EECE 4353 Image Processing

Lecture Notes: Introduction and Overview

Richard Alan Peters II
Department of Electrical Engineering and Computer Science

Fall Semester 2016

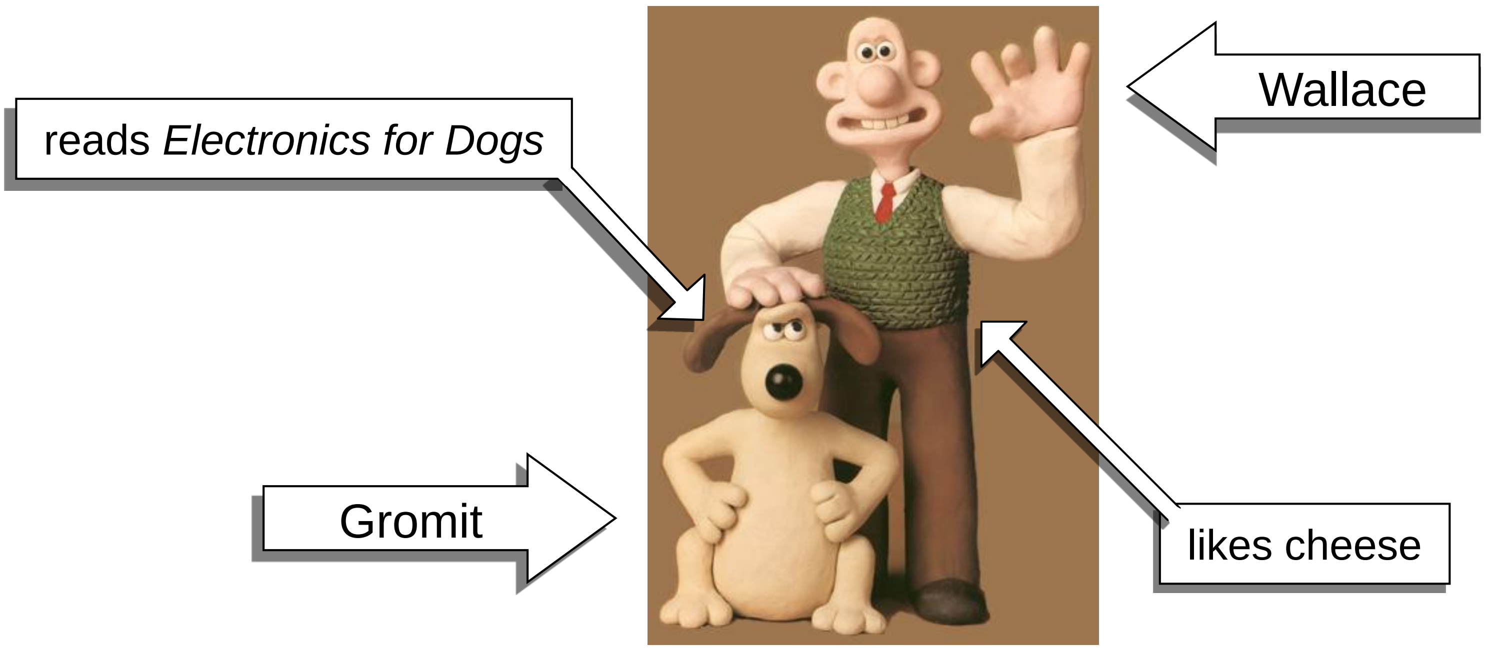
Introduction and Overview

This presentation is an *overview* of some of the ideas and techniques to be covered during the course.

Topics

1. Image formation
2. Point processing and equalization
3. Color correction
4. The Fourier transform
5. Convolution
6. Image sampling, warping, and stitching
7. Spatial filtering
8. Noise reduction
9. Mathematical morphology
10. High dynamic range imaging
11. Image compression

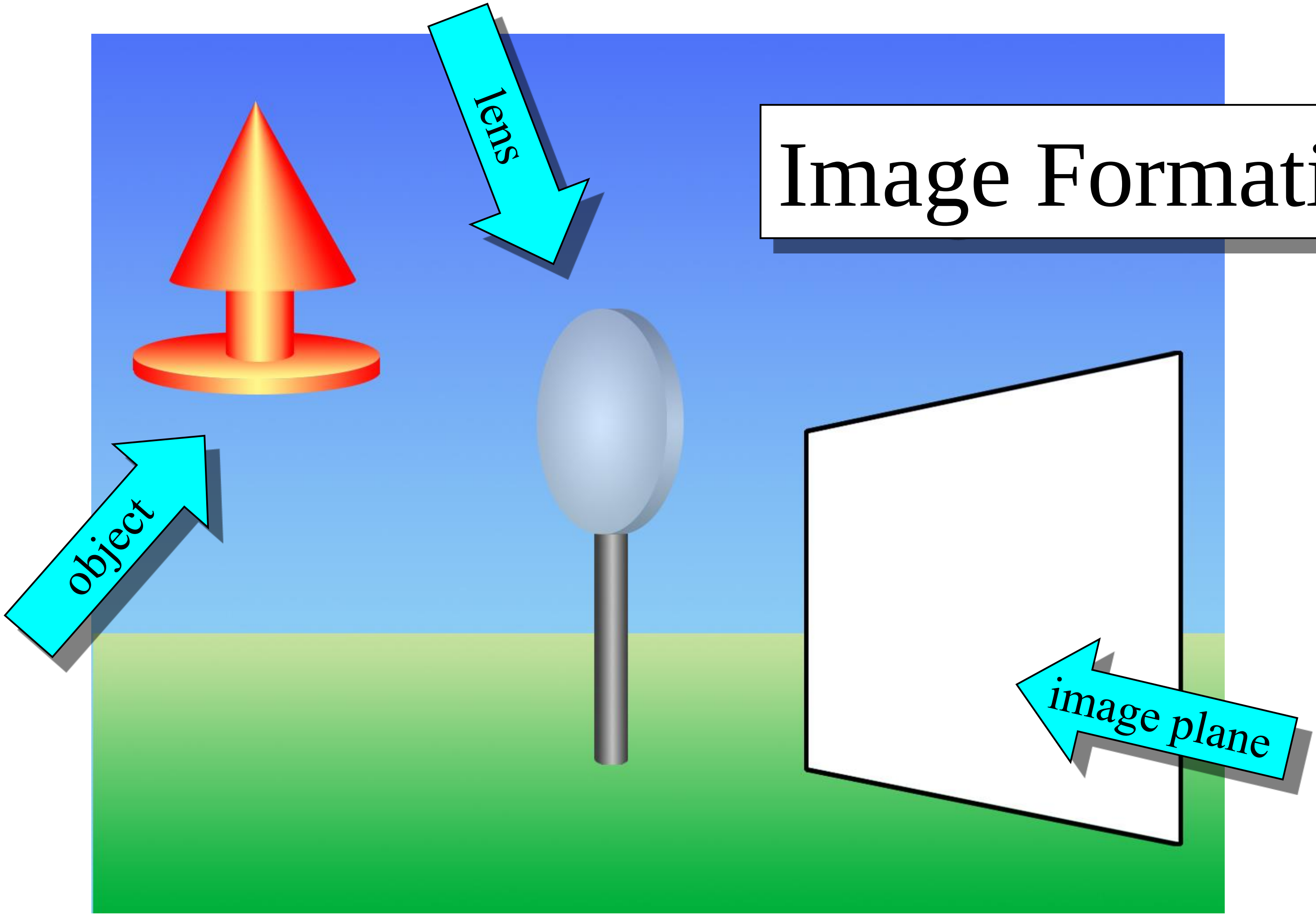
Wallace and Gromit



Wallace and Gromit will be subjects of some of the imagery in this introduction.

Visit: http://www.aardman.com/wallaceandgromit/index.shtml

Image Formation



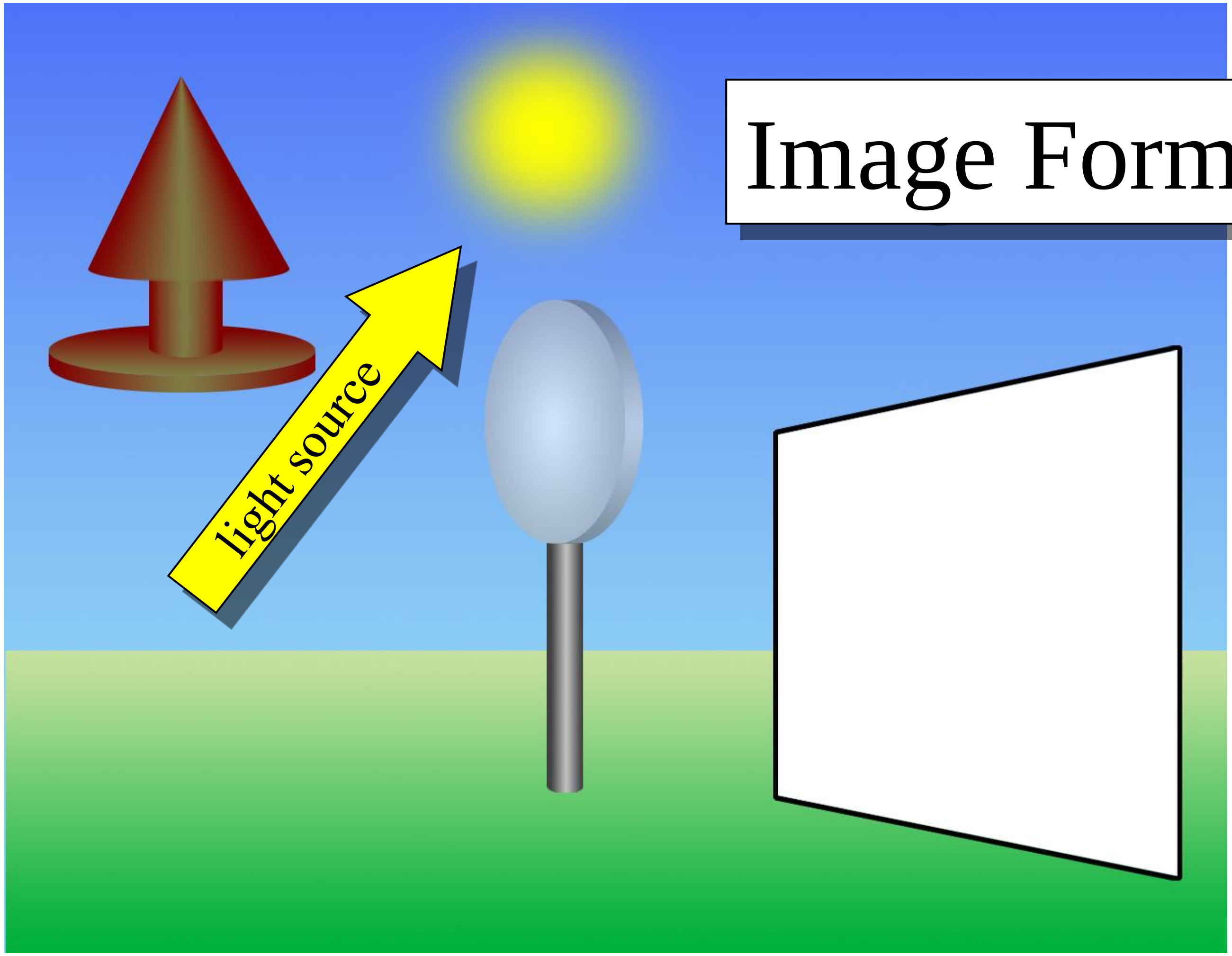


Image Formation

Image Formation

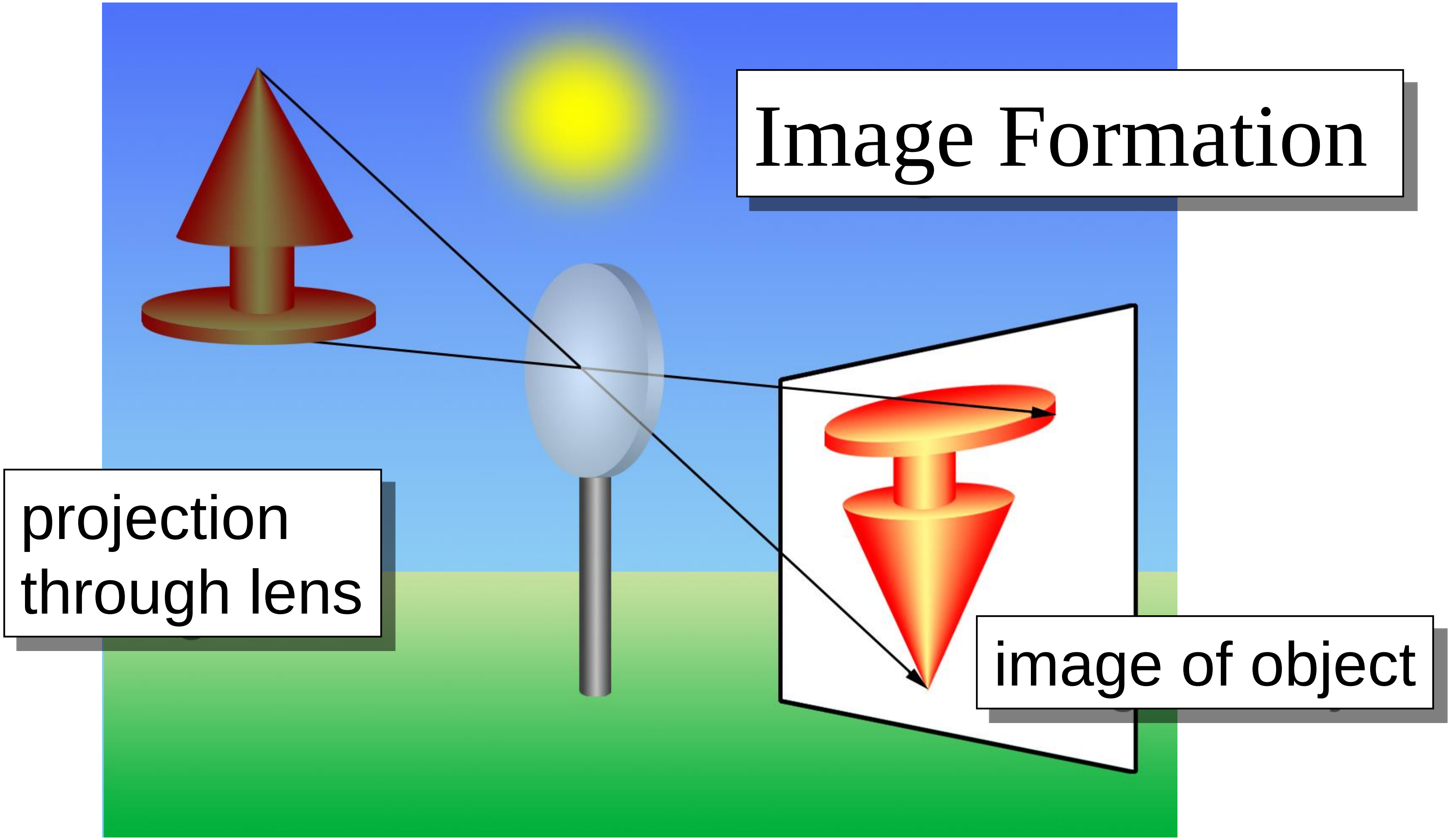
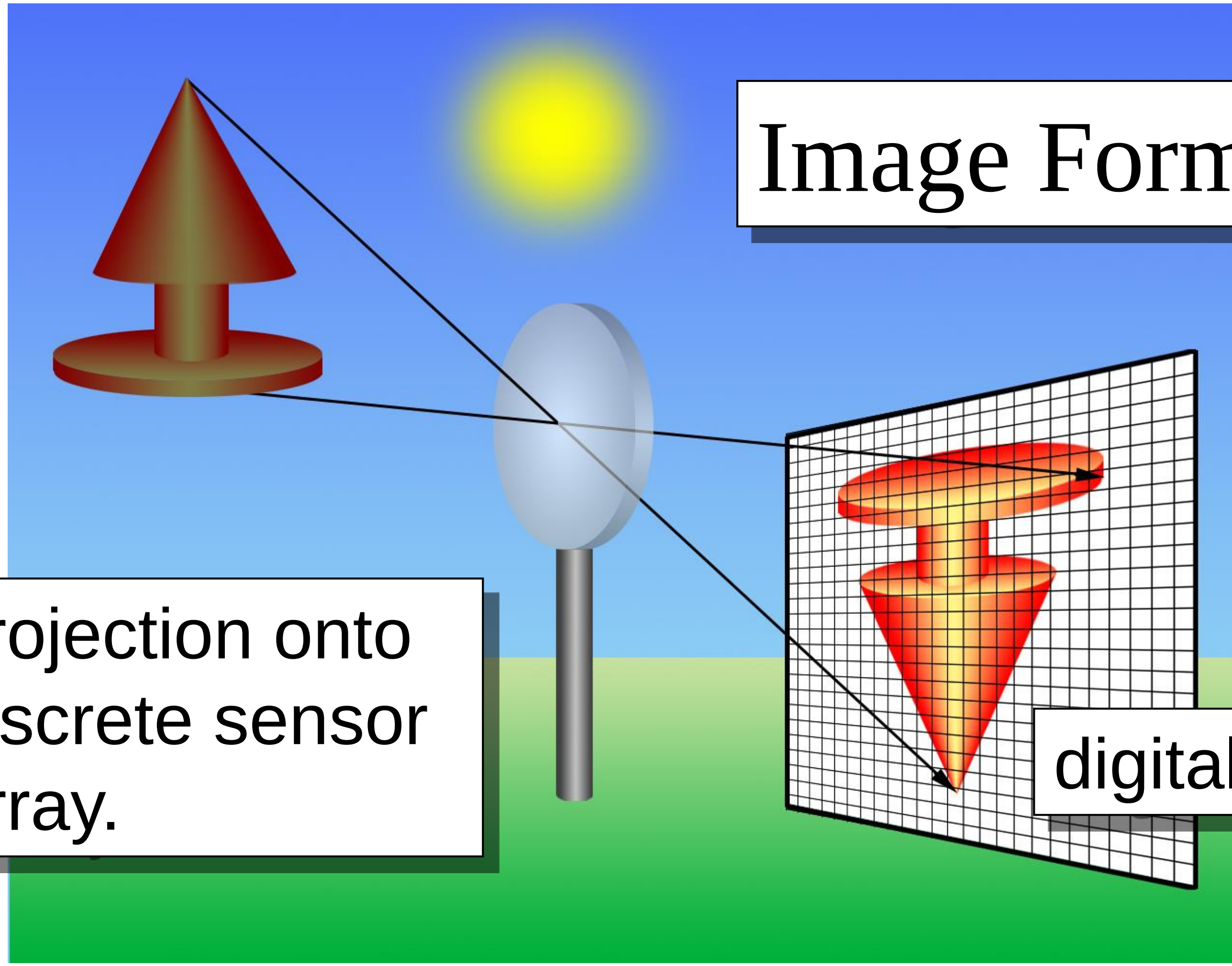


