EECE 4353 Image Processing

Lecture Notes:
Pixelization, Quantization, and Steganography

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Pixelization

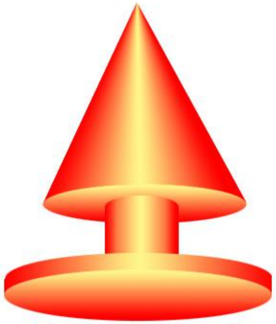
Pixelization …

… is a special effect often used to hide identities …

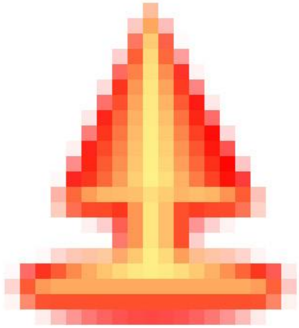
Pixelization

… or to "clean up" an image.

Pixelization and Quantization



high-res image



pixelated

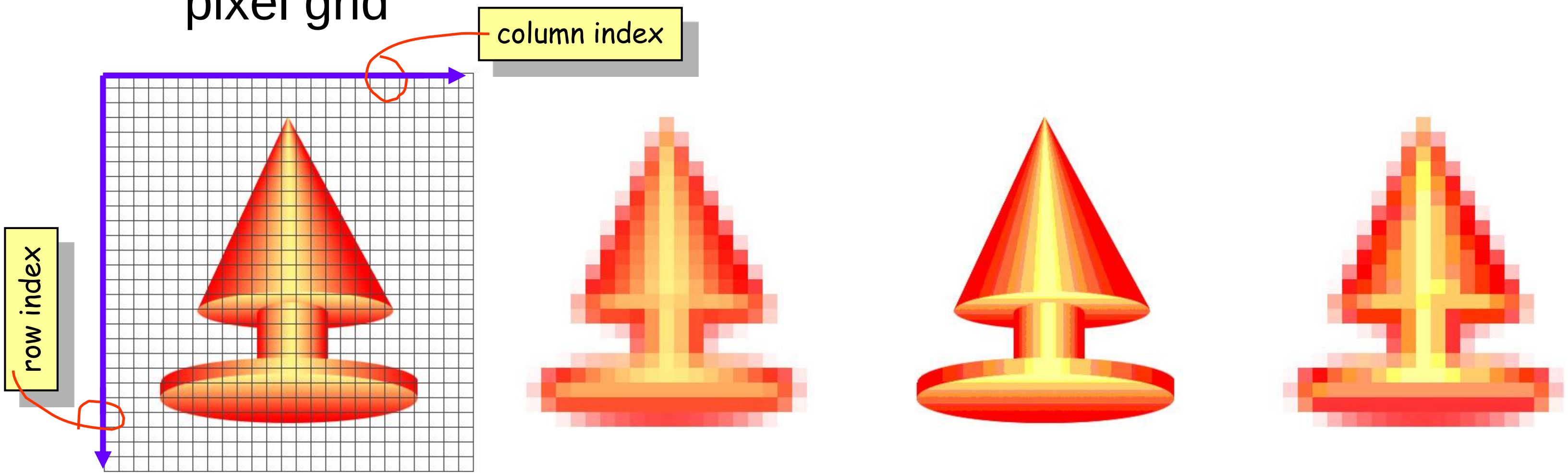
quantized

pixelated & quantized

This is what a digital camera does to the continuous tone image projected by its optics onto the sensor plane.

Pixelization and Quantization

pixel grid



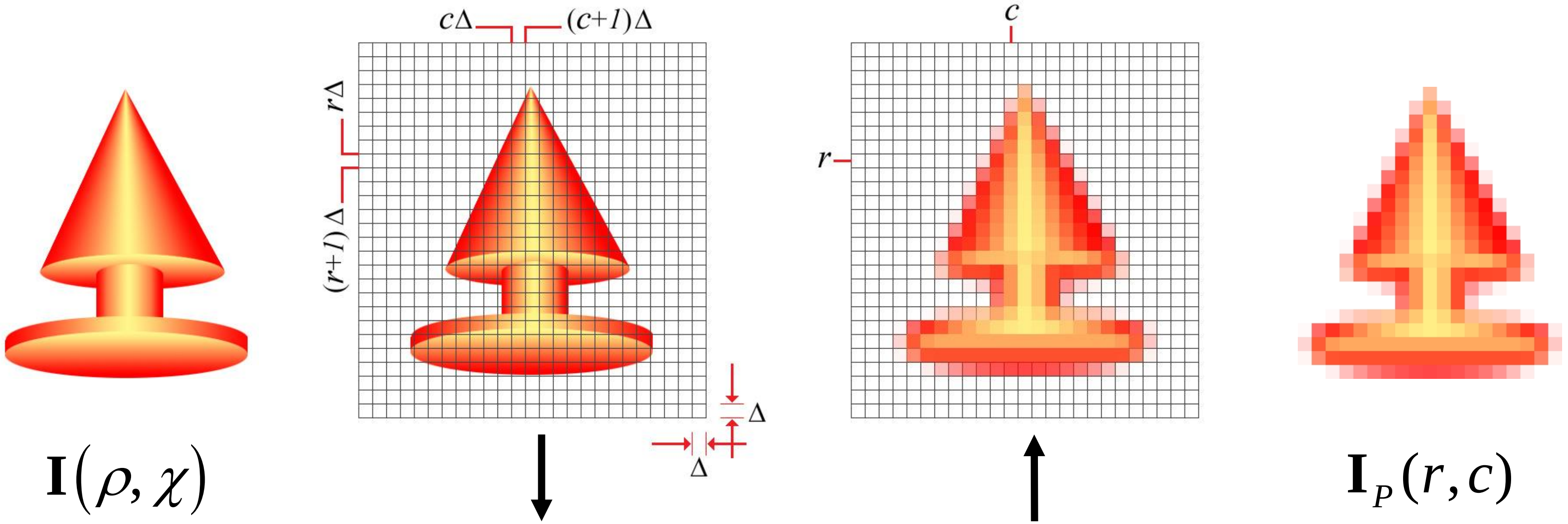
high-res image pixelated quantized pixelated & quantized

