JPAC（2013.5.13）

Principles of Digital Imaging

Sampling and Quantization of Digital Image

Graduate School of Advanced Integration Science

Division of Information Sciences

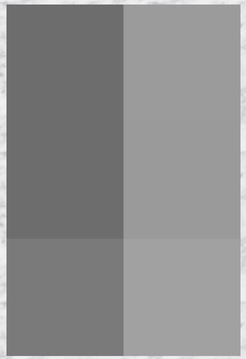
Prof. Hirohisa Yaguchi

yaguchi@faculty.chiba-u.jp

Contents

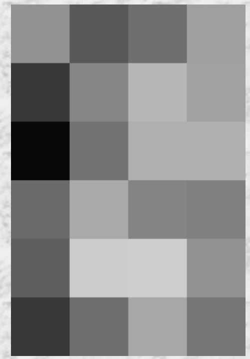
Sampling

2x3=6 (6 pixels) 8 bits/pixel=1 byte/pixel

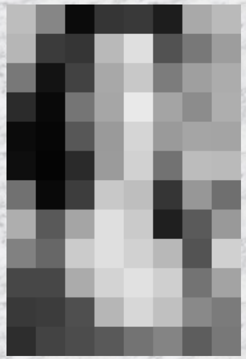


Sampling

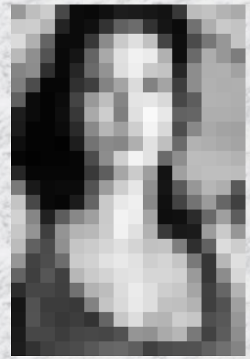
4x6=24 (24 B)



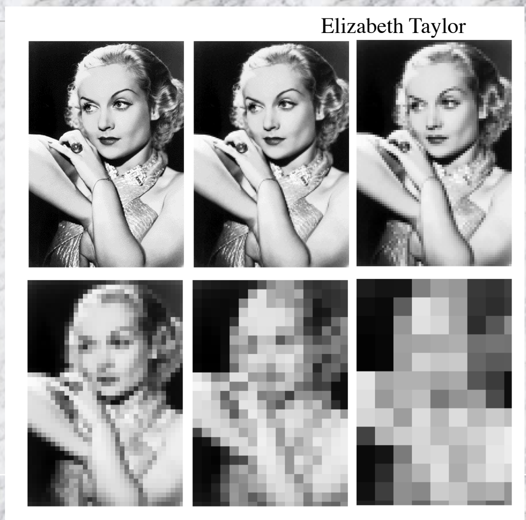
Sampling
8 x 12 = 98B



Sampling
16 x 24 = 384B

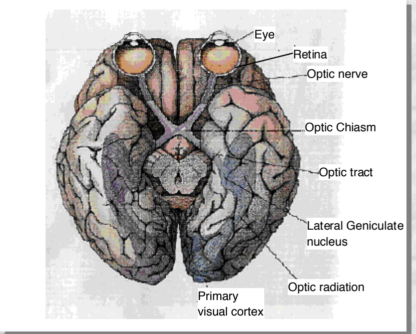


Sampling of Image



Quantization of Image

Human visual information processing



- Eye balls: Camera
- Retina：High intelligent input device
  - High sensitive sensor (rods and cones)
  - Luminance channel and chromatic channel (horizontal cells)
  - Contrast (ganglion cells)
- LGN：M-path (where),P-path (what)
  - Shape, motion, color, detail
- Visual cortex

Retina of a living human eye (1)

(David Williams, in *Optics & Photonics News*, vol.9, no.1, 1998)