Image Formation



projection onto discrete sensor array.

digital camera

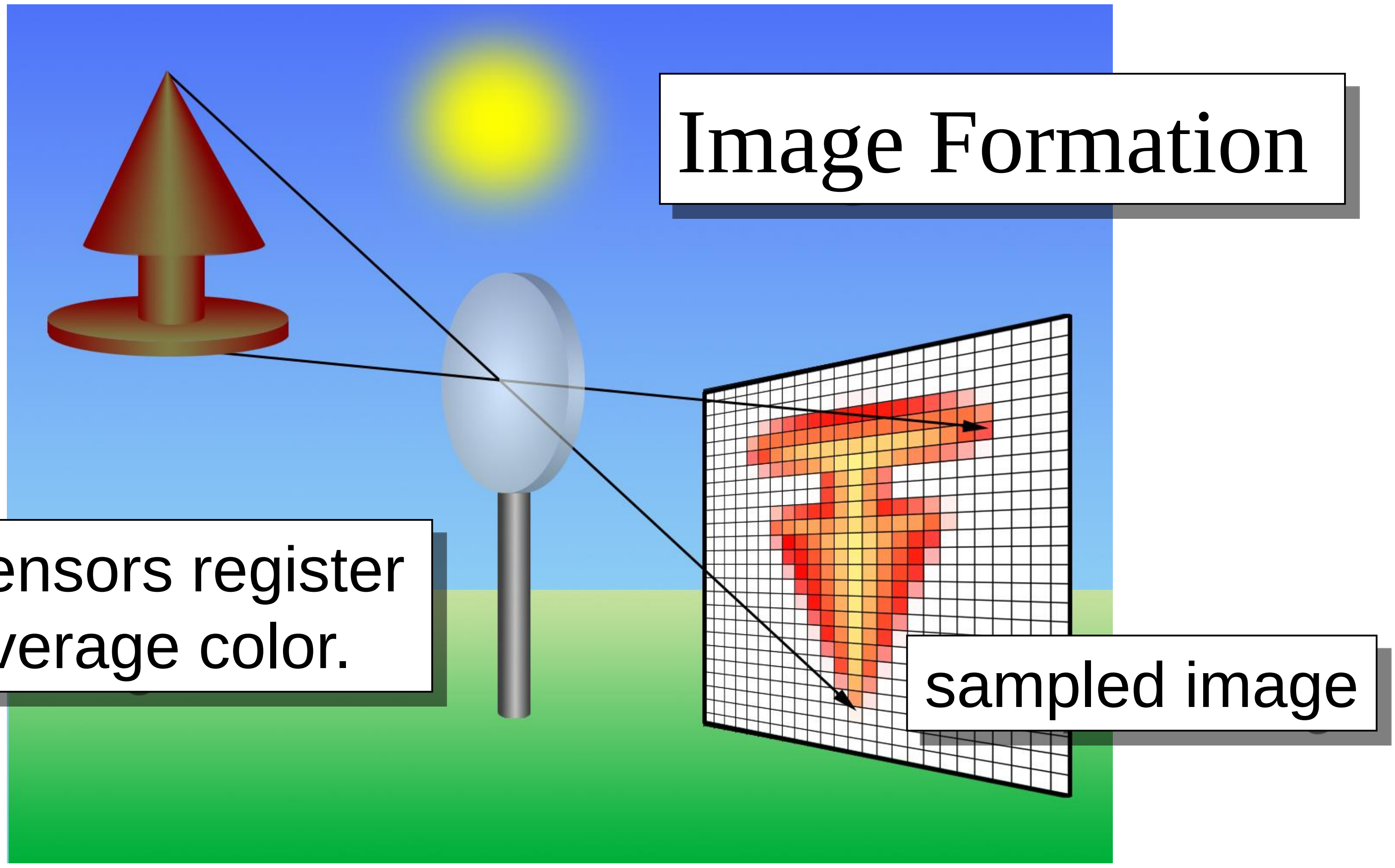
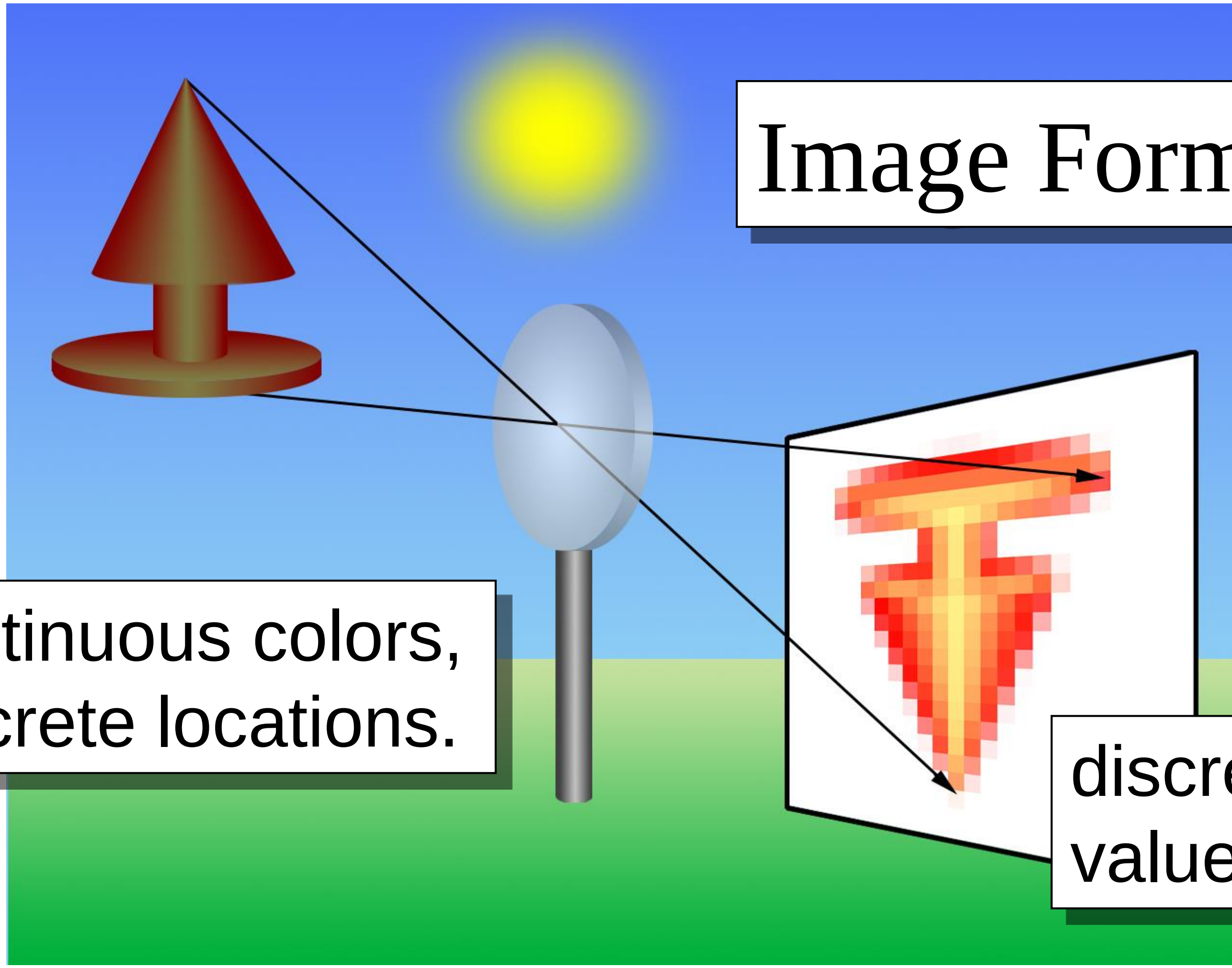
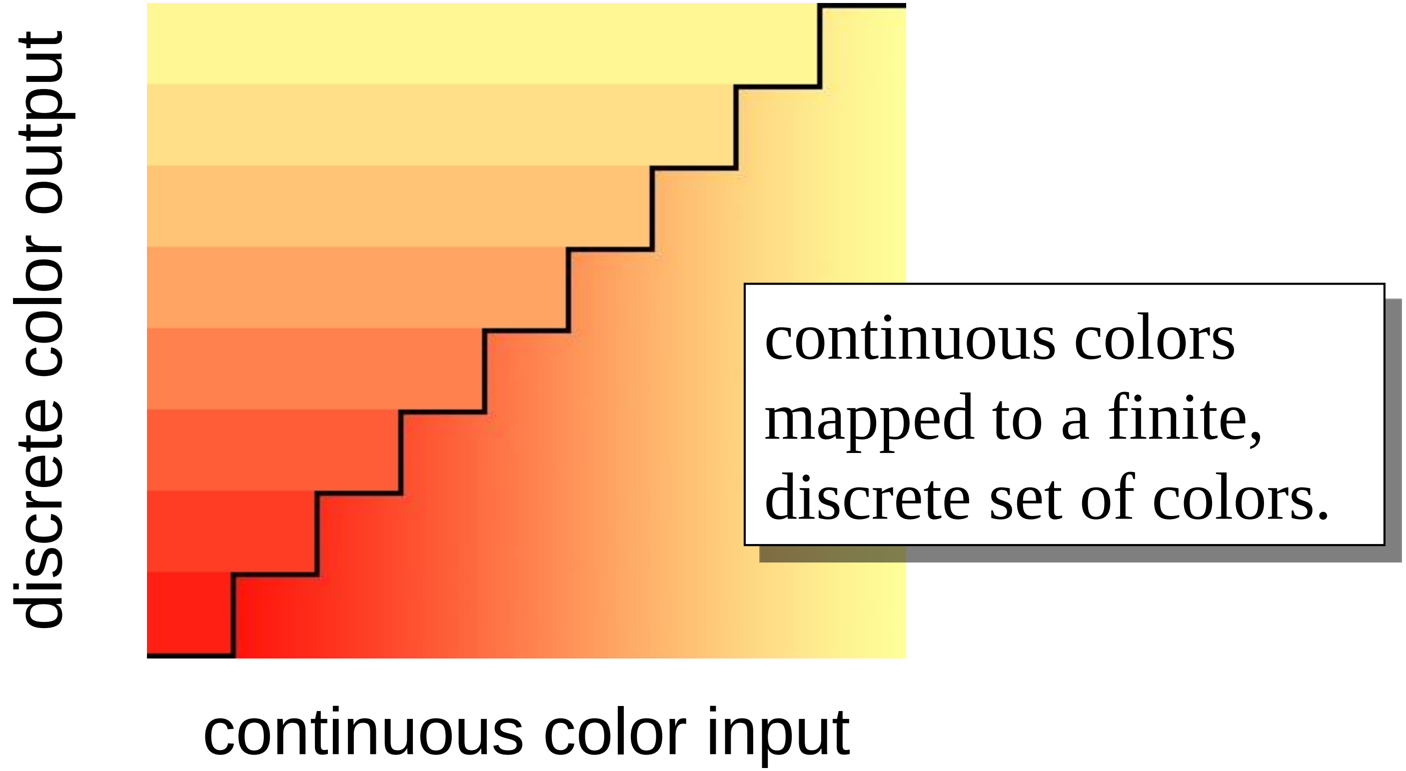


Image Formation
sensors register average color.
sampled image

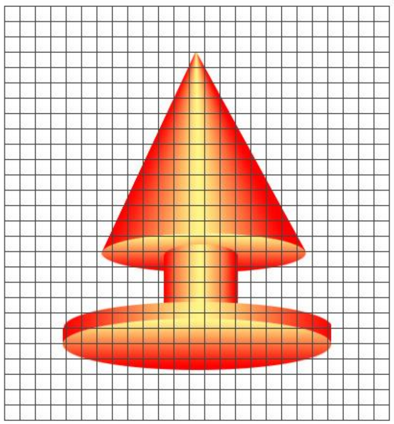
Image Formation



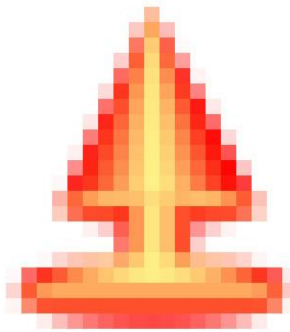
Digital Image Formation: Quantization



Sampling and Quantization

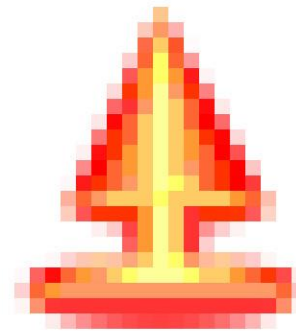


real image



sampled

quantized



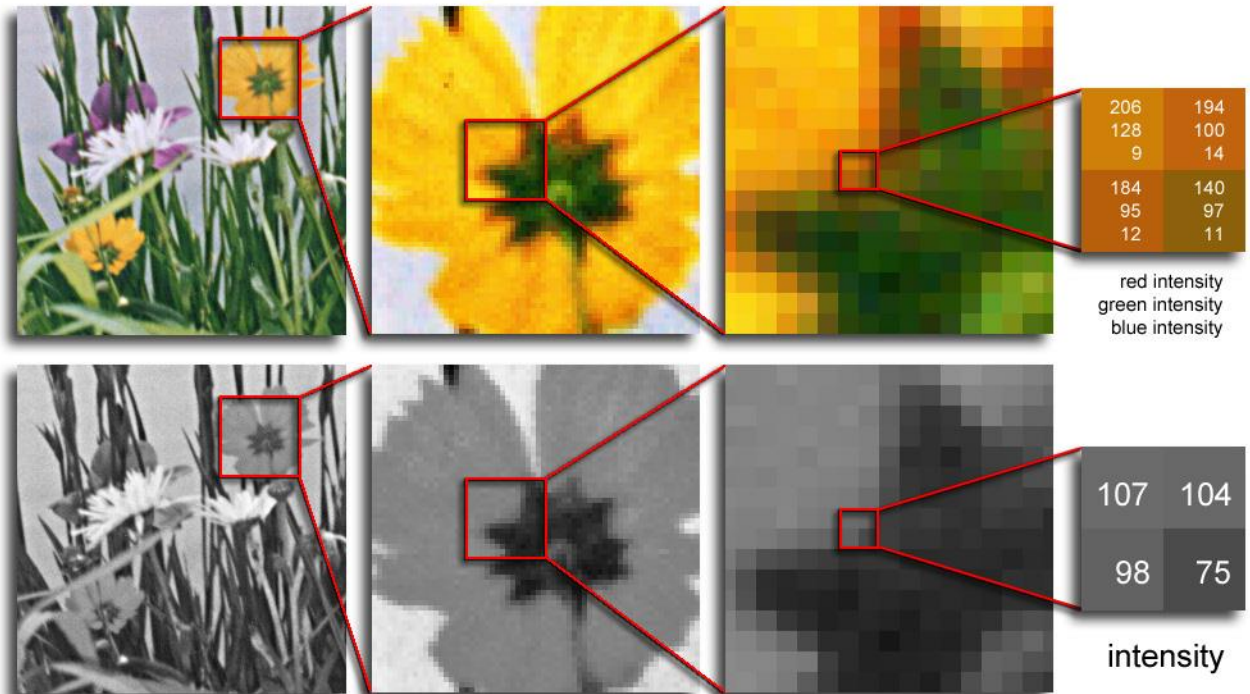
sampled & quantized

Digital Image

Color images have 3 values per pixel; monochrome images have 1 value per pixel.

