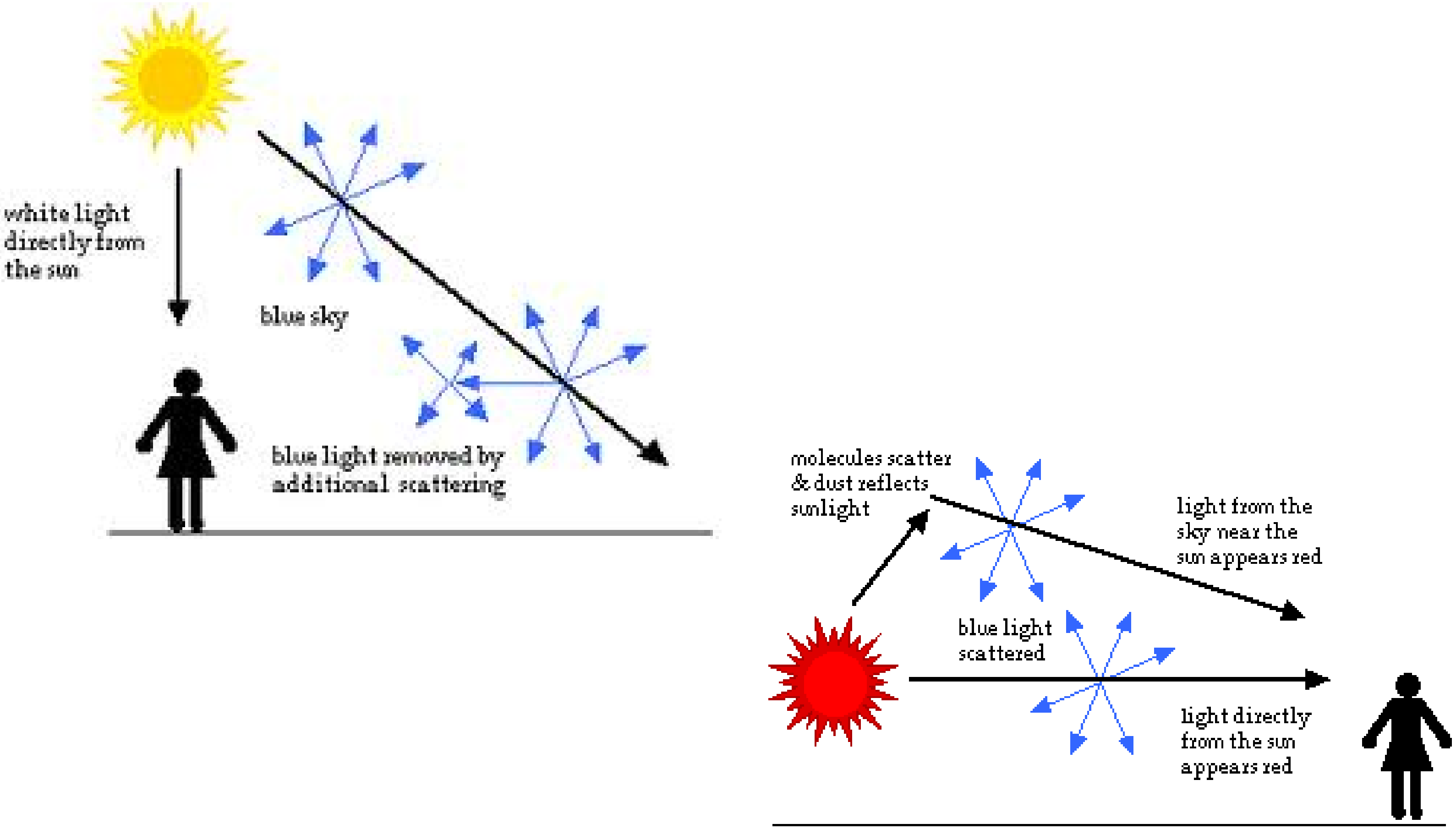


From space it looks like this

Rayleigh Scattering from Atmosphere



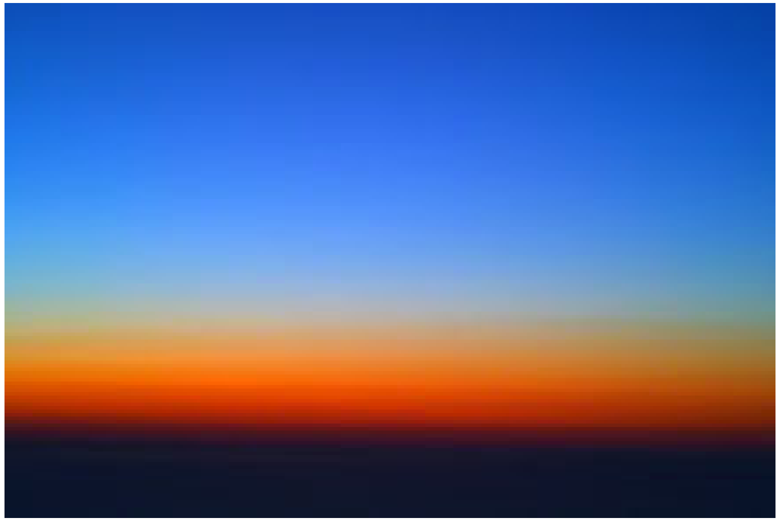
http://hyperphysics.phy-astr.gsu.edu/hbase/atmos/blusky.html



http://macaulay.cuny.edu/eportfolios/sciencefordessert/2010/09/29/why-is-the-sky-blue-and-the-sunset-red/