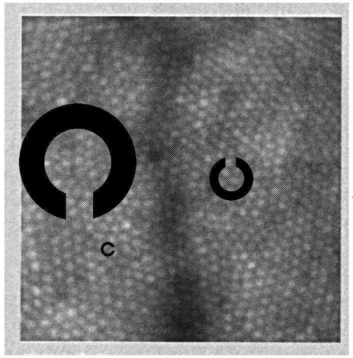
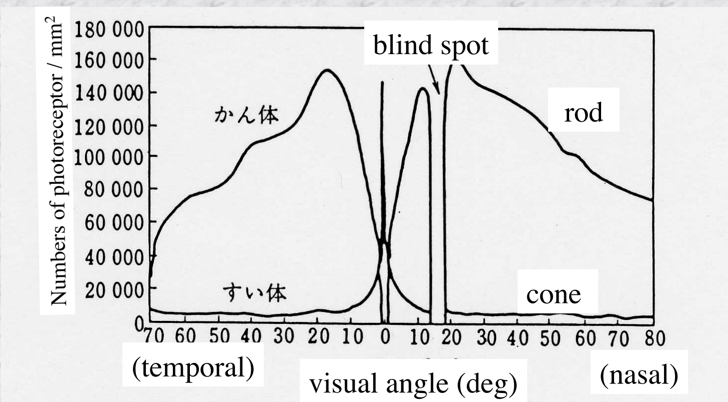


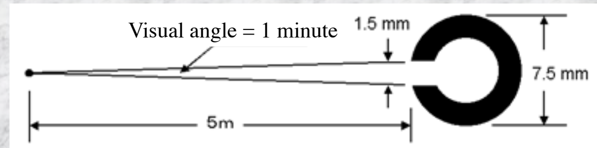
Figure 8. The retina of a living human eye taken after adaptive optical correction of the eye's optical system. The image, taken with 550 nm light, is a registered sum of 61 images taken over four days. Image size is 0.5 X 0.5 degrees (146 X 146 µm). The bright spots in the image are cone photoreceptors, each on the order of 5 µm. The darker vertical band down the center of the image is a shadow of a capillary that when focused on, is about 5 µm in diameter. The retinal location of the image is about 1° from the central fovea. The only filtering used was histogram equalization to enhance contrast.

900 cones/0.021mm^2 = 42,800 cones/mm^2

Density of rods and cones in a retina

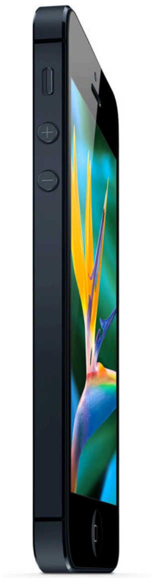


Spatial resolution of visual system



Visual acuity = $1/\theta$

θ(min): the smallest visual angle discriminatable



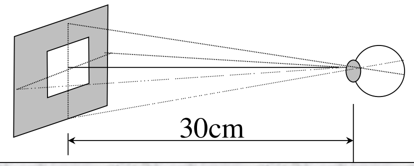
4-inch Retina display.
It's not just bigger. It's just right.

More display means more to see.
Anyone can make a larger smartphone display. But if you go large for large's sake, you end up with a phone that feels oversize, awkward, and hard to use. iPhone 5 features a 4-inch display designed the right way: it's bigger, but it's the same width as iPhone 4S. So everything you've always done with one hand — typing on the keyboard, for instance — you can still do with one hand. On a larger canvas that lets you see more of every web page. More of your inbox. More events on your calendar. Even more apps on your Home screen.

It's more vibrant, too.
This isn't just a larger display. It's a larger Retina display. At 326 pixels per inch, it has a pixel density so high your eye can't distinguish individual pixels. And as stunning as the Retina display is on the iPhone 4S, this one gives you 18 percent more pixels for an impressive 1136-by-640 resolution. Colors get a boost, too, with color saturation that's 44 percent greater than before. So with iPhone 5, the games you play, the words you read, the images you see, and the apps you love look and feel incredibly vivid and lifelike. For big-time entertainment, iPhone 5 lets you watch widescreen HD video in all its glory — without letterboxing.

iPhone 5 is nearly 9 millimeters taller than iPhone 4S, but it's the same width. So it's just as easy to type with one hand.