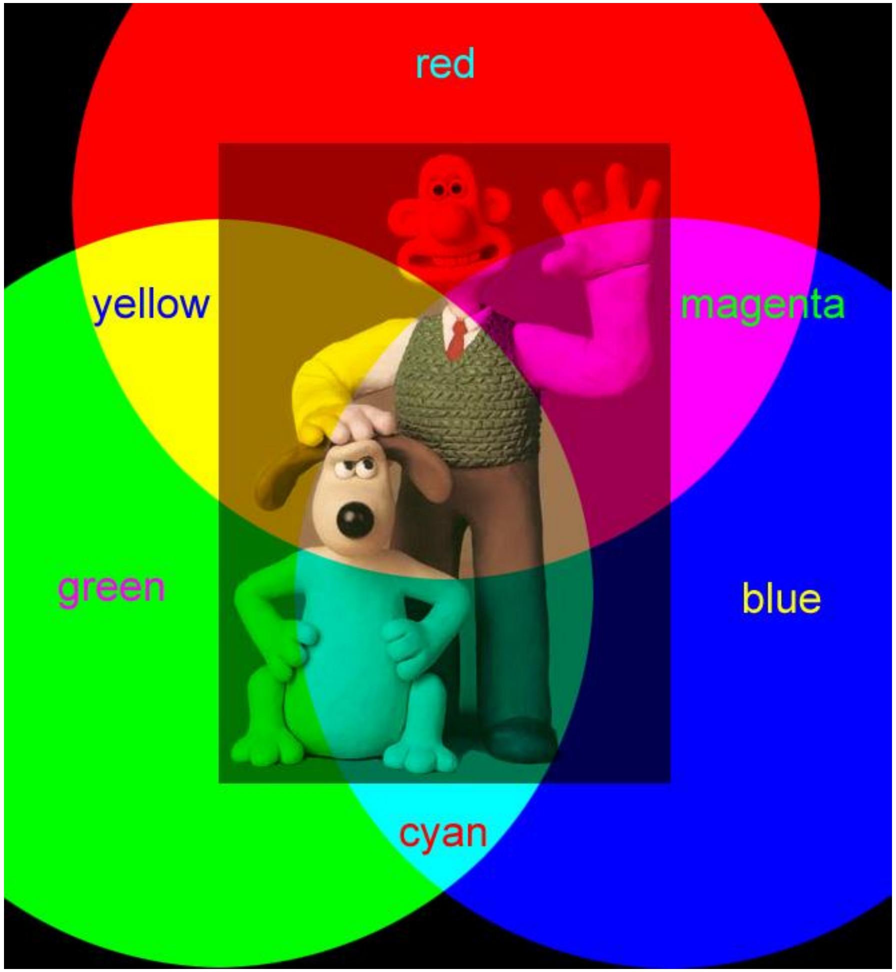
a grid of squares, each of which contains a single color

each square is called a pixel (for *picture element*)

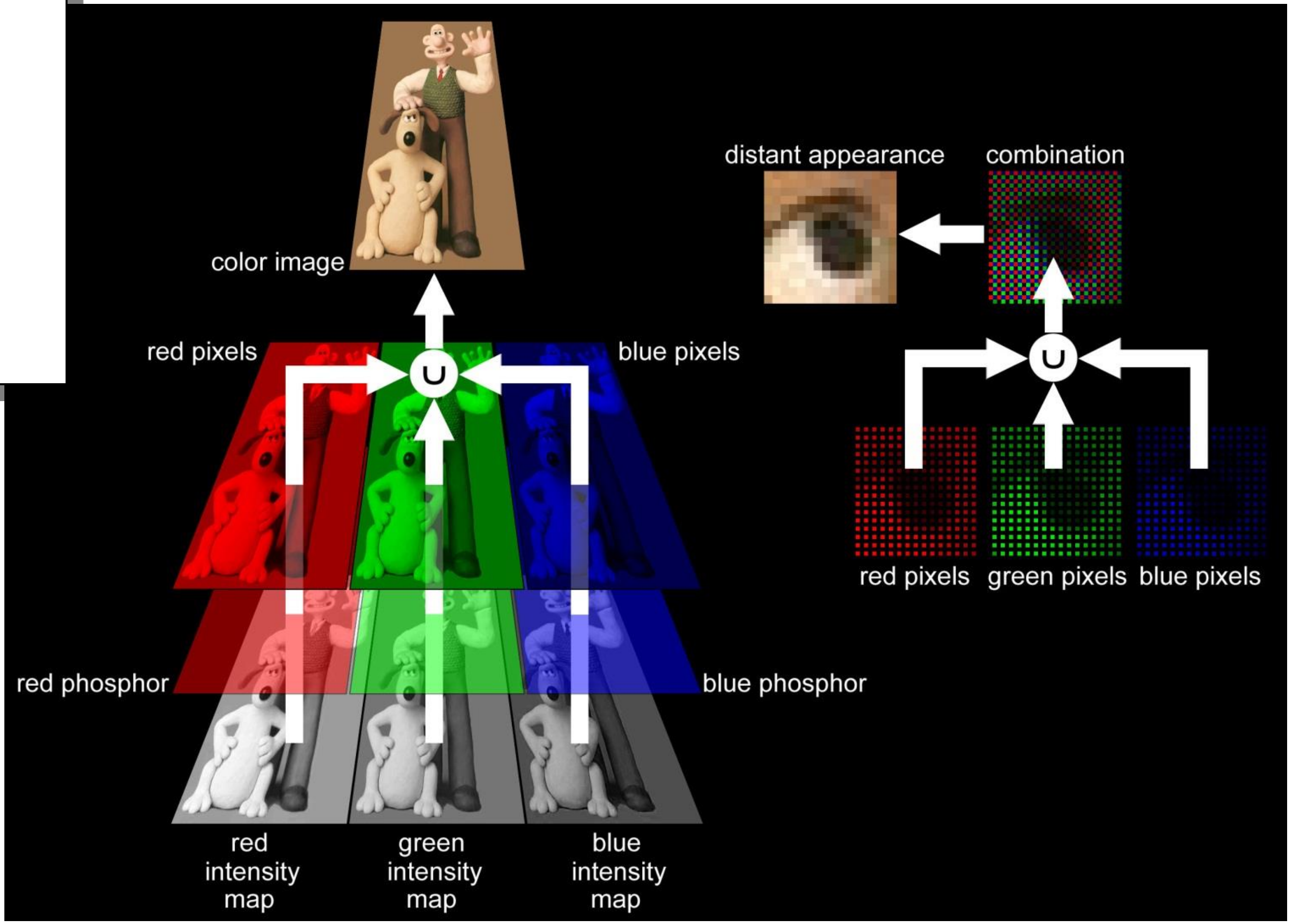


Color Images

- Are constructed from three intensity maps.
- Each intensity map is projected through a color filter (*e.g.*, red, green, or blue, or cyan, magenta, or yellow) to create a monochrome image.
- The intensity maps are overlaid to create a color image.
- Each pixel in a color image is a three element vector.



Color Images On a CRT



Point Processing

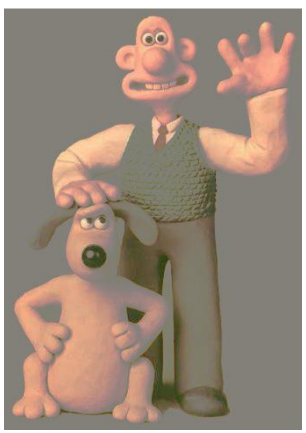
- gamma

- brightness

original

+ brightness

+ gamma



histogram mod

- contrast

original

+ contrast

histogram EQ

Color Processing

requires some knowledge of how we see colors

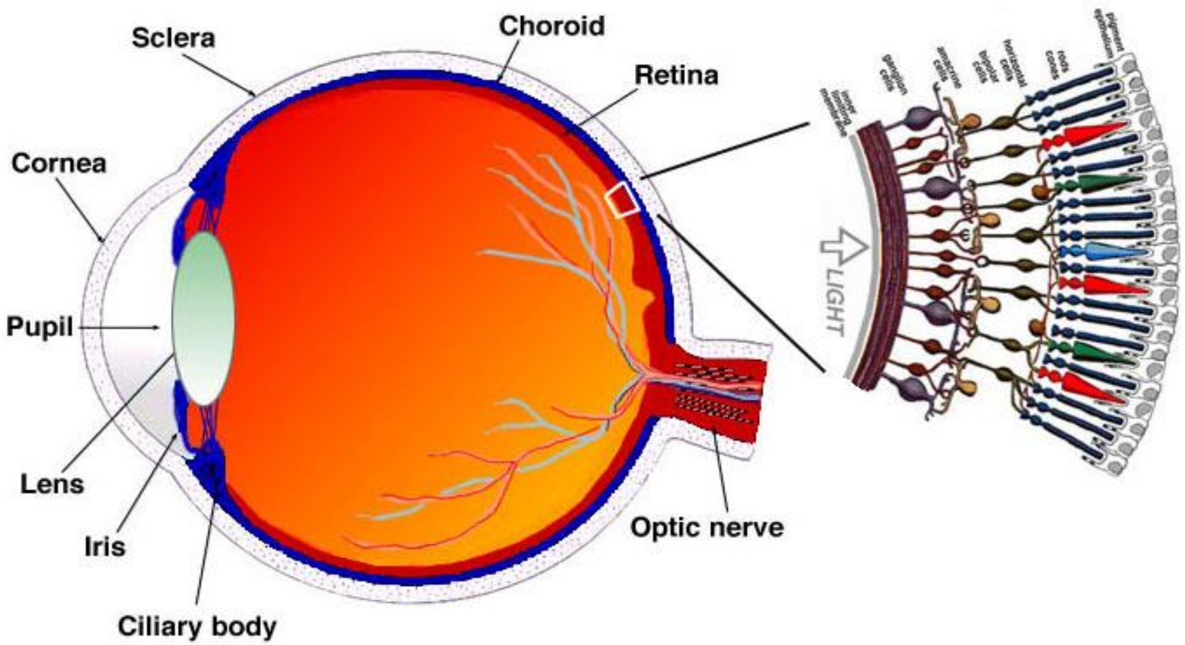
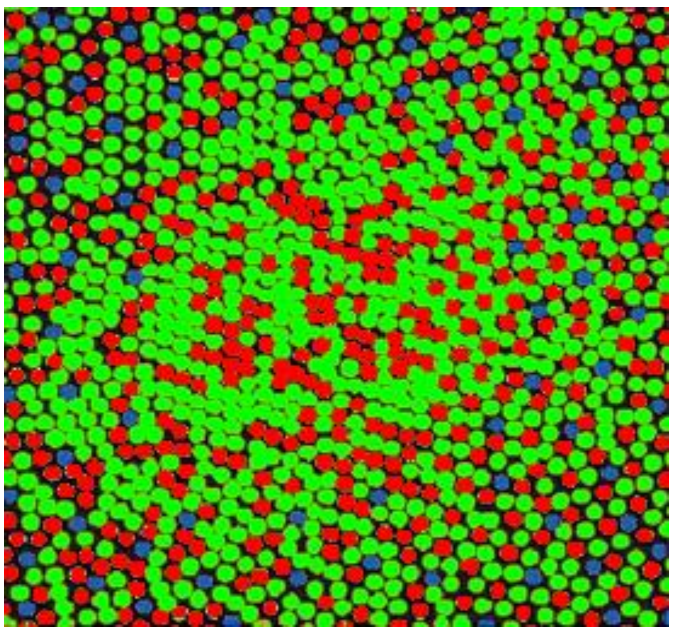


Fig. 1.1. A drawing of a section through the human eye with a schematic enlargement of the retina.

Eye’s Light Sensors

cone density near fovea



#(blue) << #(red) < #(green)

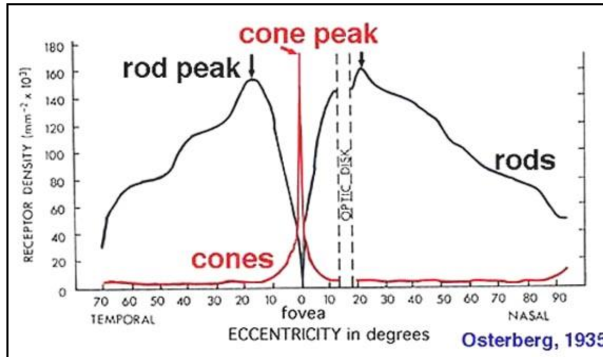


Fig. 20. Graph to show rod and cone densities along the horizontal meridian.

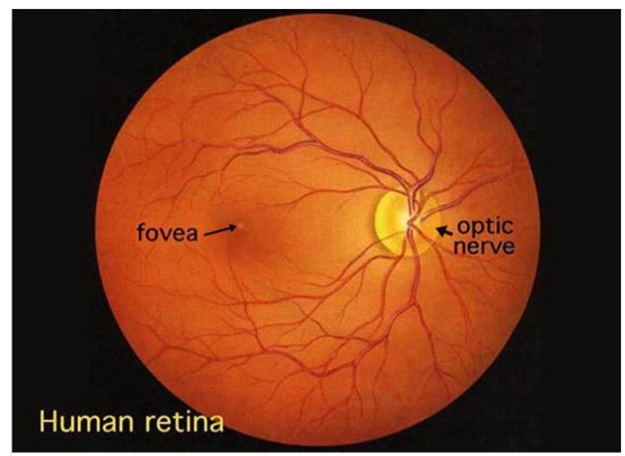
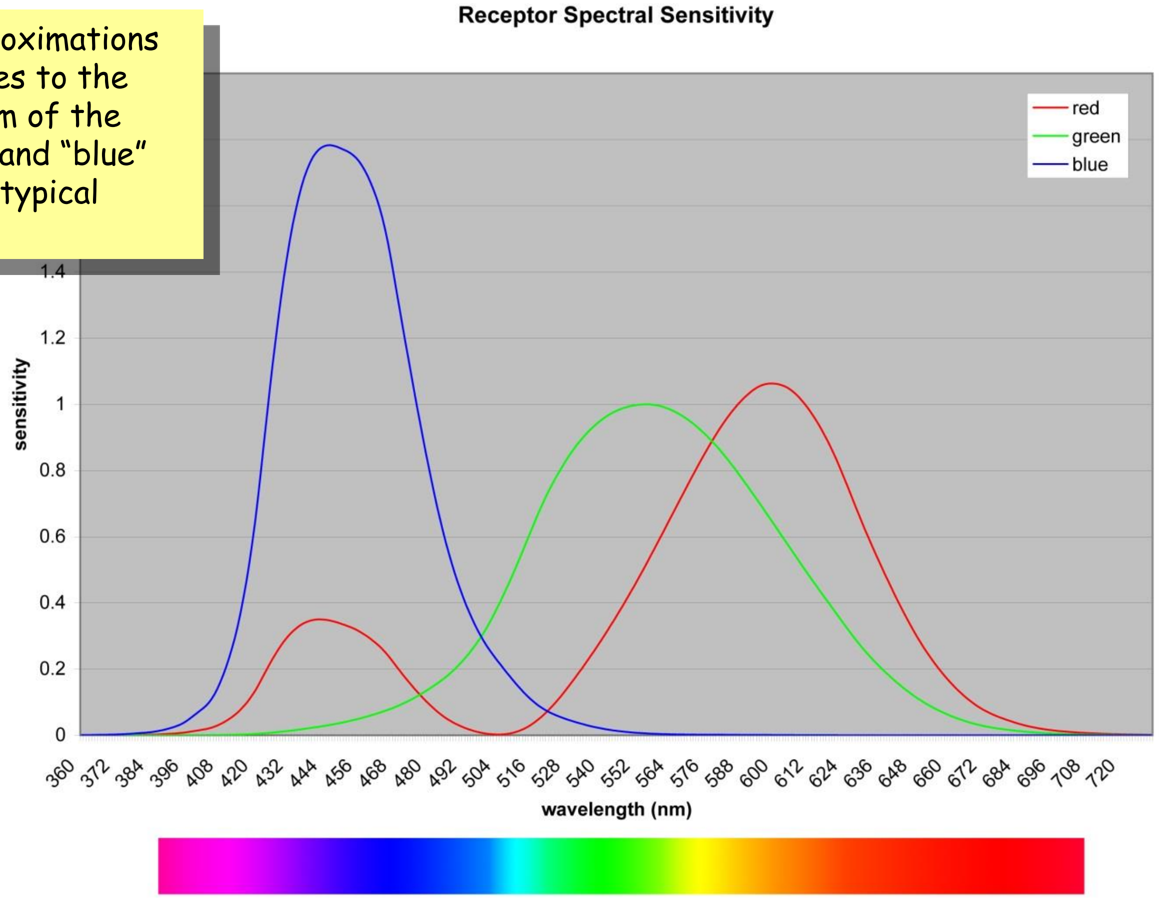


Fig. 1. Human retina as seen through an opthalmoscope.

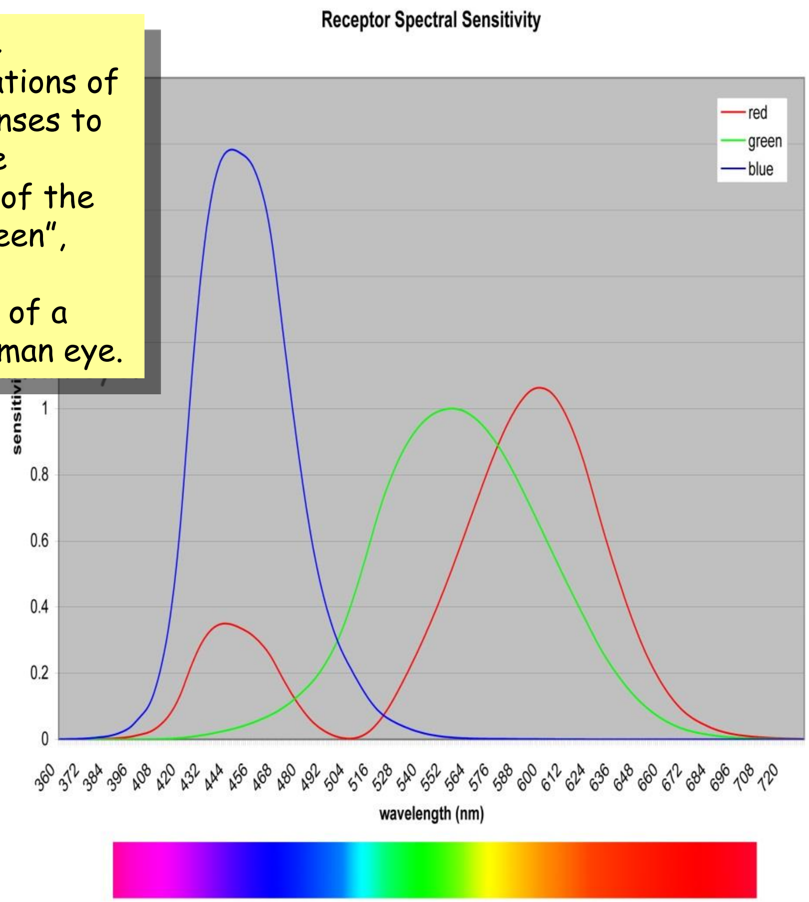
Color Sensing / Color Perception

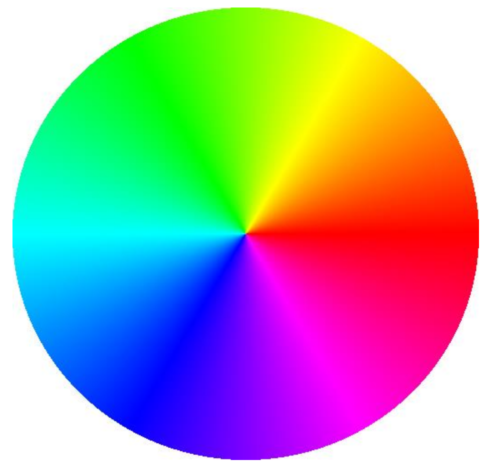
These are approximations of the responses to the visible spectrum of the "red", "green", and "blue" receptors of a typical human eye.