Evening Sky

Before Sunset



After Sunset

Light Field Cameras or Plenoptic Cameras

R. Ng, M. Levoy, M. Bredif, G. Duval, M. Horowitz, and P. Hanrahan. Light Field Photography with a Hand-Held Plenoptic Camera. Stanford University Computer Science Tech Report CSTR 2005-02, April 2005

Lytro was founded in 2006 by Executive Chairman Ren Ng, whose Ph.D. research on light field photography won Stanford University's prize for best thesis in computer science in 2006 as well as the internationally recognized ACM Dissertation award.
In 2012, Lytro released the world's first consumer Light Field Camera which offers photographic capabilities never before possible, such as focusing a picture after it's taken, changing the perspective in the picture and creating interactive living pictures that can be endlessly refocused and enjoyed by friends and family online.

Refocus after Photo Taken

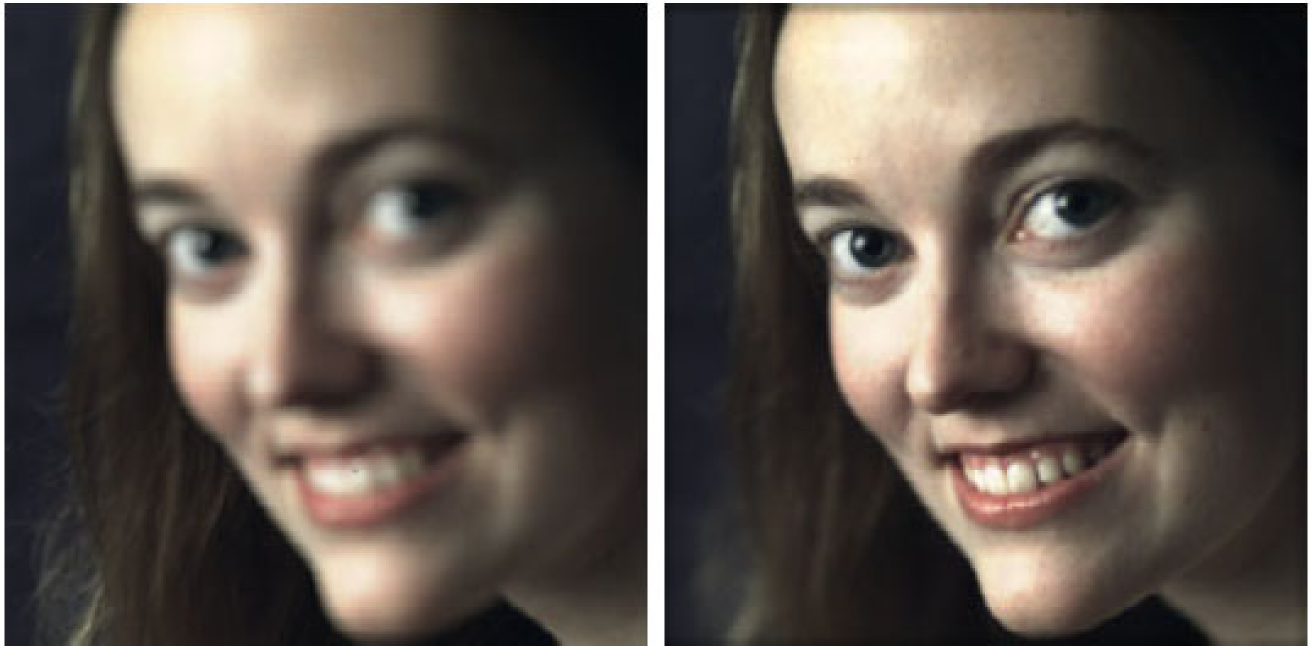


Figure 16: Refocusing of a portrait. Left shows what the conventional photo would have looked like (autofocus mis-focused by only 10 cm on the girl's hair). Right shows the refocused photograph.

