



Principles of Digital Imaging

Sampling and Quantization of Digital Image

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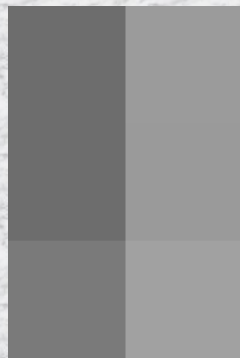
Contents

- Sampling of Image
- Quantization of Image
- Information Capacity of Image
- Sampling and Quantization by Human Visual System

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Sampling

$2 \times 3 = 6$ (6 pixels) 8 bits/pixel = 1 byte/pixel



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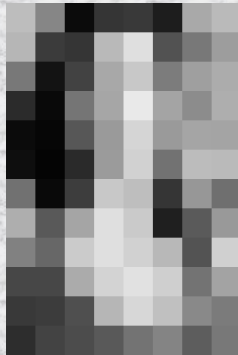
Sampling

$4 \times 6 = 24$ (24 B)



4

Sampling
 $8 \times 12 = 96B$



5

Sampling
 $16 \times 24 = 384B$



6

Sampling
 $32 \times 48 = 1,536B (1.5KB)$



7

Sampling
 $64 \times 96 = 6,144B (6KB)$



8

Sampling

$128 \times 192 = 24,576\text{B}(24\text{KB})$



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Original Image

$256 \times 384 = 98,304\text{B} (98\text{KB})$

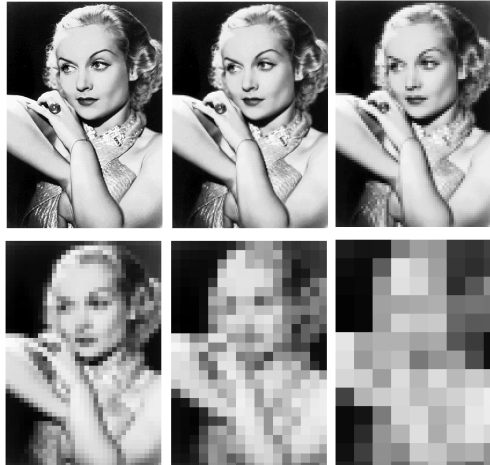


Angelina Jolie

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Sampling of Image

Elizabeth Taylor



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Original Image (98KB)

256 levels (8 b; bits = 1 B; byte) for each pixel
Total: $256 \times 384 = 98,304$ pixels



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Quantization (2 levels, 1 bit)



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Quantization (4 levels, 2 bits)



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Quantization (8 levels, 3 bits)



15

Quantization (16 levels, 4 bits)



16

Quantization (32 levels, 5 bits)



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Quantization (64 levels, 6 bits)



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Original Image (98KB)

256 levels (8 b; bits = 1 B; byte) for each pixel
Total: $256 \times 384 = 98,304$ pixels



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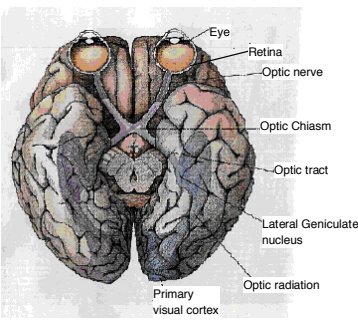
Quantization of Image

Elizabeth Taylor



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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

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Retina of a living human eye (1)

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

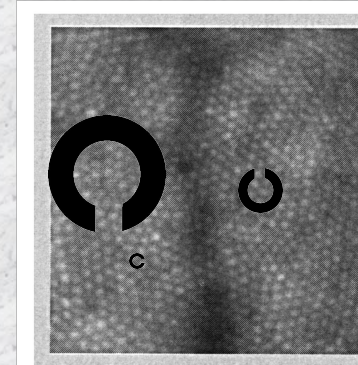
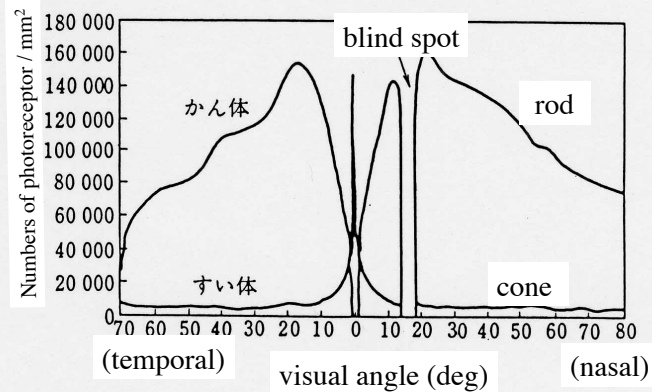