Color Sensing / Color Perception

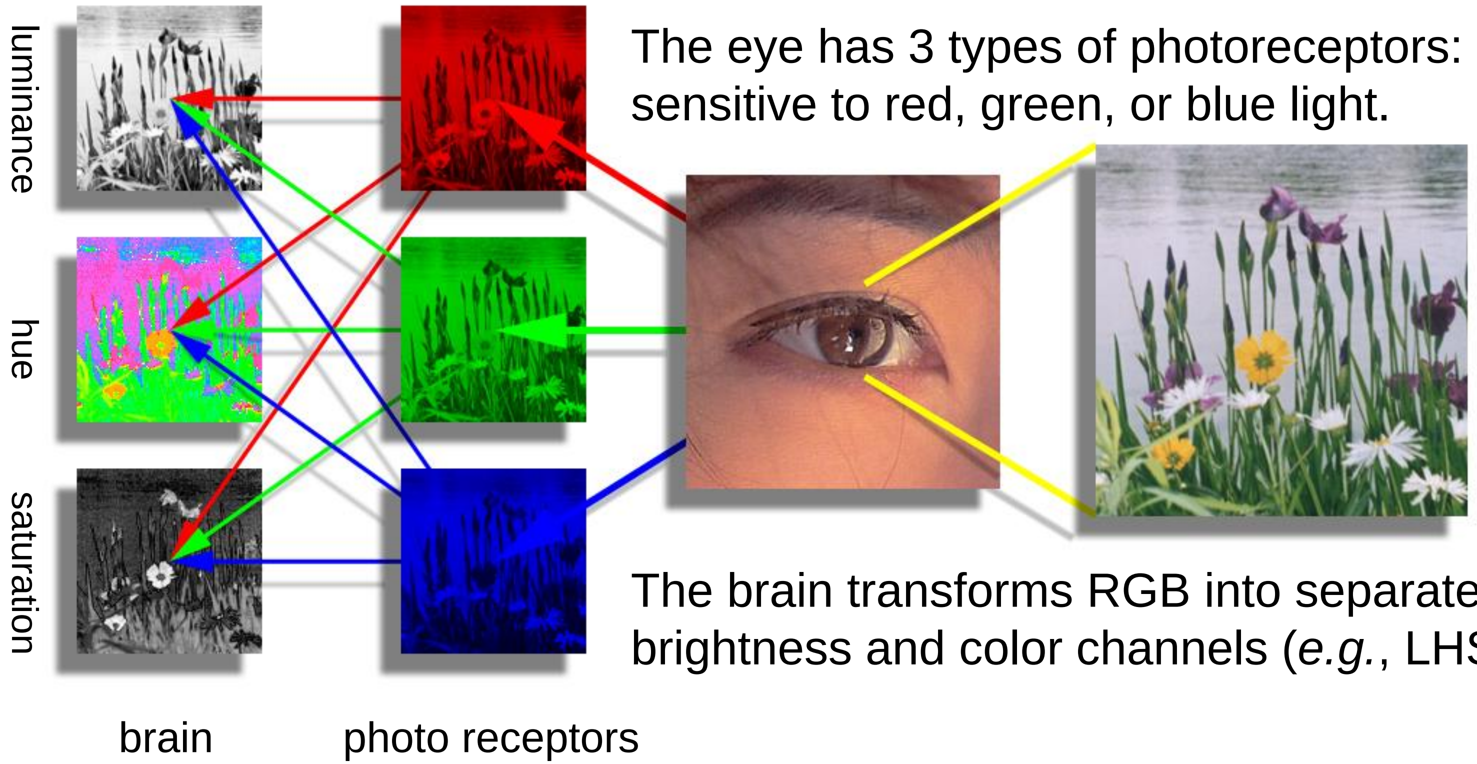
These are approximations of the responses to the visible spectrum of the "red", "green", and "blue" receptors of a typical human eye.





The simultaneous red + blue response causes us to perceive a continuous range of hues on a circle. No hue is greater than or less than any other hue.

Color Sensing / Color Perception



The eye has 3 types of photoreceptors: sensitive to red, green, or blue light.

The brain transforms RGB into separate brightness and color channels (*e.g.*, LHS).

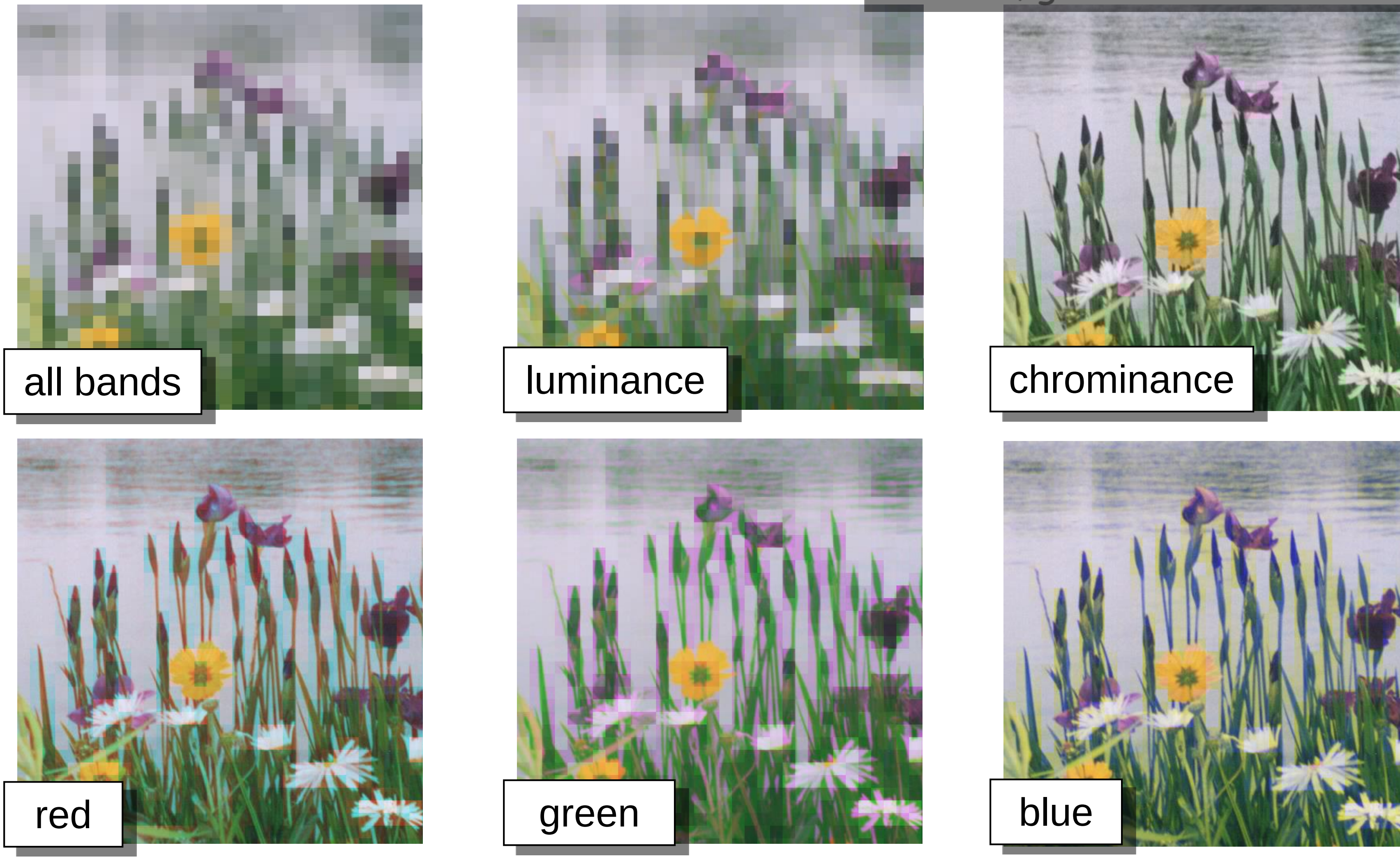
Color Perception

16× pixelization of:

EEC

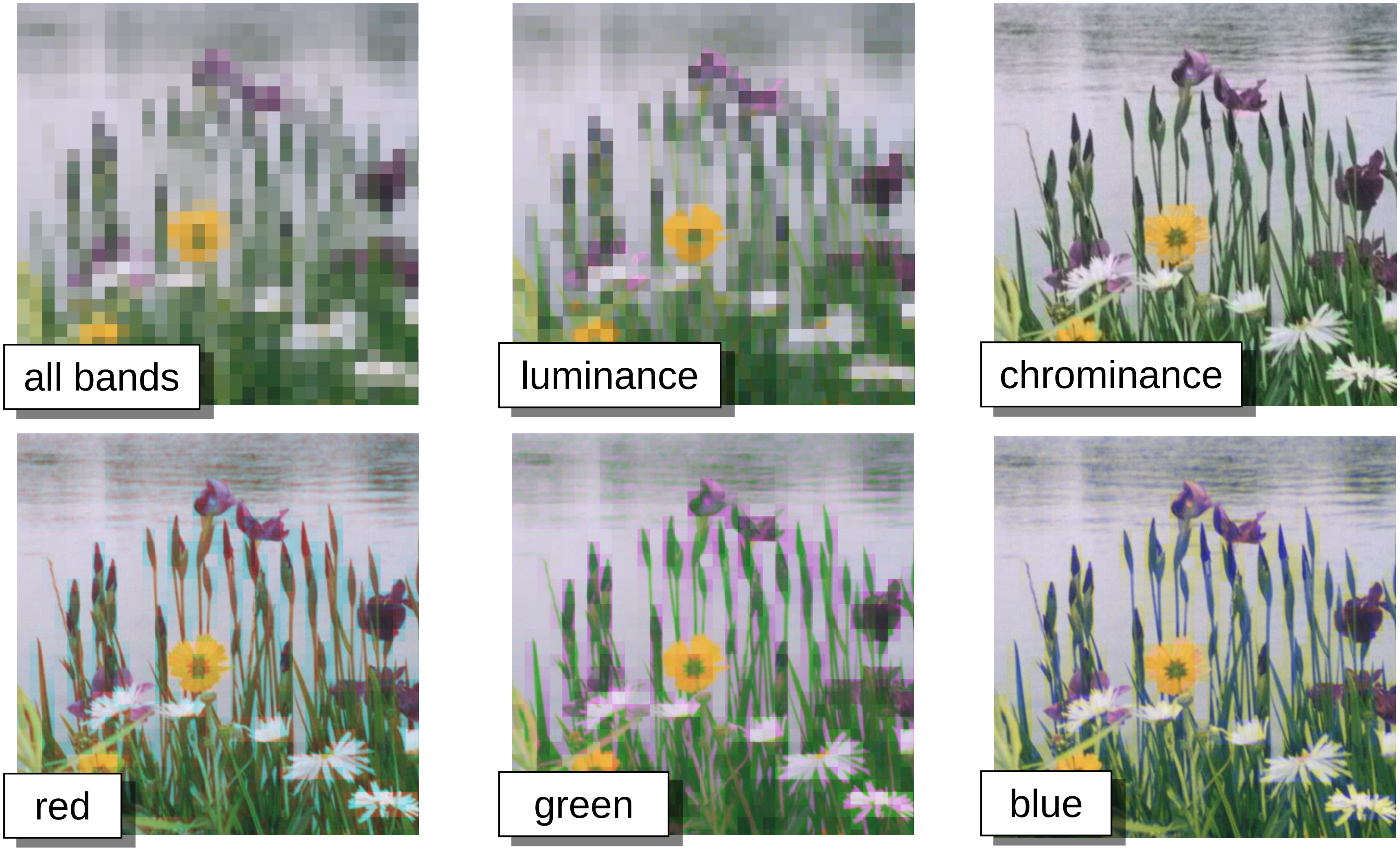
Vand

luminance and chrominance (hue+saturation) are perceived with different resolutions, as are red, green and blue.



Color Perception

16× pixelization of:



Color Balance and Saturation

Uniform changes in color components result in change of tint.

E.g., if all G pixel values are multiplied by $\alpha > 1$ then the image takes a green cast.

Color Transformations

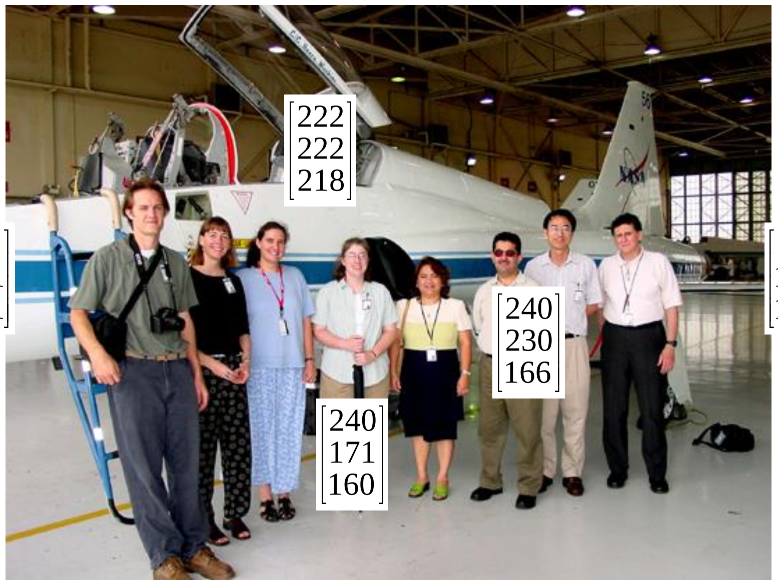


Image aging: a transformation, Φ, that mapped:

$$\begin{bmatrix}17\\122\\114\end{bmatrix} = \Phi\left\{\begin{bmatrix}17\\121\\171\end{bmatrix}\right\} \qquad \begin{bmatrix}222\\222\\185\end{bmatrix} = \Phi\left\{\begin{bmatrix}222\\222\\218\end{bmatrix}\right\} \qquad \begin{bmatrix}240\\171\\103\end{bmatrix} = \Phi\left\{\begin{bmatrix}240\\171\\160\end{bmatrix}\right\} \qquad \begin{bmatrix}236\\227\\106\end{bmatrix} = \Phi\left\{\begin{bmatrix}240\\230\\166\end{bmatrix}\right\}$$

The 2D Fourier Transform of a Digital Image

Let $I(r,c)$ be a single-band (intensity) digital image with R rows and C columns. Then, $I(r,c)$ has Fourier representation

$$I(r,c) = \sum_{u=0}^{R-1} \sum_{v=0}^{C-1} \mathfrak{I}(u,v)\, e^{+i2\pi\left(\frac{ur}{R}+\frac{vc}{C}\right)},$$

where

$$\mathfrak{I}(u,v) = \frac{1}{RC} \sum_{r=0}^{R-1} \sum_{c=0}^{C-1} I(r,c)\, e^{-i2\pi\left(\frac{ur}{R}+\frac{vc}{C}\right)}$$

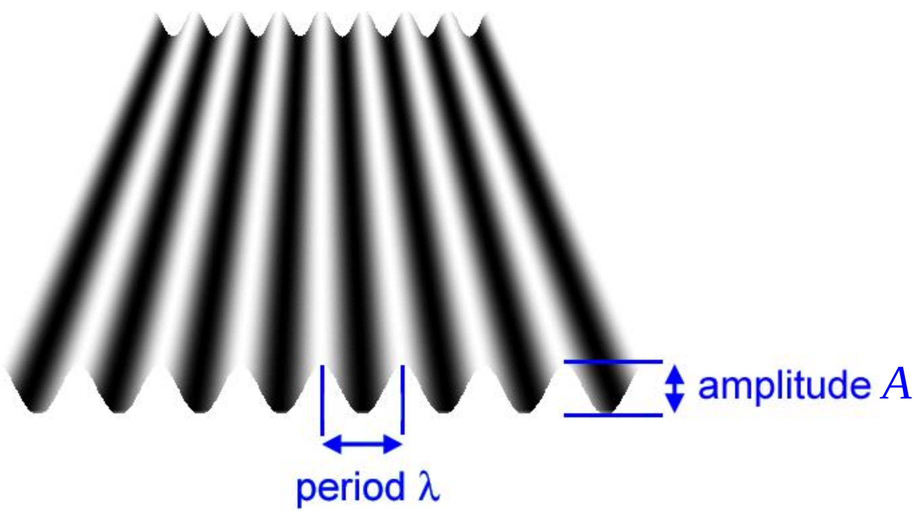
are the R x C Fourier coefficients.

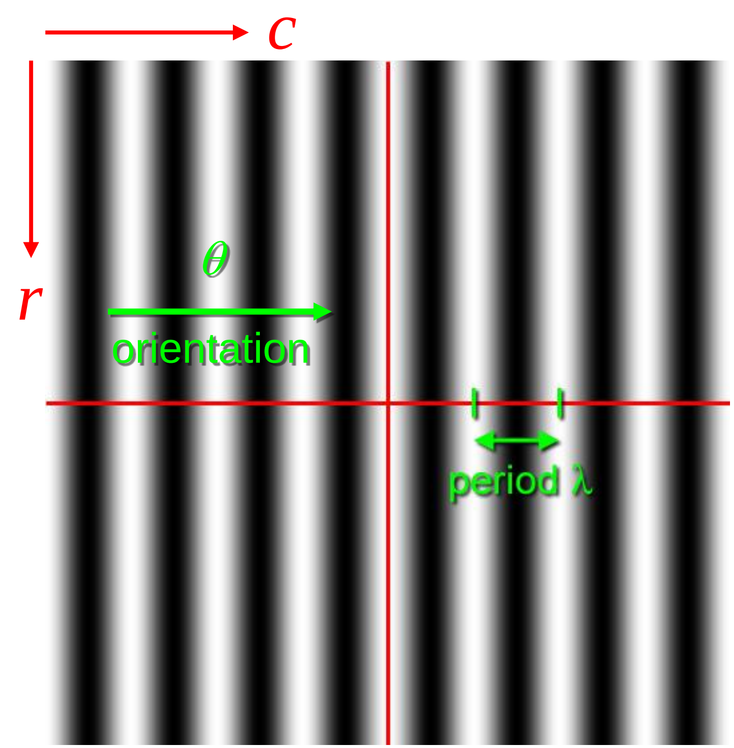
these complex exponentials are 2D sinusoids.