The Technology

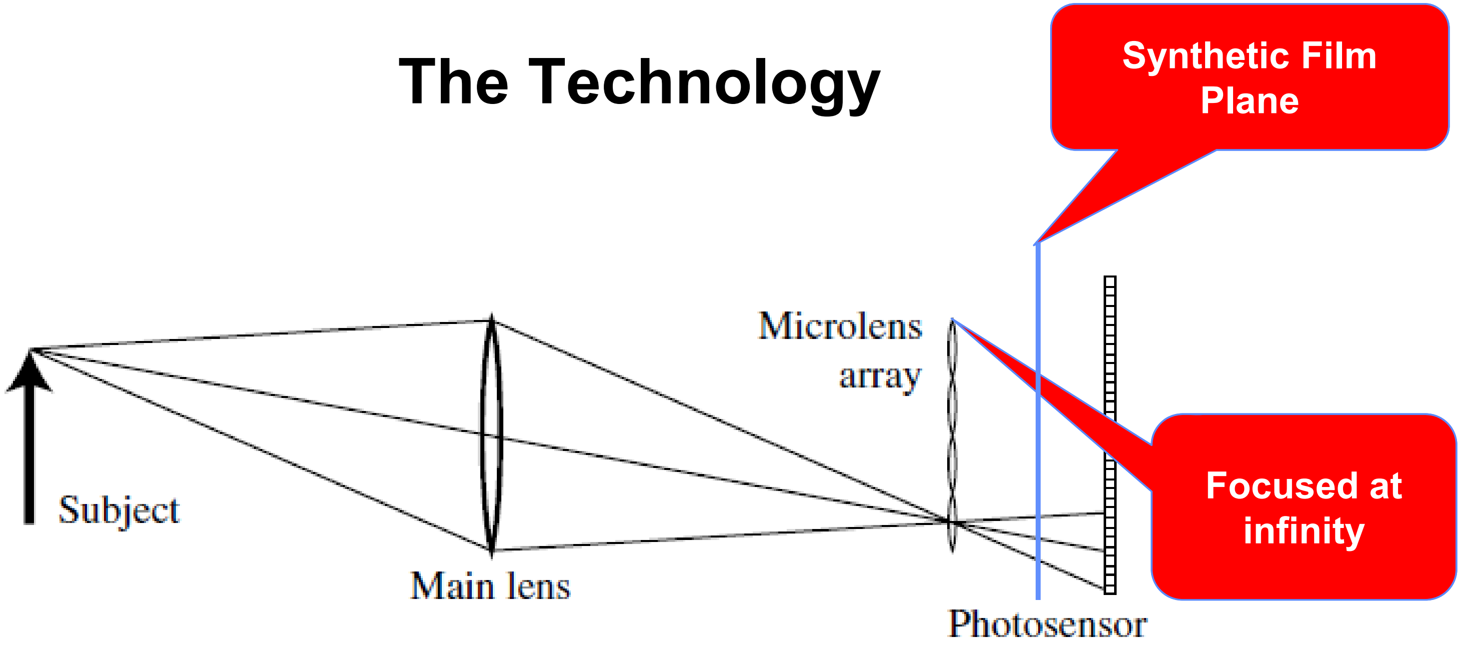
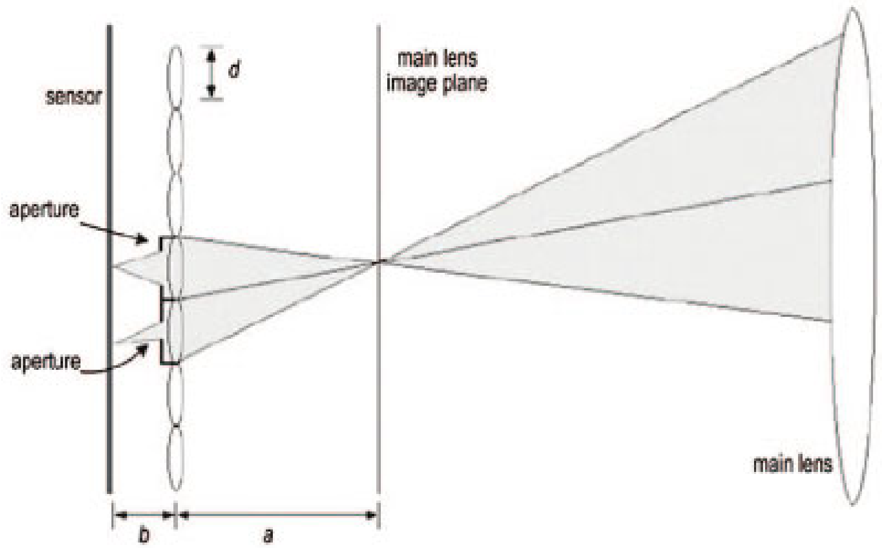
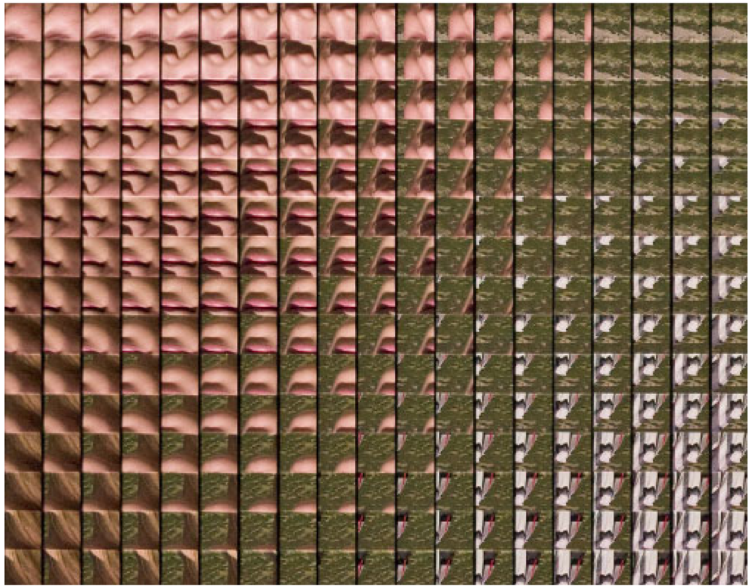


Figure 1: Conceptual schematic (not drawn to scale) of our camera, which is composed of a main lens, microlens array and a photosensor. The main lens focuses the subject onto the microlens array. The microlens array separates the converging rays into an image on the photosensor behind it.