Relation between visual acuity and the number of pixels in image



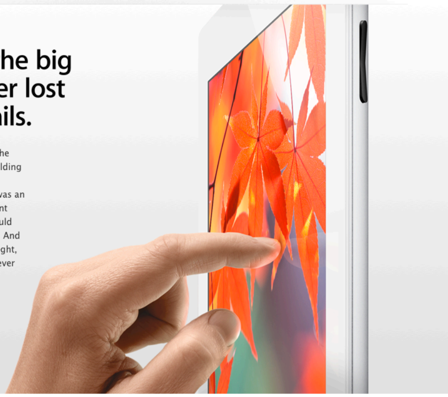
- Density of cones 120 cones/deg
- Observed from distance of 30 cm
  - 1 deg corresponds to 5.23mm
  - 23.5(=120/5.23) cones per mm
  - 23.5 dot/mm = 600 dpi (dot per inch)
  - L size (89x127) 17°x24.3° → 2,040x2,916 = 5.9Mpixels
  - A4 size (210x297) 40°x56.7° → 4,812x6,804 = 32.7 Mpixels
  - iPhone(74x50) 14°x9.5° → 1,680x1,140=1.9 Mpixels

iPhone 5: 1,136 x 640 (326ppi)
The new iPad: 2,048 x 1,536 (264ppi)
iPad mini: 1,024 x 768 (163 ppi)
MacBook Pro 13': 2,560 x 1,600 (227 ppi)

iPad   Why iPad   Features   Design   Built-in Apps   App Store   iOS   iCloud   Tech Specs   Buy Now

We focused on the big picture, but never lost sight of the details.

The most important feature on any iPad is the screen. So that's where we started — by building the breakthrough Retina display with over 3 million pixels. To create a display like this was an engineering feat in its own right. But we went even further. We designed a camera that could take images as brilliant as the display itself. And we enclosed iPad in a unibody so thin and light, you can take all those pixels with you wherever you go. And they travel beautifully.



It's breakthrough technology. For a breakthrough display.

In order to create a display with a 2048-by-1536-pixel resolution, we had to design it in a completely new way. Every pixel in a display has multiple signals telling it when to light up. But when you have a lot of pixels and a lot of signals on the same plane, signals get crossed and image quality suffers. To make sure everything on iPad looks crystal clear, Apple engineers elevated the pixels onto a different plane — separating them from the signals. It's technology that's breakthrough. Just like iPad itself.

3.1M
pixels

264
pixels per inch

1M
more pixels than an HDTV

Retina of a living human eye(2)

(Roorda and Williams, *Nature*, 397, 520-522, 1999)

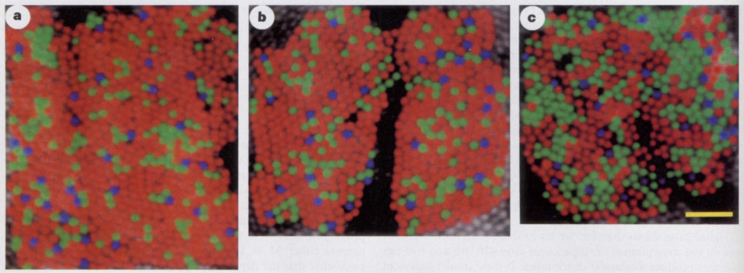
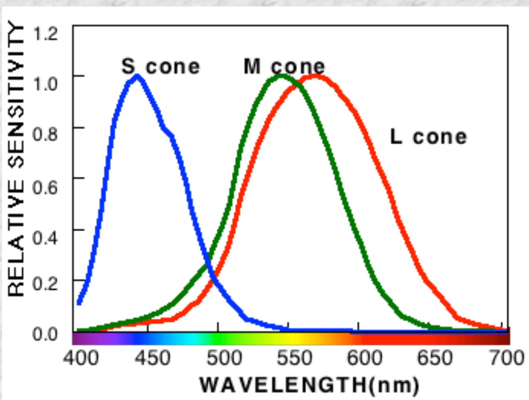
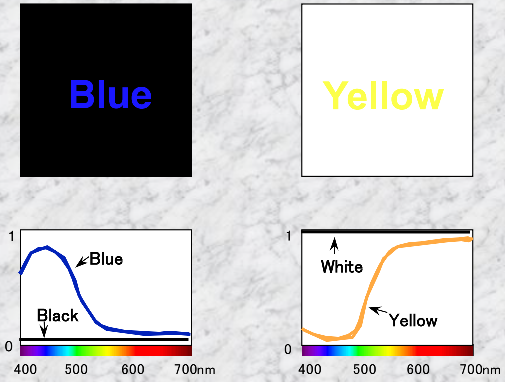