2D Sinusoids:

$$I(r,c) = \frac{A}{2}\left\{\cos\left[\frac{2\pi}{\lambda}\left(\frac{c}{C}\cos\theta - \frac{r}{R}\sin\theta\right) + \varphi\right] + 1\right\}$$

... are plane waves with grayscale amplitudes, periods in terms of lengths, ...

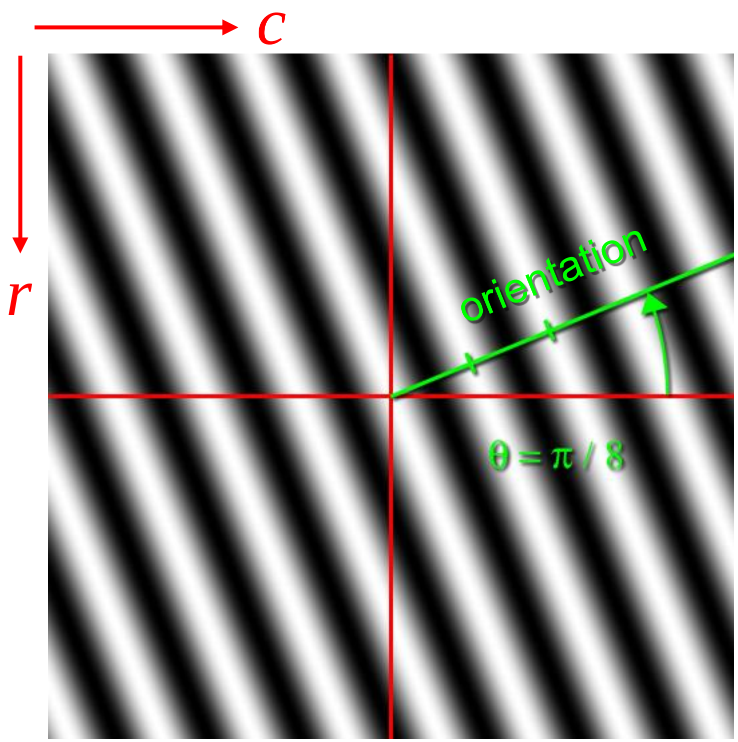


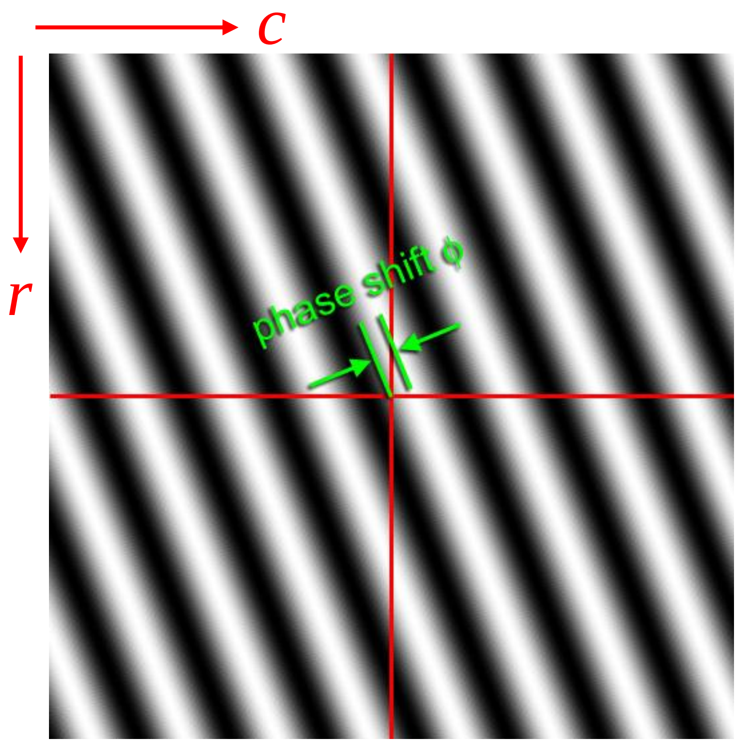


ϕ = phase shift

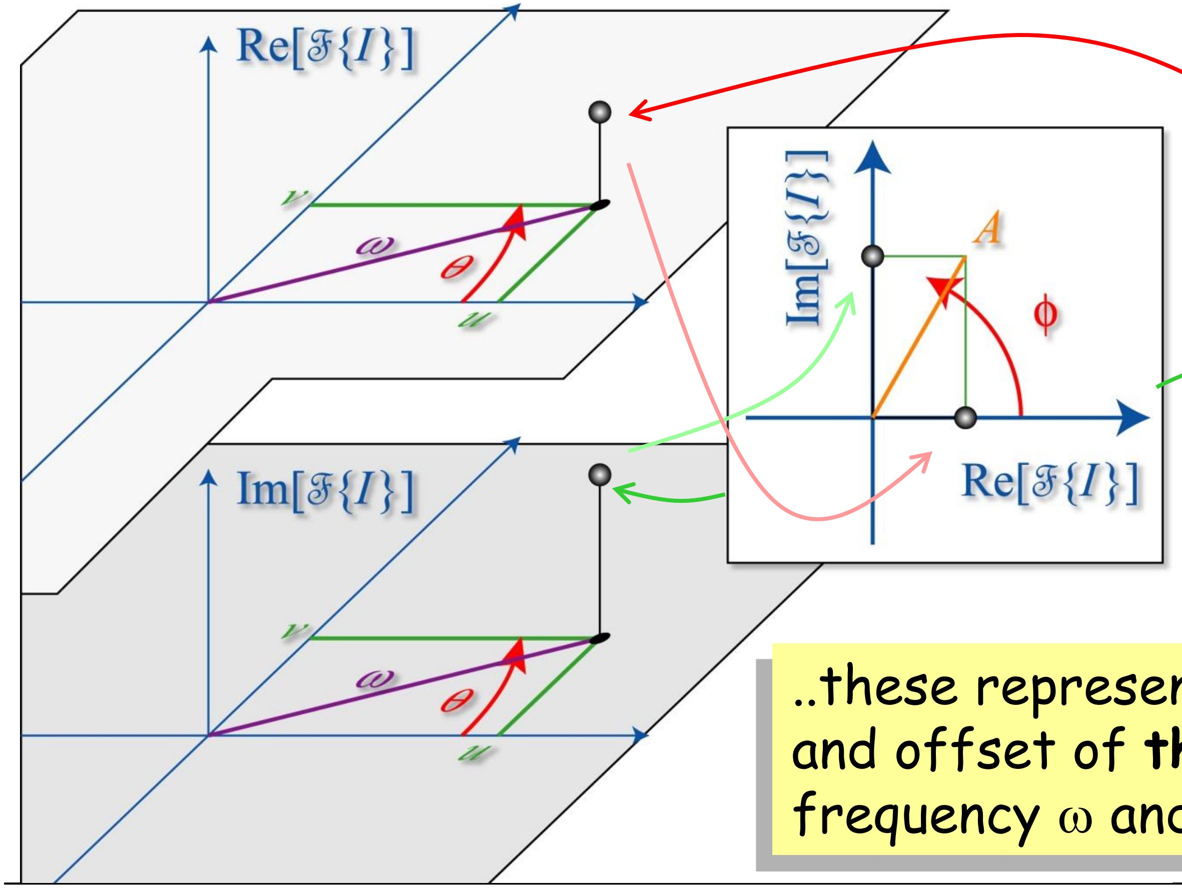
2D Sinusoids:

... specific orientations,
and phase shifts.





The Value of a Fourier Coefficient …

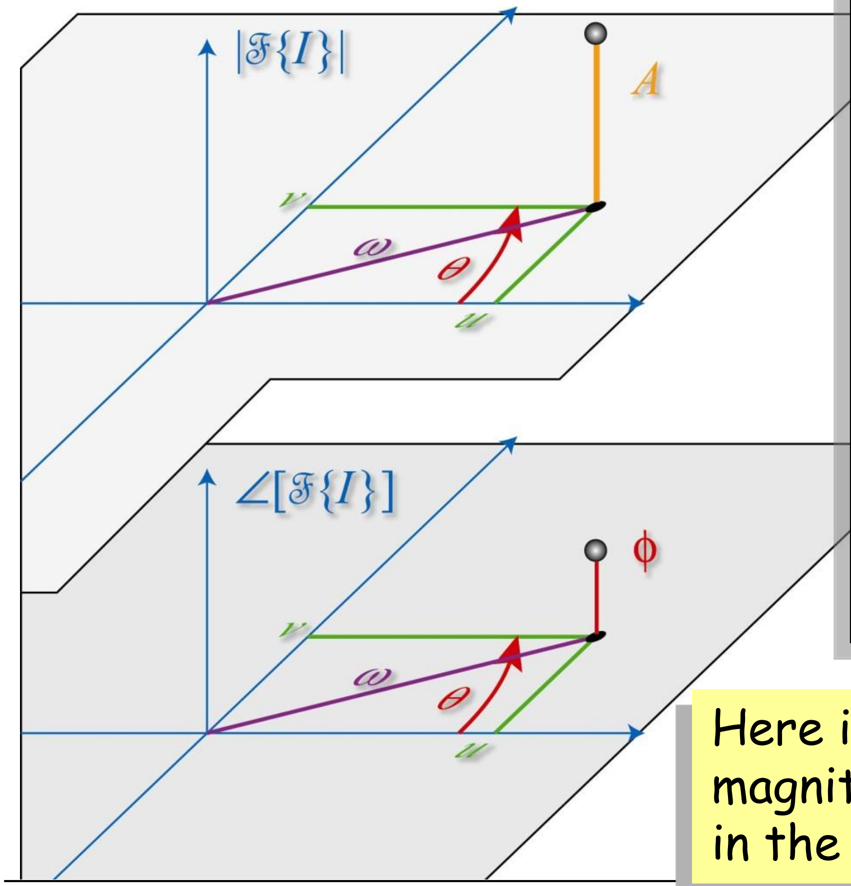


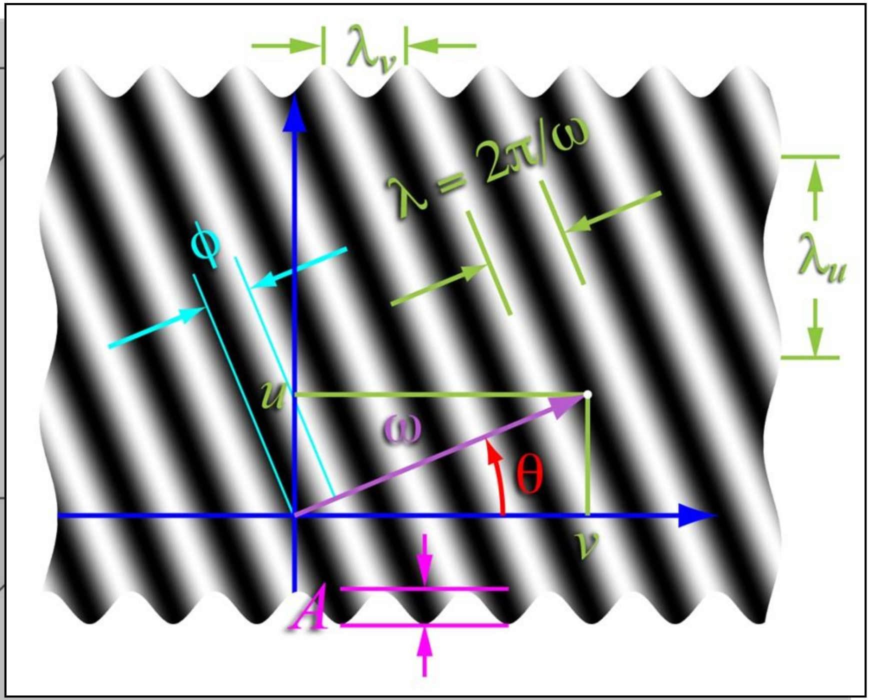
… is a complex number with a real part and an imaginary part.

If you represent that number as a magnitude, A, and a phase, ϕ, …

..these represent the amplitude and offset of **the** sinusoid with frequency ω and direction θ.

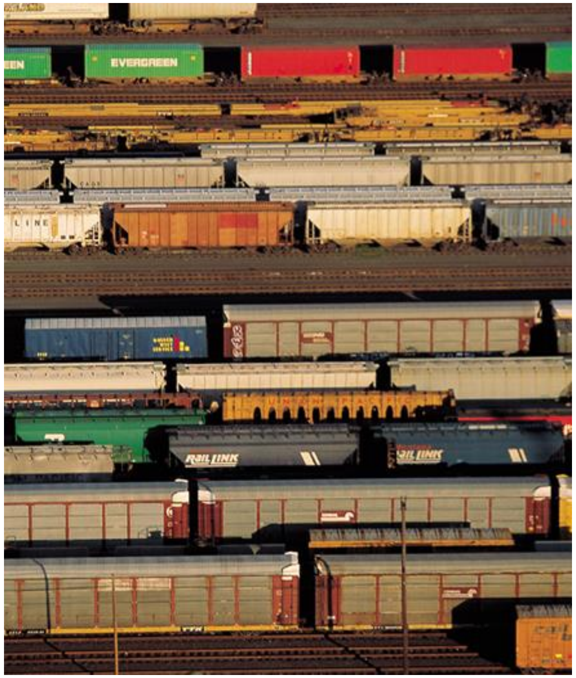
The Sinusoid from the Fourier Coeff. at (u,v)





Here is the same coefficient plotted as magnitude, A, and a phase, ϕ, and displayed in the space domain as a sinusoid.