Refocussing

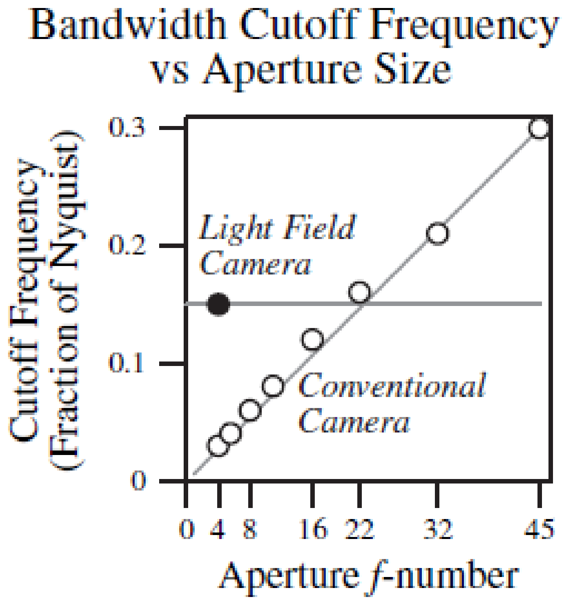
- Synthesize a film plane by shifting and adding subaperture windows
- This also reduces sensor noise





Comparison to Standard Camera

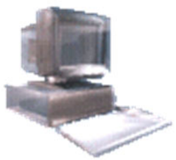
Figure 11: Comparison of bandwidth cutoff frequencies for light field camera with refocusing versus conventional cameras with stopped down apertures. We choose the cutoff frequency as the minimum that contains 75% of the transfer function energy. Note that with this criterion the light field camera most closely matches the $f/22$ conventional camera.



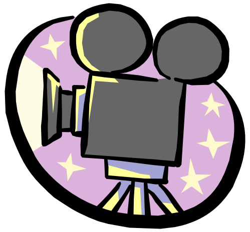
(a) (b) (c) (d)

Colour Coordinate Systems

- RGB
  - component colours, used in computer monitors and cathode ray tubes
  - Cartesian coordinate system

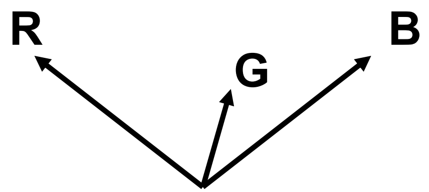


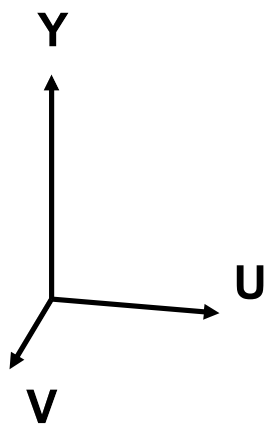
- YIQ or YUV
  - composite colour system used in PAL/NTSC colour TV transmission
  - Y denotes intensity (B&W TV signal), UV are Cartesian coordinates specifying hue and saturation
- HSV or HSI
  - similar to YUV except expressed in polar coordinates
  - H denotes hue, S denotes saturation, V (I) denotes value (intensity)

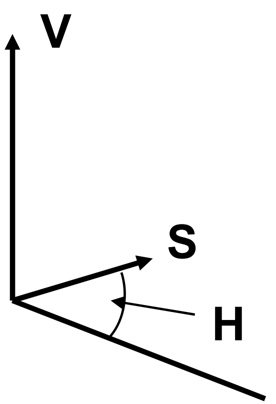


- CYMK
  - subtractive primaries for printing plus black(K)

Colour Space







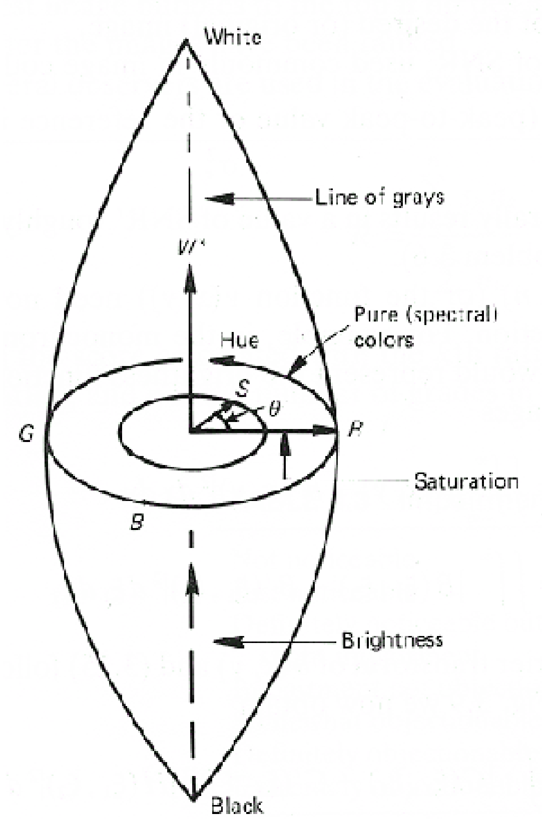
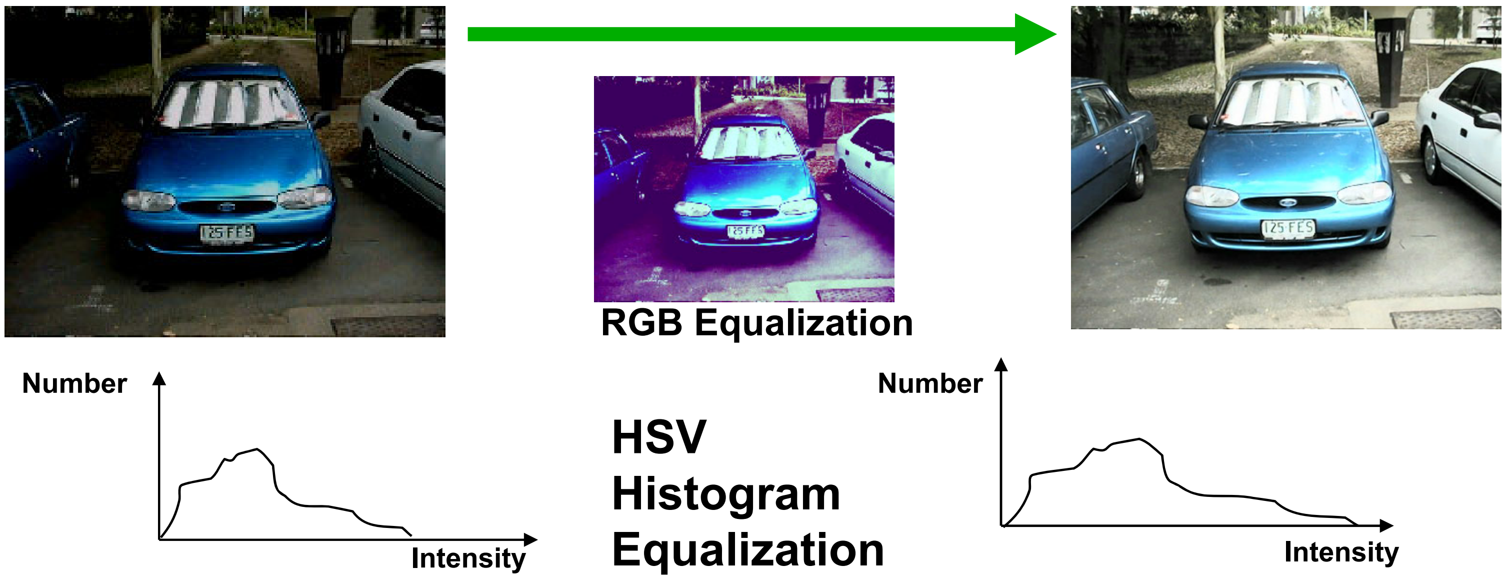