Figure 8. The retina of a living human eye taken after adaptive optical correction of the eye's optical system. The image, taken with 550 nm light, is a registered sum of 61 images taken over four days. Image size is 0.5 X 0.5 degrees (146 X 146 μm). The bright spots in the image are cone photoreceptors, 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.

$$900 \text{ cones} / 0.021 \text{ mm}^2 = 42,800 \text{ cones/mm}^2$$

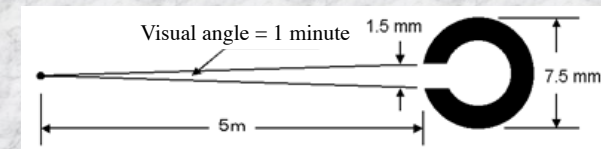
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Density of rods and cones in a retina



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Spatial resolution of visual system



$$\text{Visual acuity} = 1/\theta$$

$\theta(\text{min})$: the smallest visual angle discriminatable

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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.

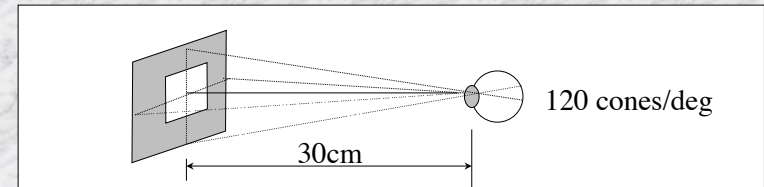
It's more vibrant, too.

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) $17^\circ \times 24.3^\circ \rightarrow 2,040 \times 2,916 = 5.9 \text{ Mpixels}$
 - A4 size (210x297) $40^\circ \times 56.7^\circ \rightarrow 4,812 \times 6,804 = 32.7 \text{ Mpixels}$
 - iPhone (74x50) $14^\circ \times 9.5^\circ \rightarrow 1,680 \times 1,140 = 1.9 \text{ Mpixels}$

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)

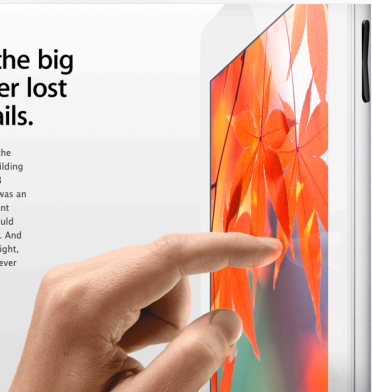
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iPad

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

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Retina of a living human eye(2)

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

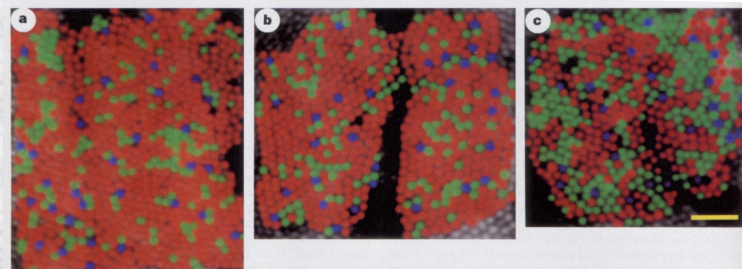
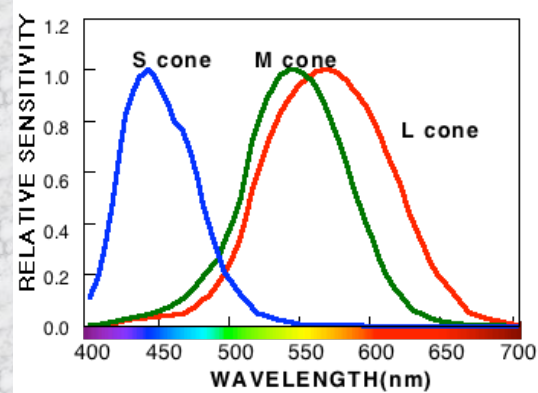


Figure 3 Pseudocolour image of the trichromatic cone mosaic. Blue, green and red colours represent the S, M and L cones, respectively. **a**, **b**, Subject JW's temporal and nasal retina, respectively, at one degree of eccentricity. **c**, Subject AN's nasal retina, at one degree of eccentricity. We performed a statistical test for randomness according to Diggle²⁷. 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.

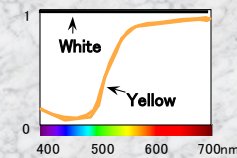
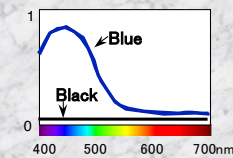
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Photoreceptors (Cones)



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Blue and Yellow



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Effects of Gaussian Blur in RGB

original



Red image blurred



Green image blurred



Blue image blurred

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