The Fourier Transform of an Image

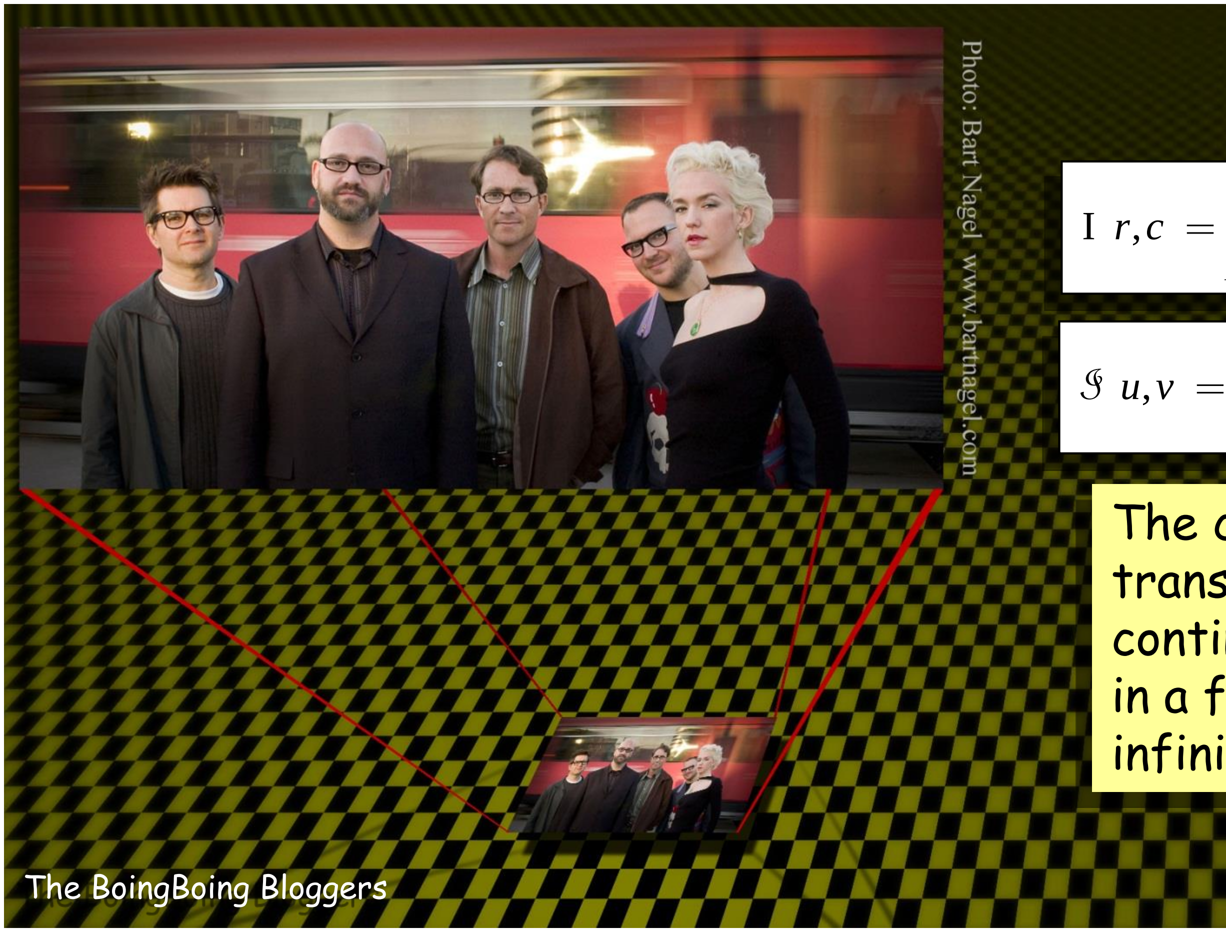


I

$|\mathfrak{F}\{I\}|$

$\angle[\mathfrak{F}\{I\}]$

Continuous Fourier Transform



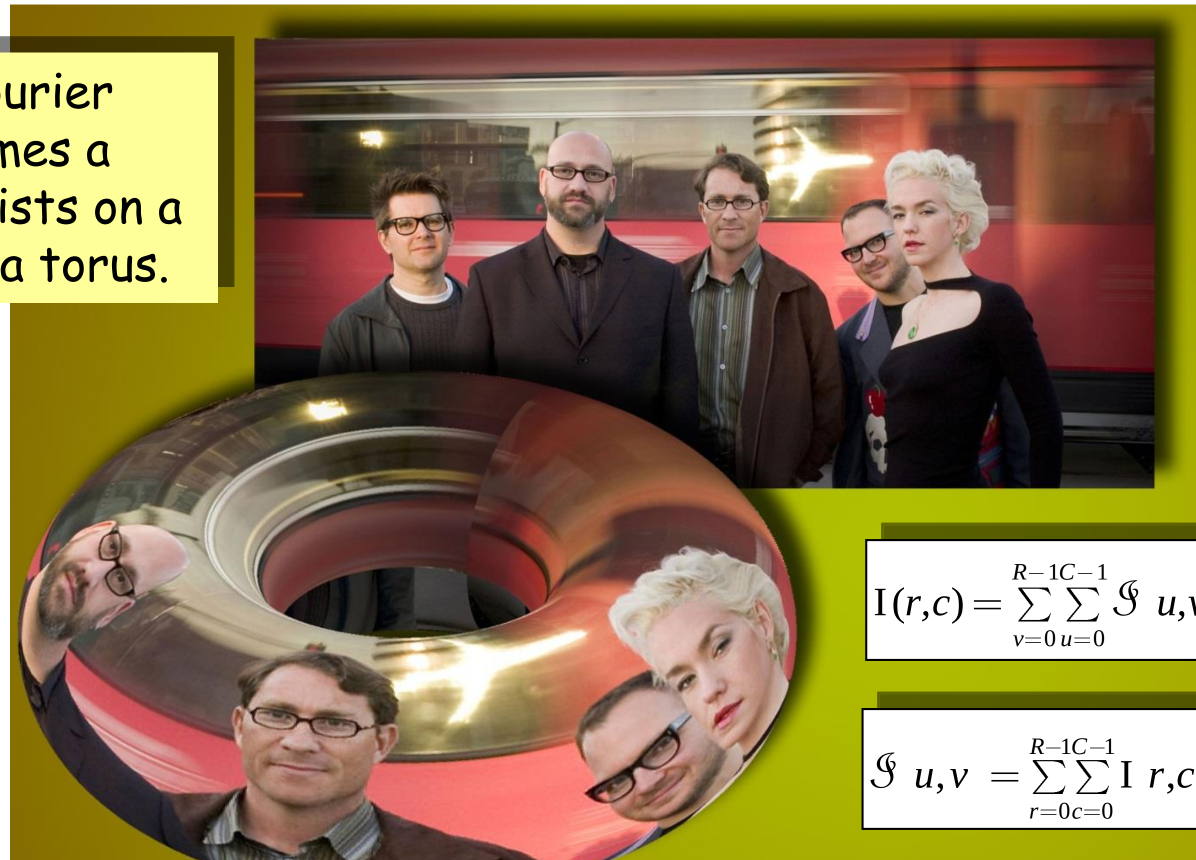
$$\mathrm{I}\ r,c = \int_{-\infty}^{\infty}\int_{-\infty}^{\infty} \Im\ u,v\ \ e^{+i2\pi(uc+vr)}\, du\, dv$$

$$\Im\ u,v = \int_{-\infty}^{\infty}\int_{-\infty}^{\infty} \mathrm{I}\ r,c\ \ e^{-i2\pi(uc+vr)}\, dc\, dr$$

The continuous Fourier transform assumes a continuous image exists in a finite region of an infinite plane.

Discrete Fourier Transform

The discrete Fourier transform assumes a digital image exists on a closed surface, a torus.



The BoingBoing Bloggers

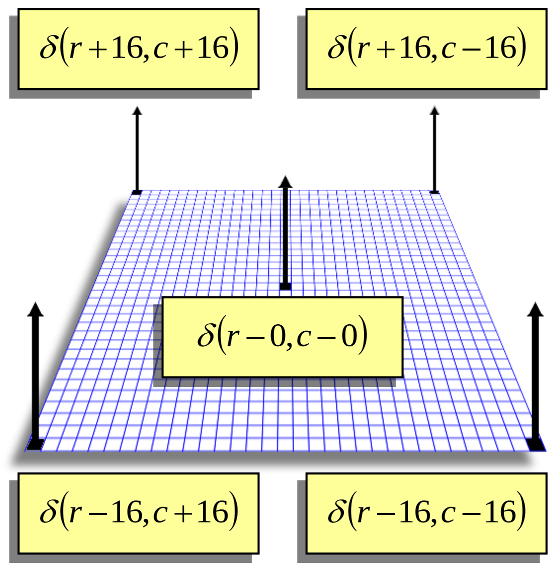
Photo: Bart Nagel www.bartnagel.com

$$\mathrm{I}(r,c)=\sum_{v=0}^{R-1}\sum_{u=0}^{C-1}\mathfrak{I}(u,v)\,e^{+i2\pi\left(\frac{uc}{C}+\frac{vr}{R}\right)}$$

$$\mathfrak{I}(u,v)=\sum_{r=0}^{R-1}\sum_{c=0}^{C-1}\mathrm{I}(r,c)\,e^{-i2\pi\left(\frac{cu}{C}+\frac{rv}{R}\right)}$$

Convolution

Sums of shifted and weighted copies of images or Fourier transforms.



Sum times 1/5

Convolution Property of the Fourier Transform

Let functions $f(r,c)$ and $g(r,c)$ have Fourier Transforms $F(u,v)$ and $G(u,v)$.

Then,

$$\mathfrak{F}\{f * g\} = F \cdot G.$$

Moreover,

$$\mathfrak{F}\{f \cdot g\} = F * G.$$

$*$ represents convolution

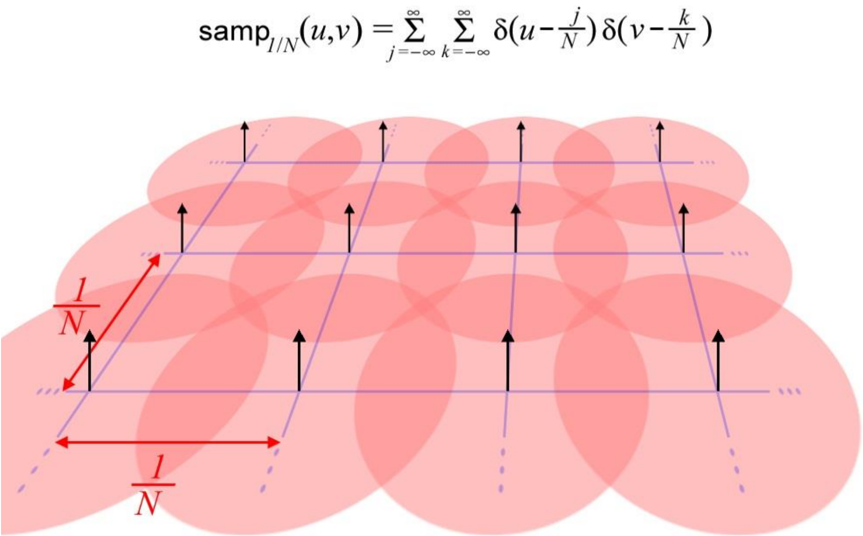
$\cdot$ represents pointwise multiplication

Then, a spatial convolution can be computed by

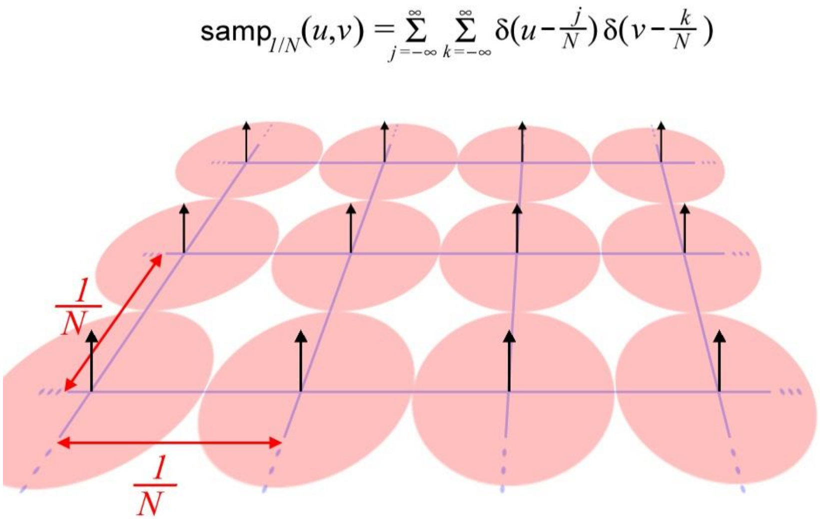
$$f * g = \mathfrak{F}^{-1}\{F \cdot G\}.$$

The Fourier Transform of a product equals the convolution of the Fourier Transforms. Similarly, the Fourier Transform of a convolution is the product of the Fourier Transforms

Sampling, Aliasing, & Frequency Convolution

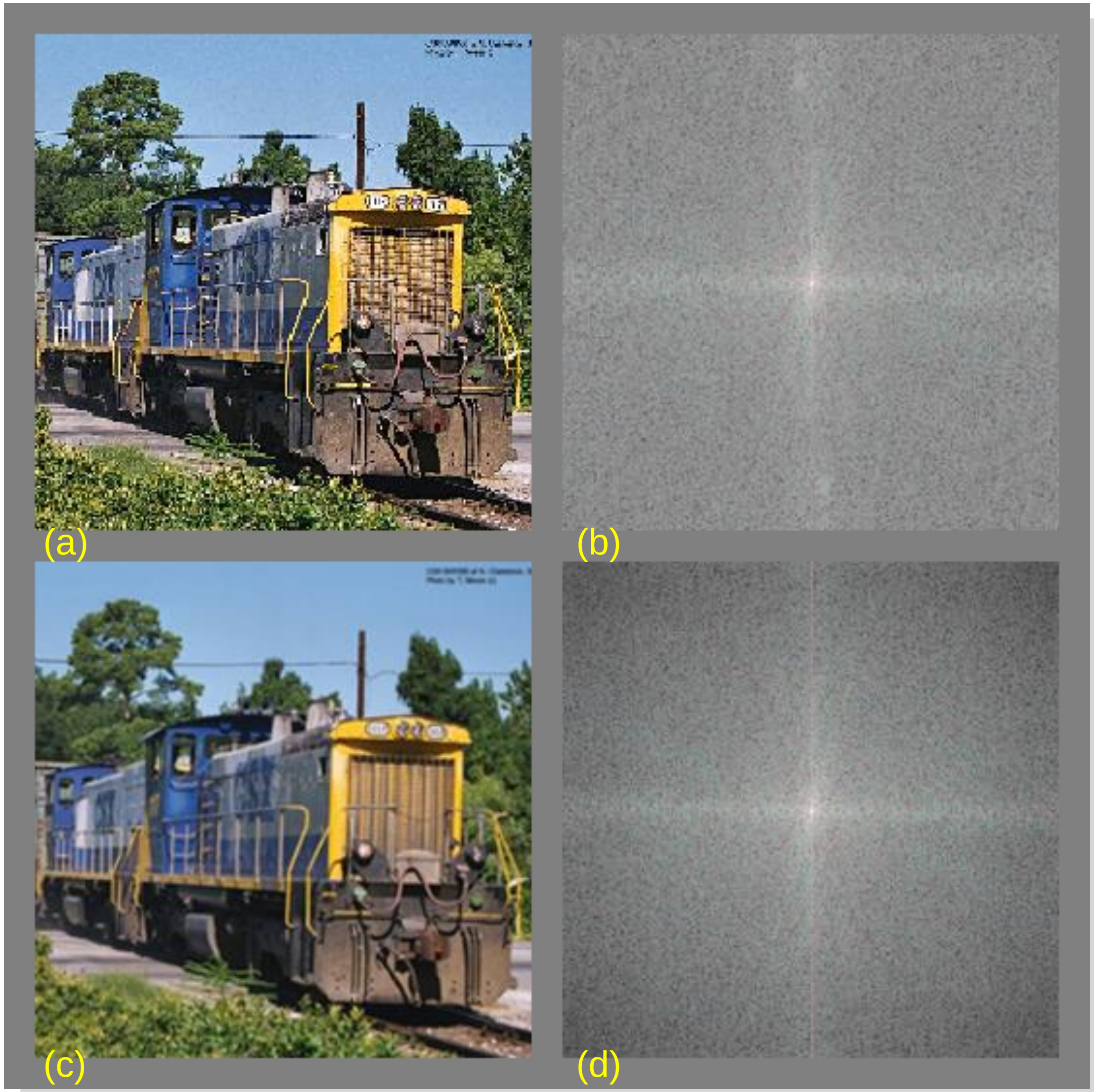


aliasing (the jaggies)



no aliasing (smooth lines)

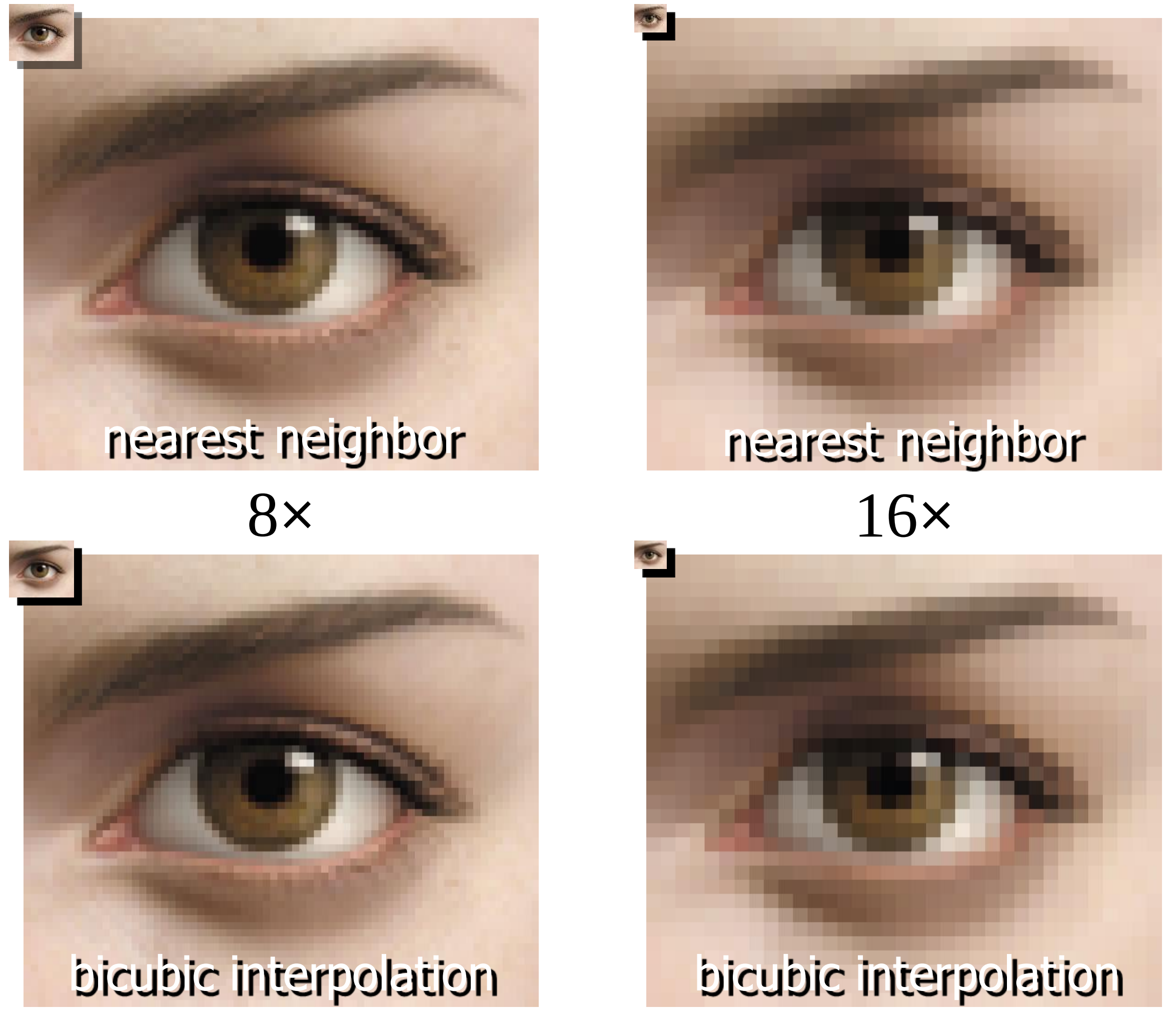
Sampling, Aliasing, & Frequency Convolution



(a) aliased
(b) power spectrum
(c) unaliased
(d) power spectrum

Resampling

(resizing)



Rotation

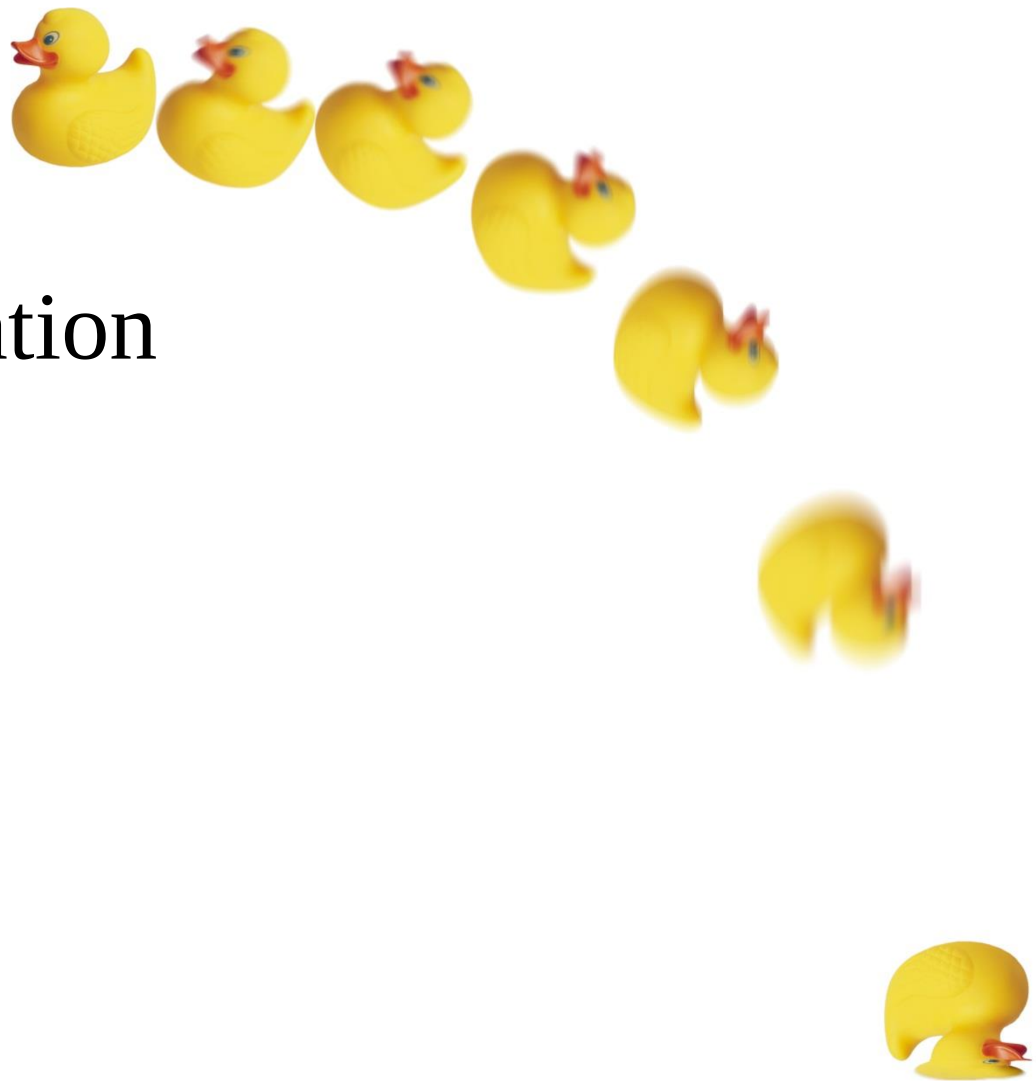


Image Warping

Panorama via Overlay

Originals

Merged*

Bruno Postle http://hugin.sourceforge.net/tutorials/two-photos/en.shtml

*not so good.