Image Enhancement

- Operations such as image adjustment for under and overexposure are best done in, say, HSV space rather than RGB space



The Colour Constancy Problem

Colour constancy is an example of subjective constancy and a feature of the human color perception system which ensures that the perceived color of objects remains relatively constant under varying illumination conditions. A green apple for instance looks green to us at midday, when the main illumination is white sunlight, and also at sunset, when the main illumination is red. This helps us identify objects.

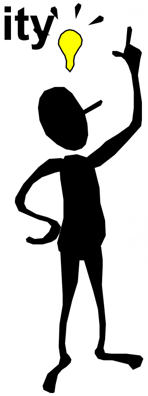
Cameras use white balance and other mechanisms to make pictures Look right.

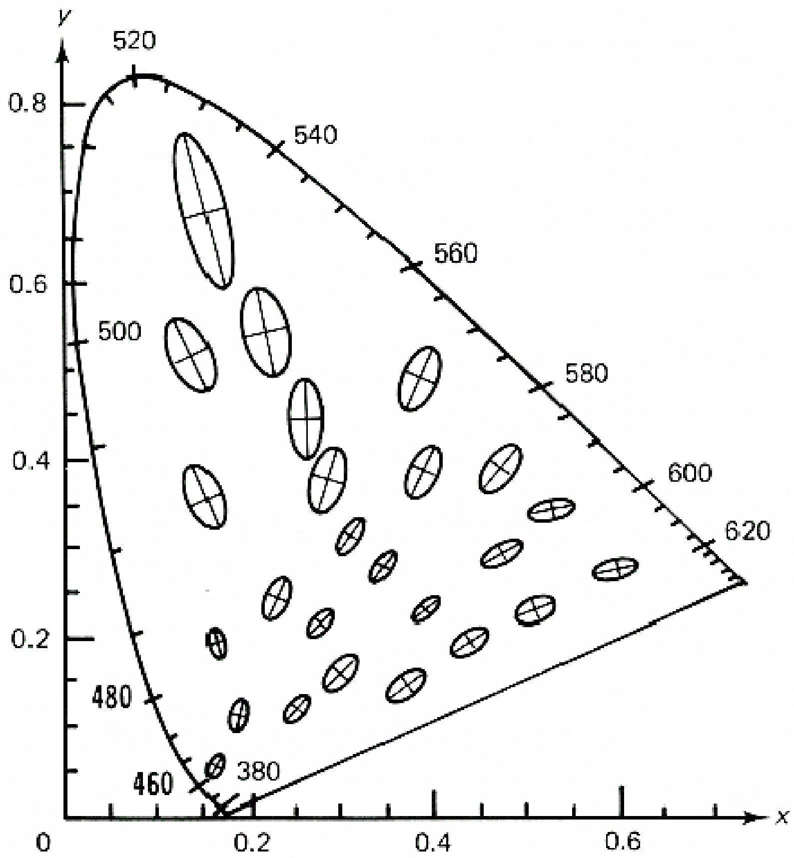
Colour Matching

- If we wish to use these colour coordinates to compare colours we have a problem.
  - For some colours, very small changes in RGB space, say, can yield very noticeable differences
  - For other colours, large changes in RGB values cause very little colour change
  - In other words, these colour coordinate systems are perceptually non-linear
  - What we need is a warping of these spaces so that Euclidean distances correspond to colour differences
  - Use *CIE perceptually linear colour space*, sometimes called the *uniform chromaticity scale* (UCS)

Just Noticeable Differences

This nonlinearity can be shown by plotting JND (just noticeable difference) ellipses on the chromaticity diagram.