Figure 3 Pseudocolour image of the trichromatic cone mosaic. Blue, green and red colours represent the S, M and L cones, respectively. **a, b,** Subject JW's temporal and nasal retina, respectively, at one degree of eccentricity. **c,** Subject AN's nasal retina, at one degree of eccentricity. We performed a statistical test for randomness according to Diggle[27]. We compared the distribution of all intercone distances of the measured M-cone array with 100 simulations derived from the same mosaic in which the same number of M cones were randomly assigned. JW's array was no different from random at either location. AN's array showed significant clumping of the data ($P < 0.01$) but, because of optical blur, the possibility of a random assignment of M cones cannot be ruled out. Scale bar represents 5 arcmin of visual angle.

Photoreceptors (Cones)



Blue and Yellow



Effects of Gaussian Blur in RGB

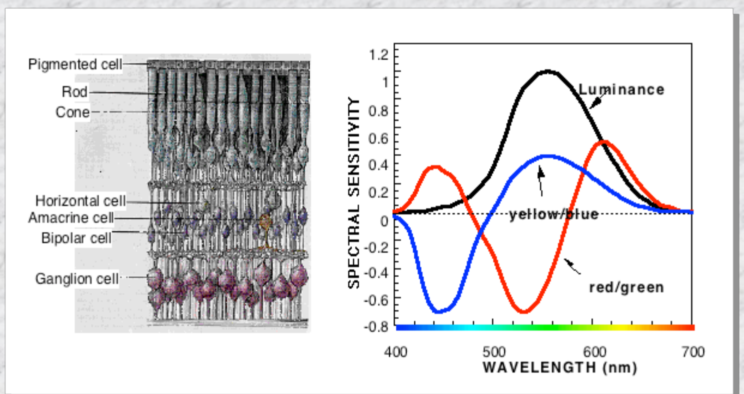
original

Red image blurred

Green image blurred

Blue image blurred

Opponent-color Stage (Luminance and Color)



Electrophysiological response from carp's cones

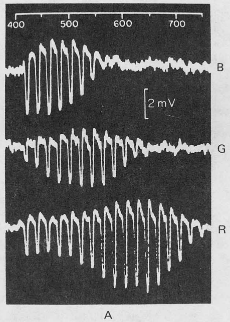


FIGURE 7.6 A: Sample recordings from single cones of the carp retina, for the three types of cones that were found. (Continued on page 222.)

Electrophysiological response from carp's horizontal cells

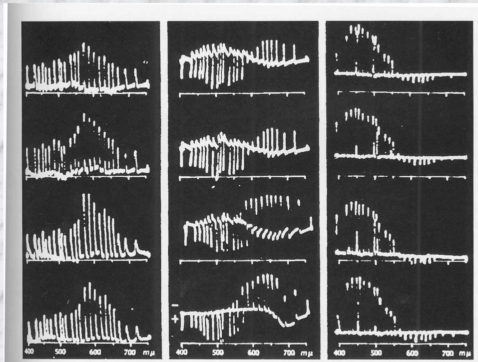
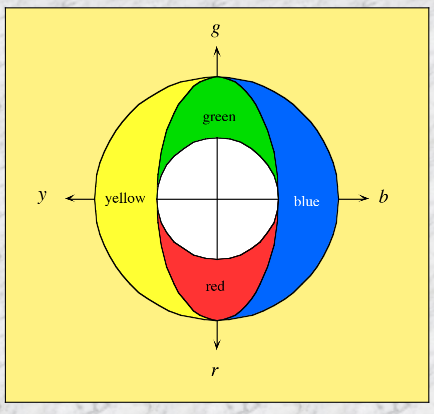
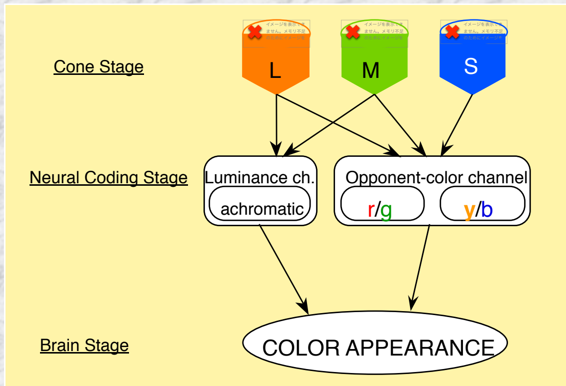