Panorama via Stitching

Originals

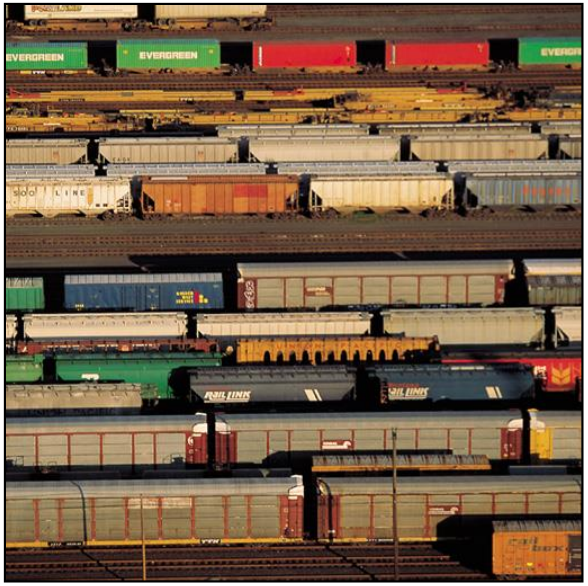
Merged*

Bruno Postle http://hugin.sourceforge.net/tutorials/two-photos/en.shtml

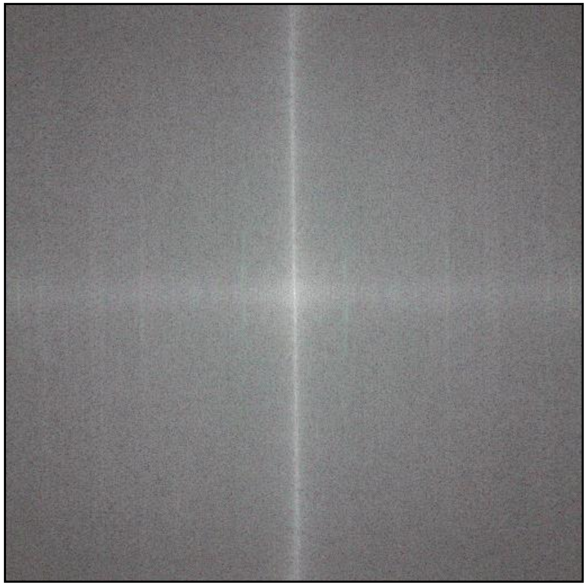
*much better.

Frequency Domain (FD) Filtering

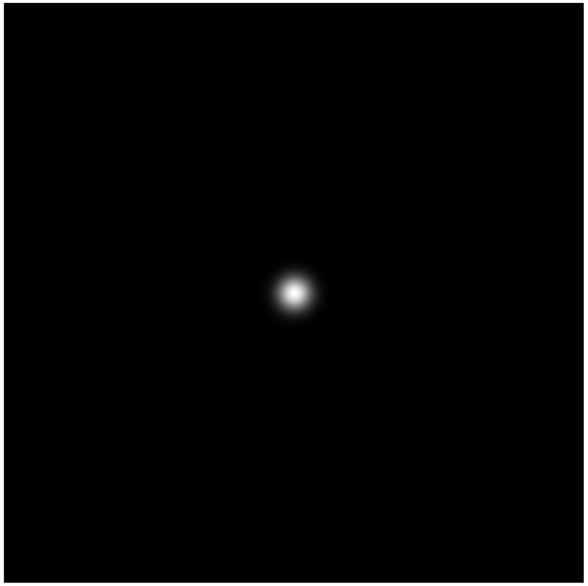
Image size: 512x512
SD filter sigma = 8



Original Image



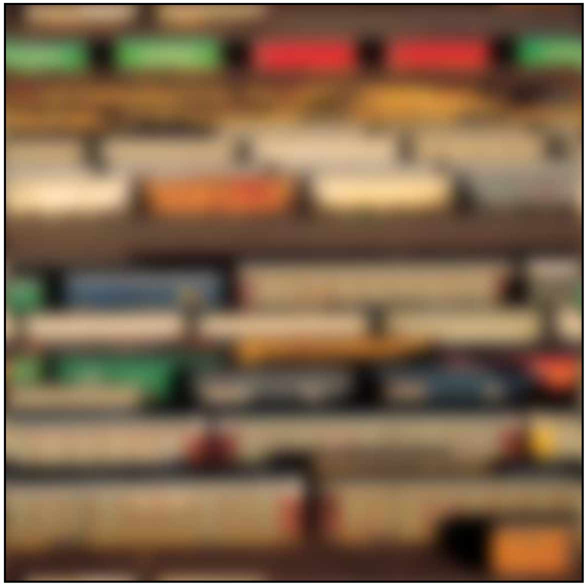
Power Spectrum

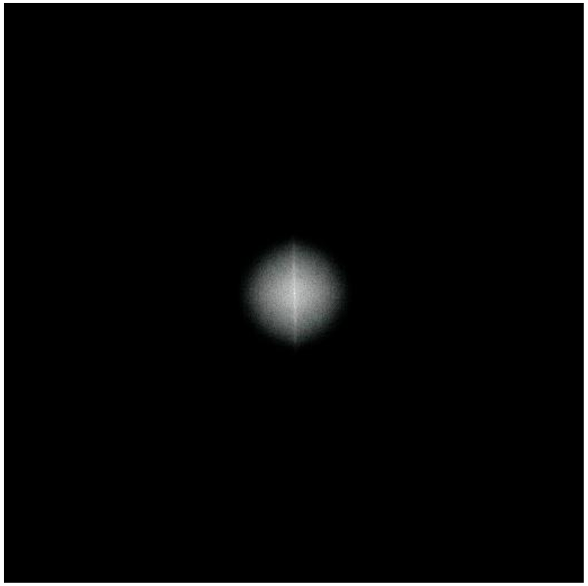


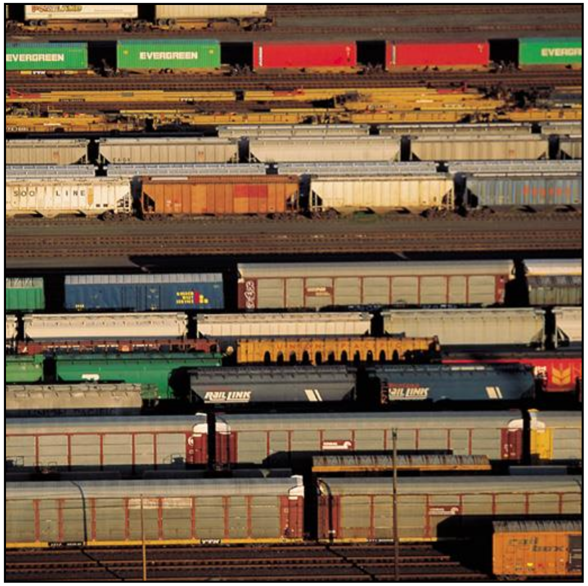
Gaussian LPF in FD

FD Filtering: Lowpass

Image size: 512x512
SD filter sigma = 8







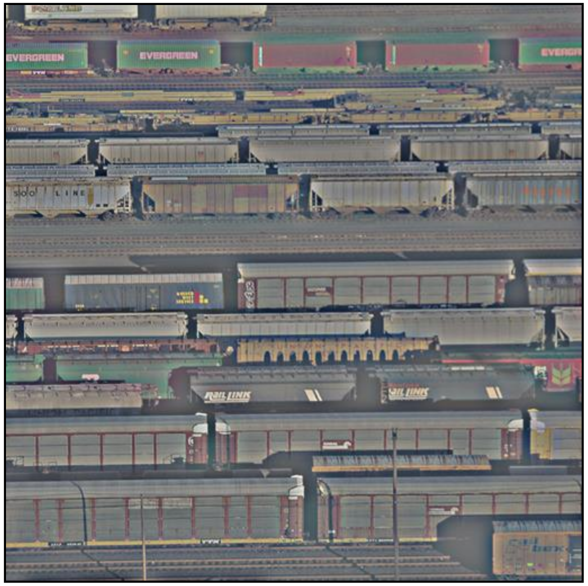
Filtered Image

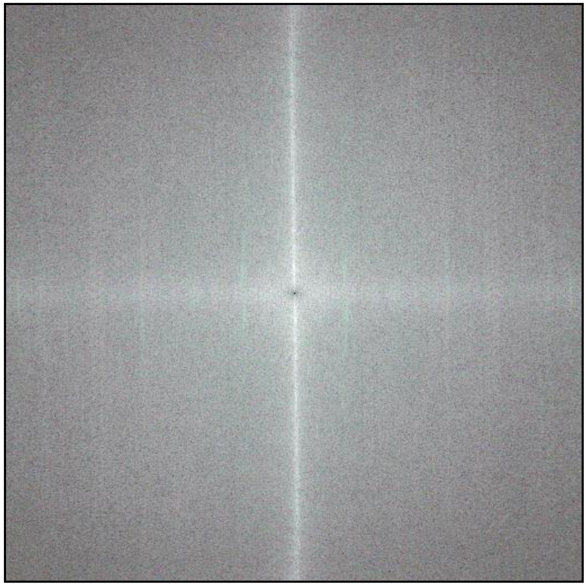
Filtered Power Spectrum

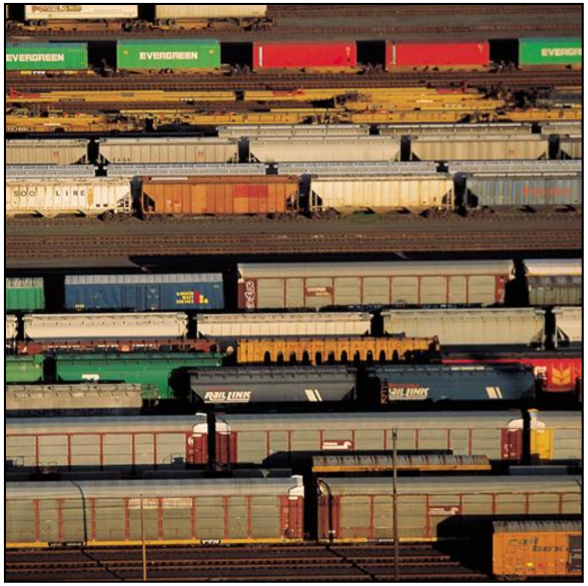
Original Image

FD Filtering: Highpass

Image size: 512x512
FD notch sigma = 8







Filtered Image

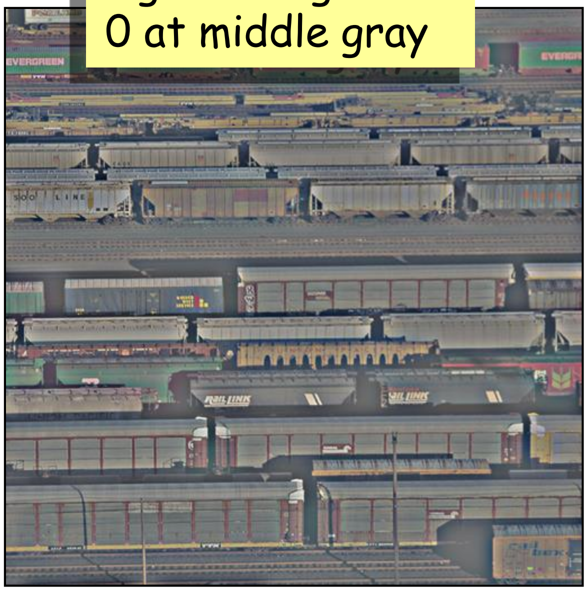
Filtered Power Spectrum

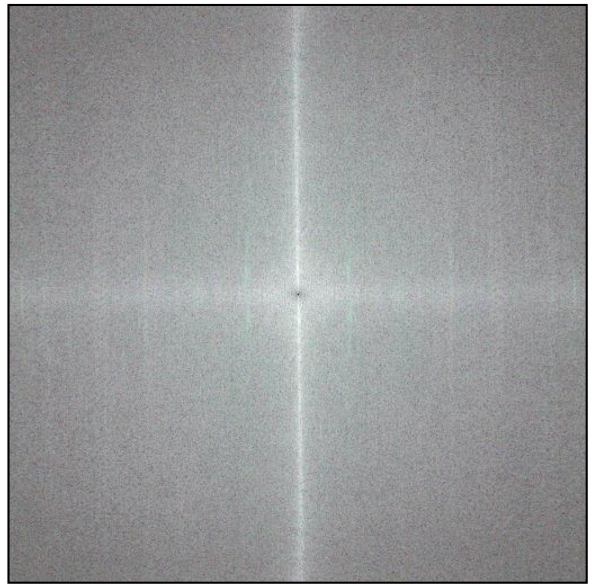
Original Image

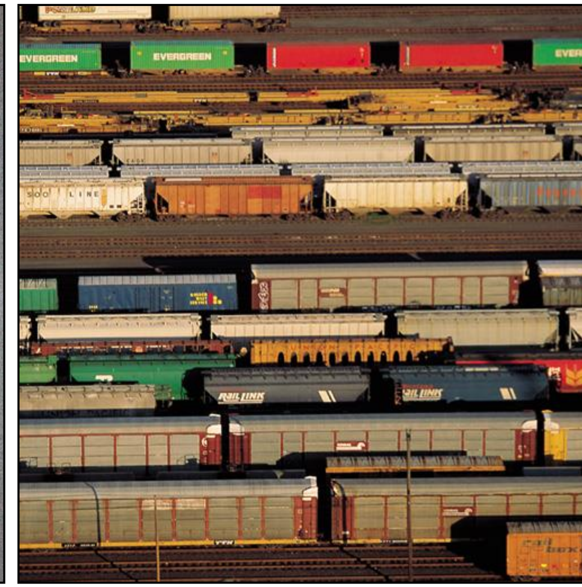
FD Filtering: Highpass

Image size: 512x512
FD notch sigma = 8

signed image with
0 at middle gray







Filtered Image

Filtered Power Spectrum

Original Image

Spatial Filtering

blurred

original

sharpened

Spatial Filtering

bandpass filter

original

unsharp masking

Spatial Filtering

signed image with
0 at middle gray

bandpass filter

original

unsharp masking

Motion Blur

regional

vertical

original

zoom

rotational

Noise Reduction

blurred image

color noise

color-only blur

Noise Reduction

blurred image

color noise

5x5 Wiener filter

Noise Reduction

periodic noise

original

frequency tuned filter

Shot Noise or Salt & Pepper Noise

+ shot noise

s&p noise

- shot noise

Nonlinear Filters: the Median

original

s&p noise

median filter

Nonlinear Filters: Min and Maxmin


+ shot noise


min filter


maxmin filter

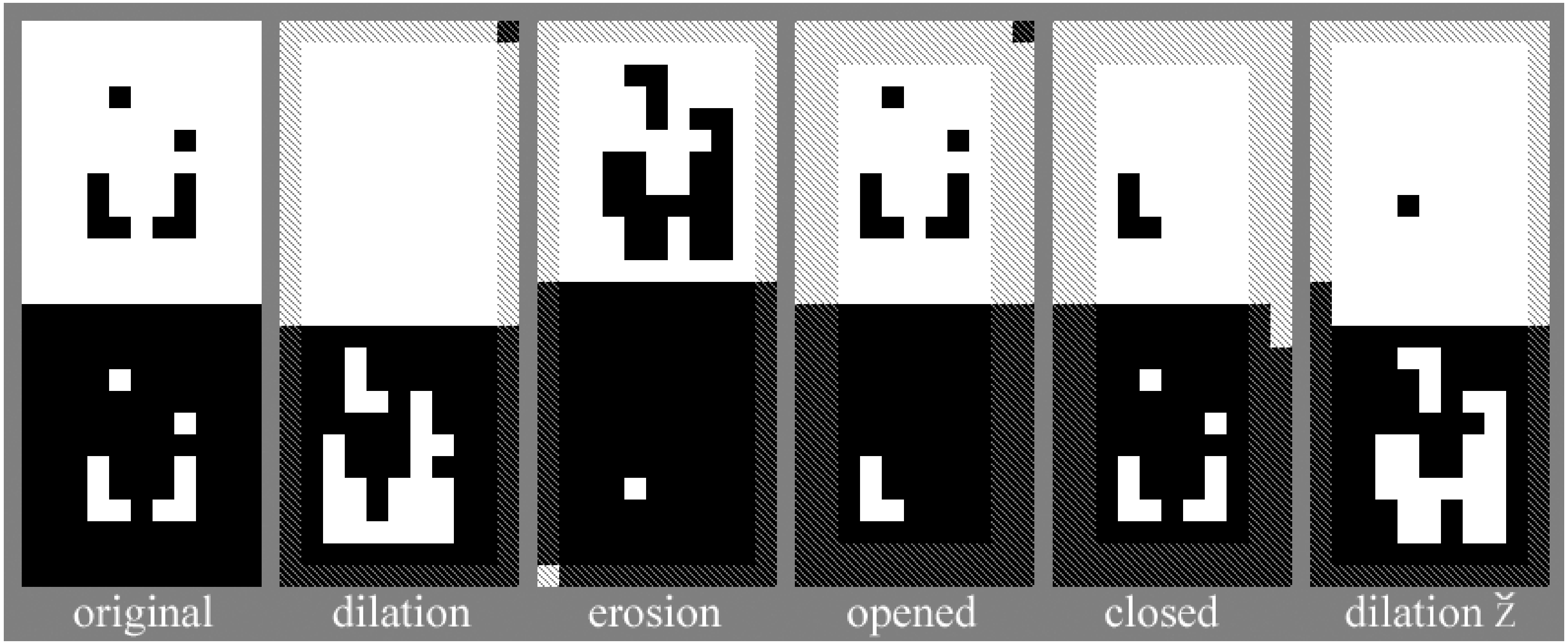
Nonlinear Filters: Max and Minmax

- shot noise

max filter

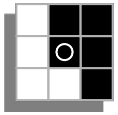
minmax

Nonlinear Processing: Binary Morphology



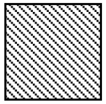
“L” shaped SE

O marks origin



Foreground: white pixels

Background: black pixels



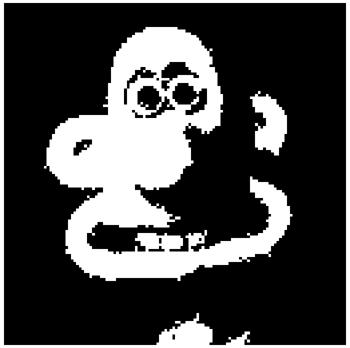
Cross-hatched pixels are indeterminate.