Conversion of YUV to UCS

Colour Distance

$$(\Delta s)^2 = (\Delta L^*)^2 + (\Delta u^*)^2 + (\Delta v^*)^2$$

$$L^* = 25\left(\frac{100Y}{Y_0}\right)^{1/3} - 16$$

$$u^* = 13L^*(u' - u_0);\ v^* = 13L^*(v' - v_0)$$

$$u' = u;\ v' = 1.5v$$

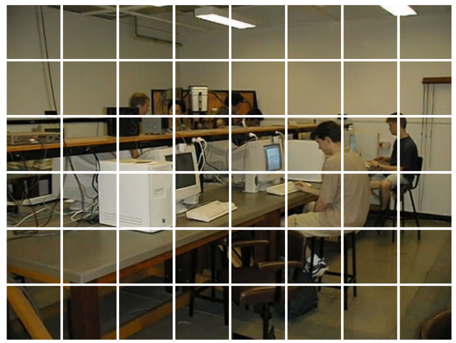
u_0, v_0, Y_0 corresponds to reference white **CIE 1976**

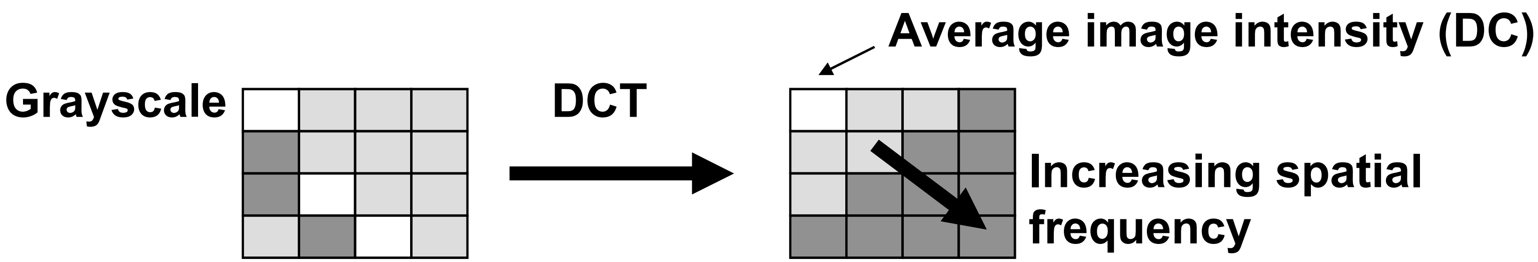
Some File Formats

- PPM
  - portable pixel map, 8/24 bit colour, uncompacted (big files)
- BMP
  - windows bitmap, uncompacted
- Compuserve GIF (Generic Interchange Format)
  - 256 (8 bit) colours only, compacted (lossless compression)
- TIFF
  - 8/24 bit colour, compacted
- JPEG (Joint Photographic Experts Group)
  - 8/24 bit colour, usually compressed (lossy)
  - Usually best for photographs, very small files

JPEG Encoding

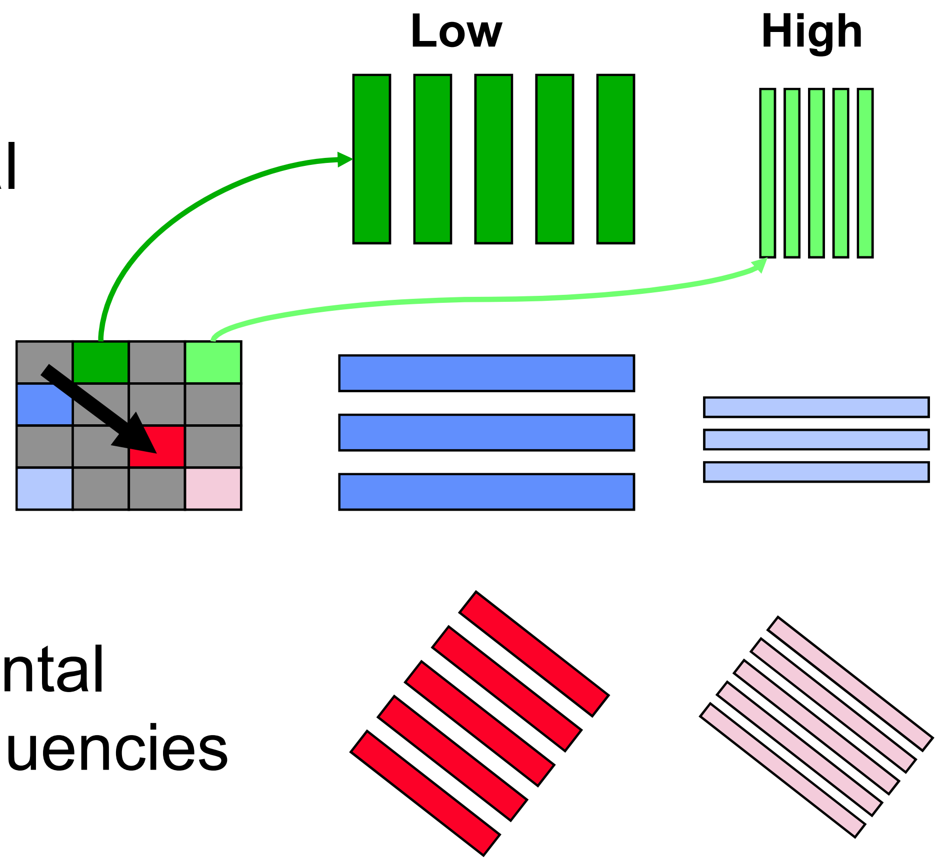
- Split Image up into RGB monochrome components
- Split monochrome components into 8x8 grayscale pixel blocks
- Perform Discrete Cosine Transform (DCT) on each block to get 8x8 spatial frequency bins (all real)