Figure 7.5 Sample recordings from horizontal cells of carp retina. The left column shows data analogous to an spectrally nonopponent, achromatic signal. The middle column represents a spectrally opponent red-green signal and the right column represents a blue-yellow signal. (From Svaetichin, 1956).

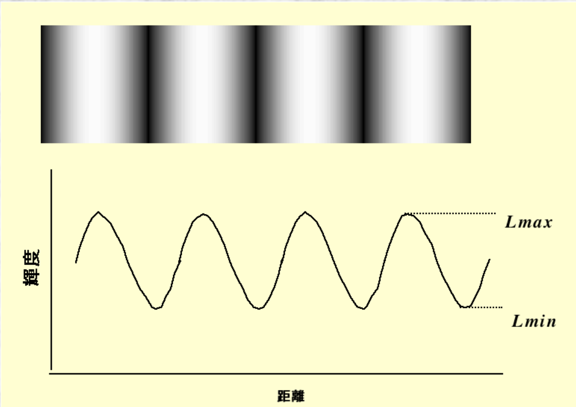
Hering's Color Circle



Human Color Vision Model



Spatial contrast sensitivity function

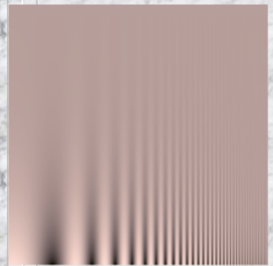


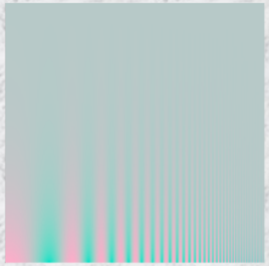
$$C = \frac{L_{max} - L_{min}}{L_{max} + L_{min}}$$

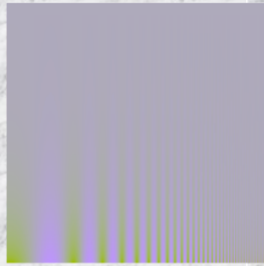
Contrast sensitivity functions

Achromatic, luminance ch.

Chromatic, opponent color ch.





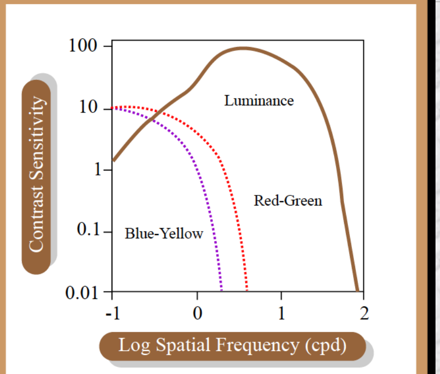


black/white

red/green

yellow/blue

Contrast sensitivity functions for luminance channel and chromatic channel



Spatial contrast sensitivity functions for luminance and chromatic contrast.

Image adapted from:
Mark D. Fairchild. *Color Appearance Models*. Prentice Hall PTR, November 1997. ASIN: 0201634643

Effects of Blur in Luminance and Opponent-color channel

original

Blurred luminance image

Blurred a*(r/g) image

Blurred b*(y/b) image