Nonlinear Processing: Binary Reconstruction

- Used after opening to *grow back* pieces of the original image that are connected to the opening.
- Permits the removal of small regions that are disjoint from larger objects without distorting the small features of the large objects.

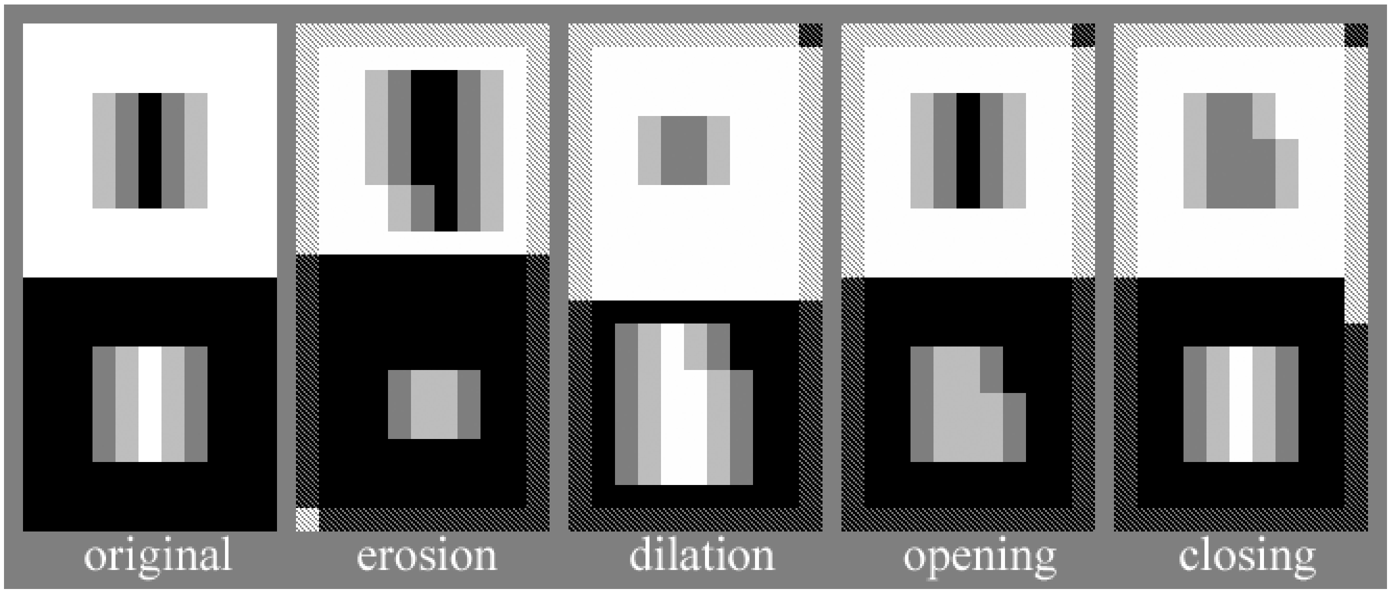
original

opened



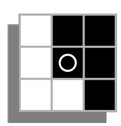
reconstructed

Nonlinear Processing: Grayscale Morphology



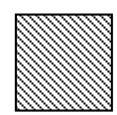
"L" shaped SE

O marks origin



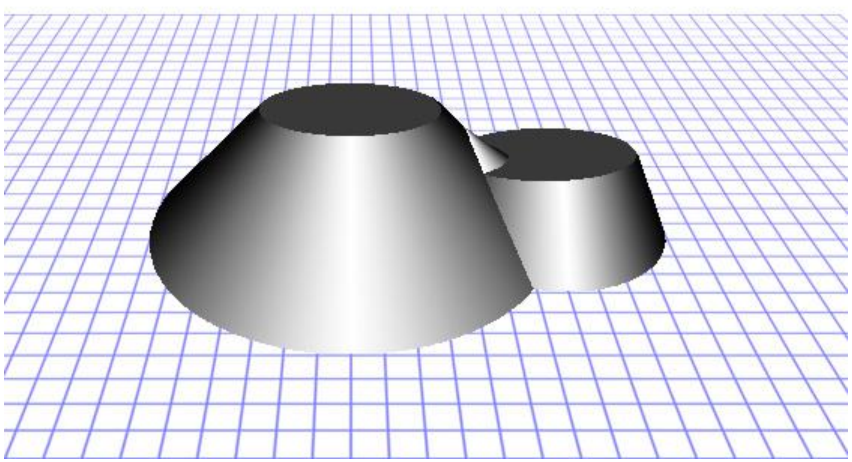
Foreground: white pixels

Background: black pixels

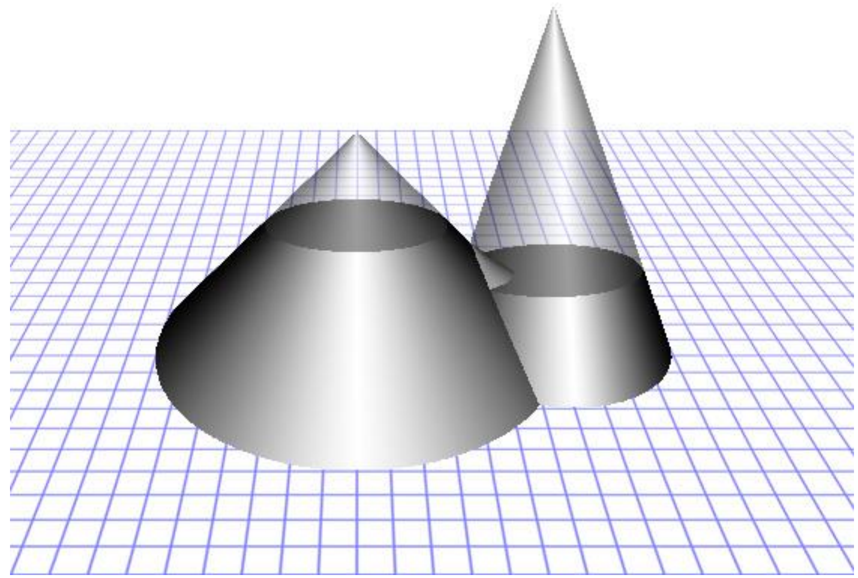


Cross-hatched pixels are indeterminate.

Grayscale Morphology: Opening

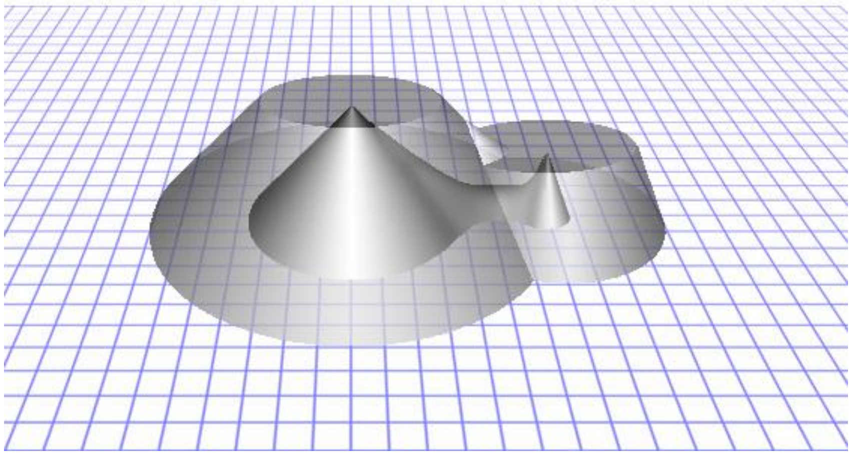


opening: erosion then dilation

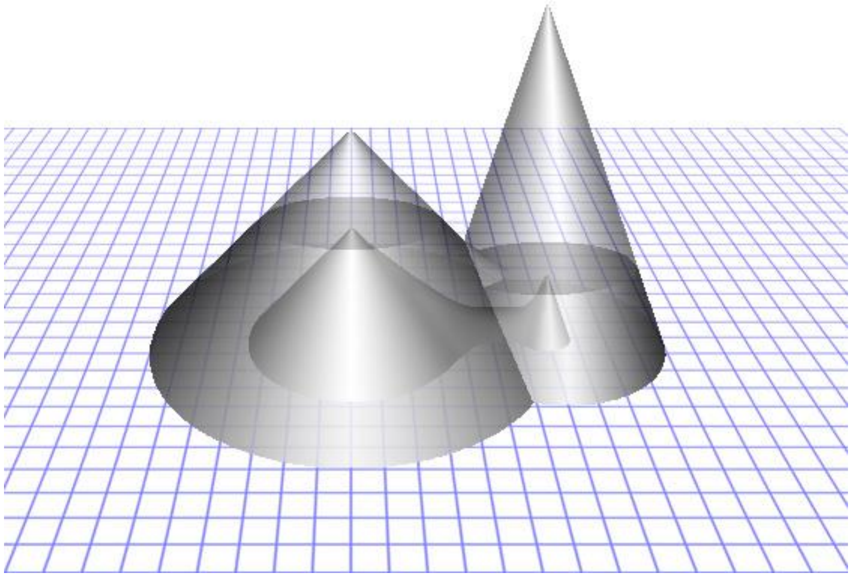


opened & original

Grayscale Morphology: Opening



erosion & opening



erosion & opening & original

Nonlinear Processing: Grayscale Reconstruction

Forensic Analysis of Photographs

Which came first?

Photo Restoration by Dennis Purcell

Photo Restoration by Dennis Purcell

Photographs by Robert Fenton of a battlefield in the Crimean war taken on 23 April 1855. From Morris, Errol, “Which Came First, the Chicken or the Egg?”, Parts 1-3, *New York Times*, *Zoom Editorial Section*, 25 Sept. 2007 (pt.1), 7 Oct. 2007 (pt.2), 30 Oct. 2007 (pt.3).

Forensic Analysis of Photographs

Photo Restoration by Dennis Purcell

Photographs by Robert Fenton of a battlefield in the Crimean war taken on 23 April 1855. From Morris, Errol, "Which Came First, the Chicken or the Egg?", Parts 1-3, *New York Times, Zoom Editorial Section,* 25 Sept. 2007 (pt.1), 7 Oct. 2007 (pt.2), 30 Oct. 2007 (pt.3).

Forensic Analysis of Photographs

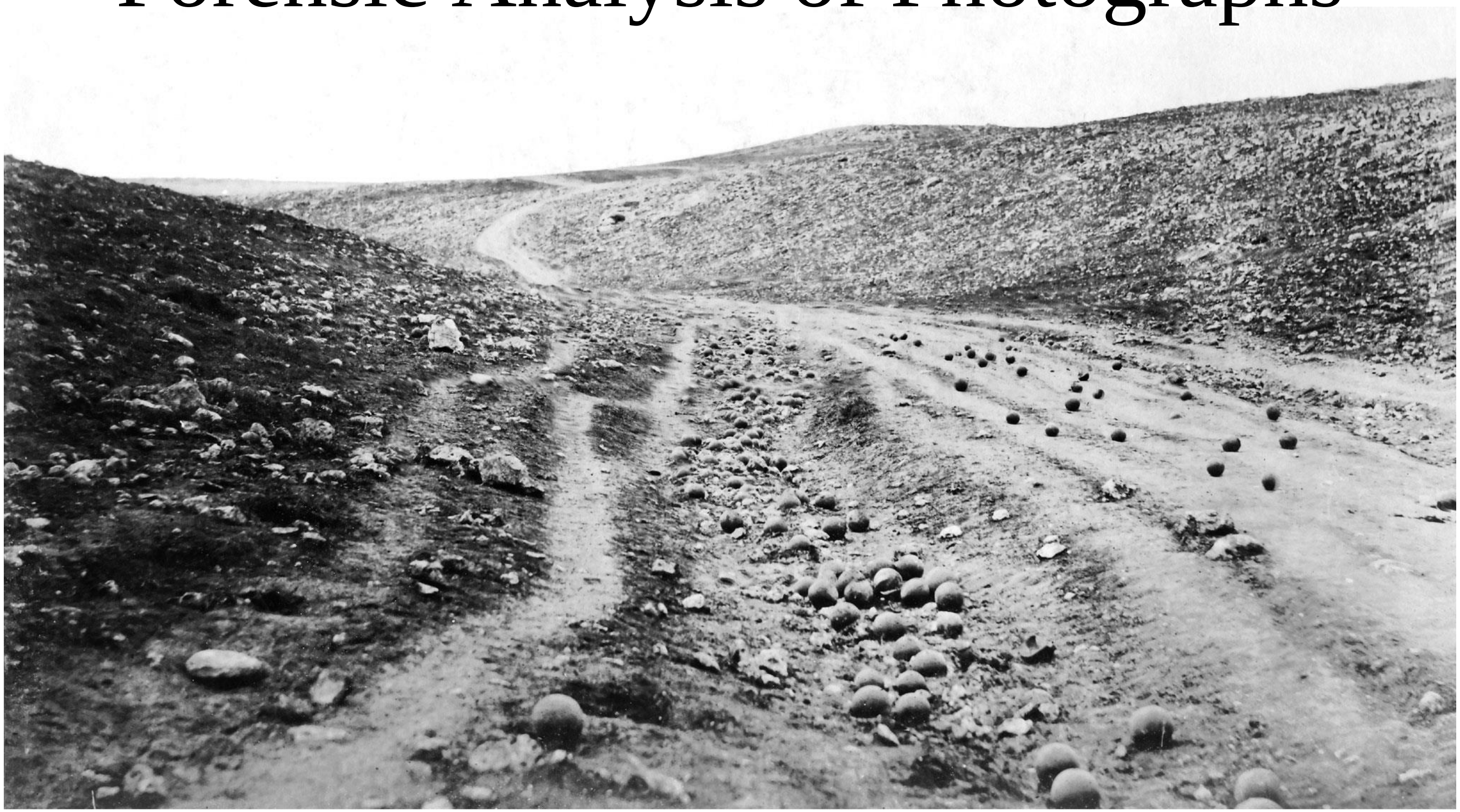


Photo Restoration by Dennis Purcell

Photographs by Robert Fenton of a battlefield in the Crimean war taken on 23 April 1855. From Morris, Errol, “Which Came First, the Chicken or the Egg?”, Parts 1-3, *New York Times, Zoom Editorial Section,* 25 Sept. 2007 (pt.1), 7 Oct. 2007 (pt.2), 30 Oct. 2007 (pt.3).

High Dynamic Range (HDR) Imaging

Bartlomiej Okonek http://www.easyhdr.com/examples.php

under exposed

High Dynamic Range (HDR) Imaging

default exposure

Bartlomiej Okonek http://www.easyhdr.com/examples.php

High Dynamic Range (HDR) Imaging

Bartlomiej Okonek http://www.easyhdr.com/examples.php

over exposed

High Dynamic Range (HDR) Imaging

combined

Bartlomiej Okonek http://www.easyhdr.com/examples.php

Image Compression

Original image is
5244w x 4716h
@ 1200 ppi:
127MBytes

Yoyogi Park, Tokyo, October 1999. Photo by Alan Peters.

Image Compression: JPEG

JPEG quality level

File size in bytes

Image Compression: JPEG

JPEG quality level

No Compr. 197kB

JPEGQ: 12 76kB

JPEGQ: 6 21kB

JPGEQ: 0 12kB

File size in bytes

Image Compositing

- Combine parts from separate images to form a new image.
- It's difficult to do well.
- Requires relative positions, orientations, and scales to be correct.
- Lighting of objects must be consistent within the separate images.
- Brightness, contrast, color balance, and saturation must match.
- Noise color, amplitude, and patterns must be seamless.

Image Compositing Example

Prof. Peters in his home office. Needs a better shirt.

Image Compositing Example

This shirt demands a monogram.

Image Compositing Example

He needs some more color.

Image Compositing Example

Nice. Now for the way he'd wear his hair if he had any.

Image Compositing Example

He can't stay in the office like this.

Image Compositing Example

Where's a hepcat Daddy-O like this belong?

Image Compositing Example

In the studio!