Spatial Frequencies

- Horizontal Spatial Frequency
- Vertical Spatial Frequency
- Mixture of Horizontal and Vertical Frequencies



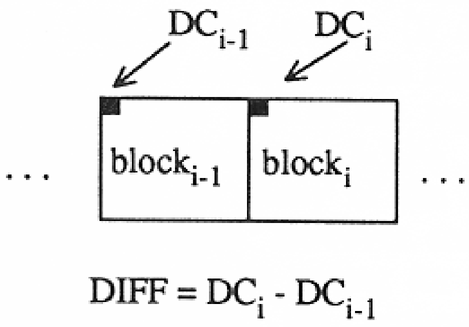
Purpose of DCT

- Coefficient at index (0,0) corresponds to DC or average intensity and is always positive
- The other 63 coefficients correspond to AC components and can be either positive or negative
- Because pixel values typically vary slowly from point to point across an image, the DCT achieves data compression by concentrating most of the signal in the lower spatial frequencies
- For a typical 8x8 block most spatial frequencies will be zero or near zero and need not be encoded

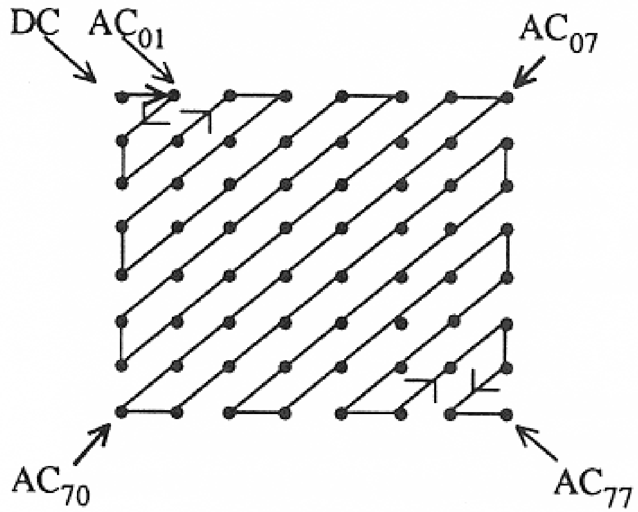
Quantization

- After the DCT each coefficient is quantized non-uniformly into 8 bits. The quantization levels were carefully determined from psychovisual experiments (error level below perceptual threshold)
- After quantization, the DC coefficient is handled separately.
  - This is worth while, because it always contains a significant fraction of the image energy
  - It is encoded as the difference from the last DC coefficient encoded
- AC coefficients are scanned in a zigzag pattern and then compacted with either Huffman or Arithmetic coding
  - The zigzag ordering helps the compaction by placing low-frequency coefficients (which are more likely to be non-zero) before high frequency coefficients.

Zigzag Encoding



Differential DC encoding



Zig–zag sequence

JPEG Processing Chain

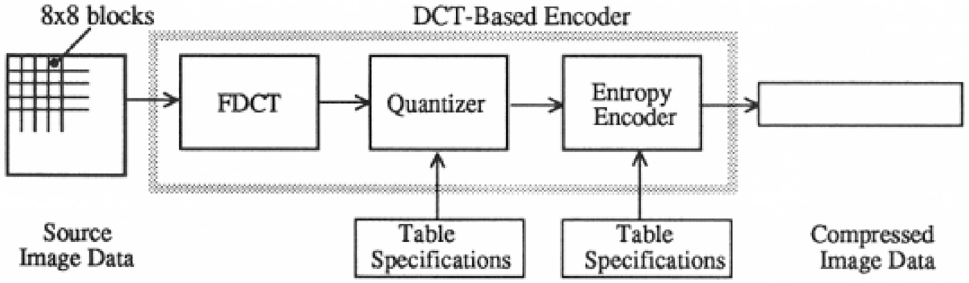


Figure 1. DCT-Based Encoder Processing Steps

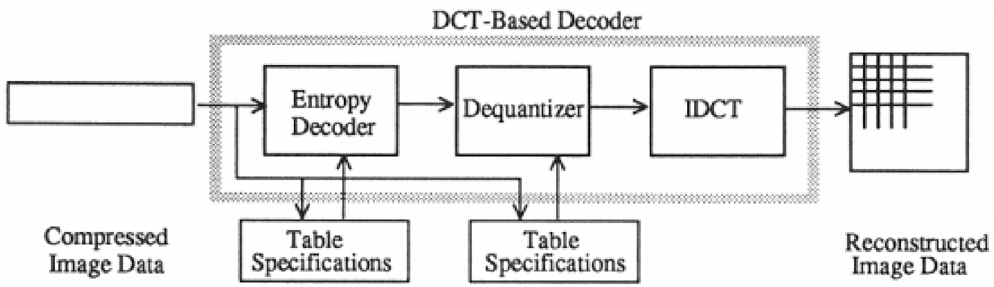


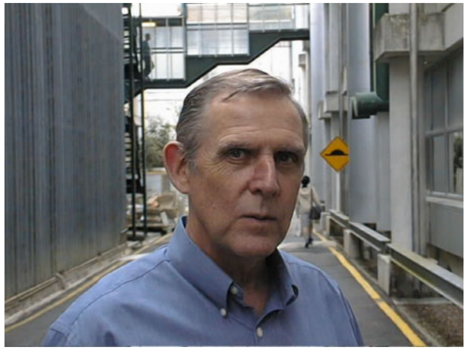
Figure 2. DCT-Based Decoder Processing Steps

Overall Performance

- 0.25-0.5 bits/pixel: moderate to good quality
- 0.5-0.75 bits/pixel: good to very good quality
- 0.75-1.5 bits/pixel: excellent quality, sufficient for most applications

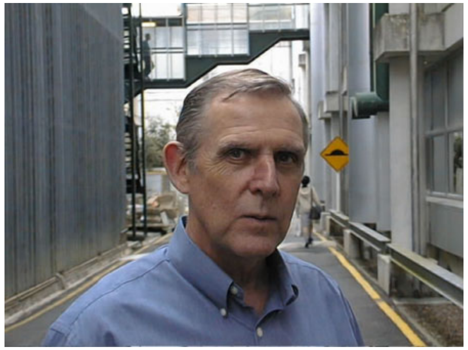
Note: JPEG can be lossless but rarely implemented

Original BMP file 1:1
448x336 pixels



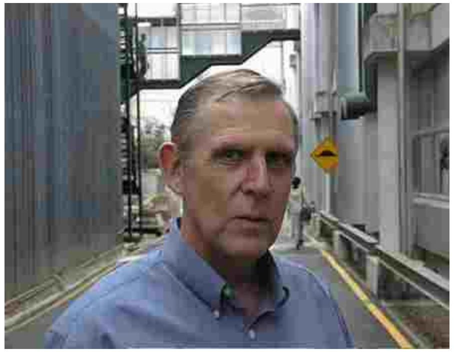
442 kB

Good JPEG 14:1



32 kB

Acceptable JPEG 63:1



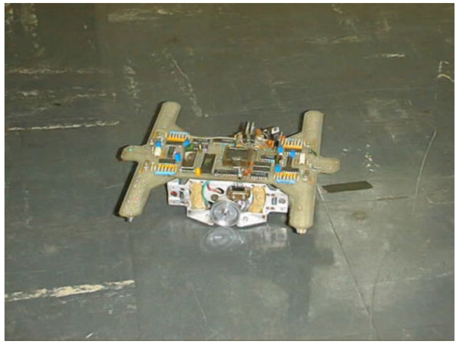
7 kB

Common Image Processing Tasks

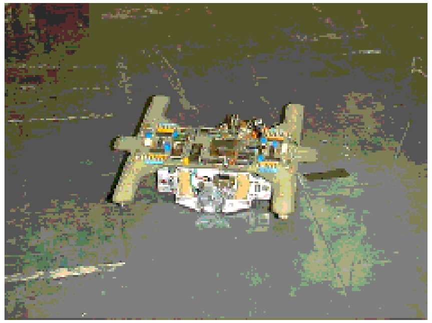
- Thresholding (2 level quantization)
- Requantizing (changing number of quantization levels)
  - sometimes called posterizing in application packages
  - necessary to convert 24 bit colour to 8 bit colour models
  - may require dither to prevent “false contours”
- Blurring
  - convolving with a 2D low pass FIR filter (point spread function)
- Sharpening
  - convolving with a 2D high boost FIR filter
  - note: do not use high pass as you will lose DC component and resultant image will have negative intensity values

Examples

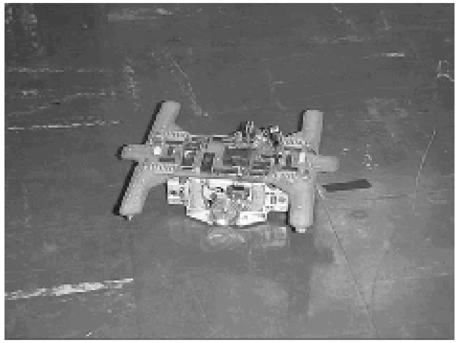
Original Image



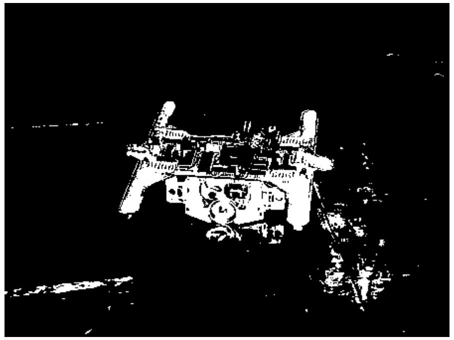
Posterizing: reduced to 8 colours only



Grayscale conversion



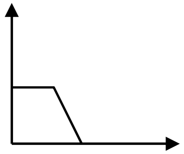
Thresholding



Examples

3x3 2D Filter

$$\frac{1}{9}*\begin{bmatrix} 1 & 1 & 1 \\ 1 & 1 & 1 \\ 1 & 1 & 1 \end{bmatrix}$$



lowpass

2D CONVOLUTION

Blurred

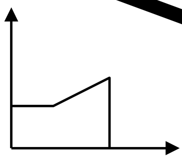
2D CONVOLUTION

Sharpened

3x3 2D Filter

HIGHPASS **ALLPASS** **HIGH BOOST**

$$\frac{1}{10}*\begin{bmatrix} 1 & -1 & 1 \\ -1 & 0 & -1 \\ 1 & -1 & 1 \end{bmatrix}+\begin{bmatrix} 0 & 0 & 0 \\ 0 & 1 & 0 \\ 0 & 0 & 0 \end{bmatrix}=\begin{bmatrix} 0.1 & -0.1 & 0.1 \\ -0.1 & 1 & -0.1 \\ 0.1 & -0.1 & 0.1 \end{bmatrix}$$



highboost