All the photons that hit a single sensor combine to produce a single intensity. The result is pixelization of the image.

The intensity values are quantized – mapped to a limited range of numbers.

Pixelization

Take the average within each square.



$\mathbf{I}(\rho,\chi)$

high-res image

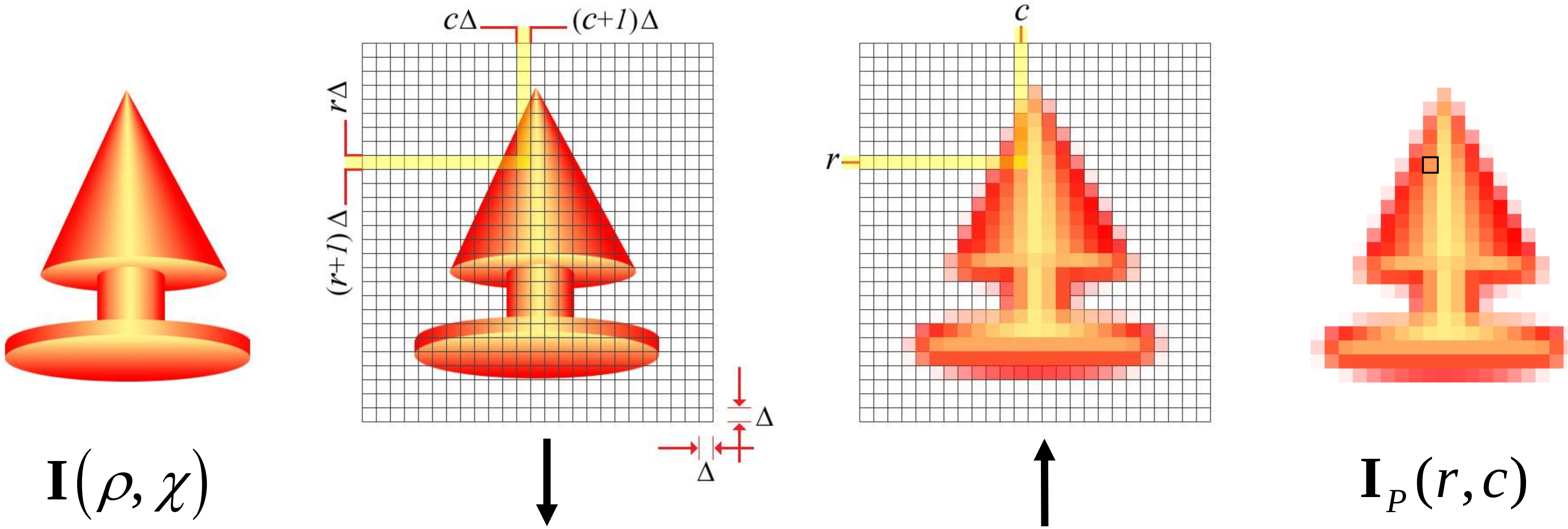
$$\mathbf{I}_{\mathrm{DS}}(r,c)=\frac{1}{\Delta^2}\sum_{\rho=r\Delta}^{(r+1)\Delta-1}\sum_{\chi=c\Delta}^{(c+1)\Delta-1}\mathbf{I}(\rho,\chi);\quad \mathbf{I}_{\mathbf{P}}=\mathbf{I}_{\mathrm{DS}}\underset{(upsampled)}{\uparrow\Delta}$$

$\mathbf{I}_P(r,c)$

pixelated image

Pixelization

Take the average within each square.



$\mathbf{I}(\rho,\chi)$

$\mathbf{I}_P(r,c)$

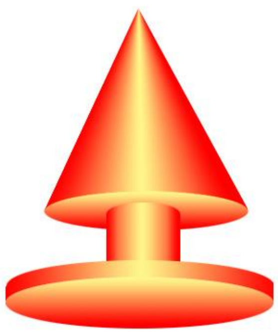
high-res image

pixelated image

$$\mathbf{I}_{\mathrm{DS}}(r,c)=\frac{1}{\Delta^2}\sum_{\rho=r\Delta}^{(r+1)\Delta-1}\sum_{\chi=c\Delta}^{(c+1)\Delta-1}\mathbf{I}(\rho,\chi); \quad \mathbf{I_P}=\mathbf{I}_{\mathrm{DS}}\uparrow\Delta \ (upsampled)$$

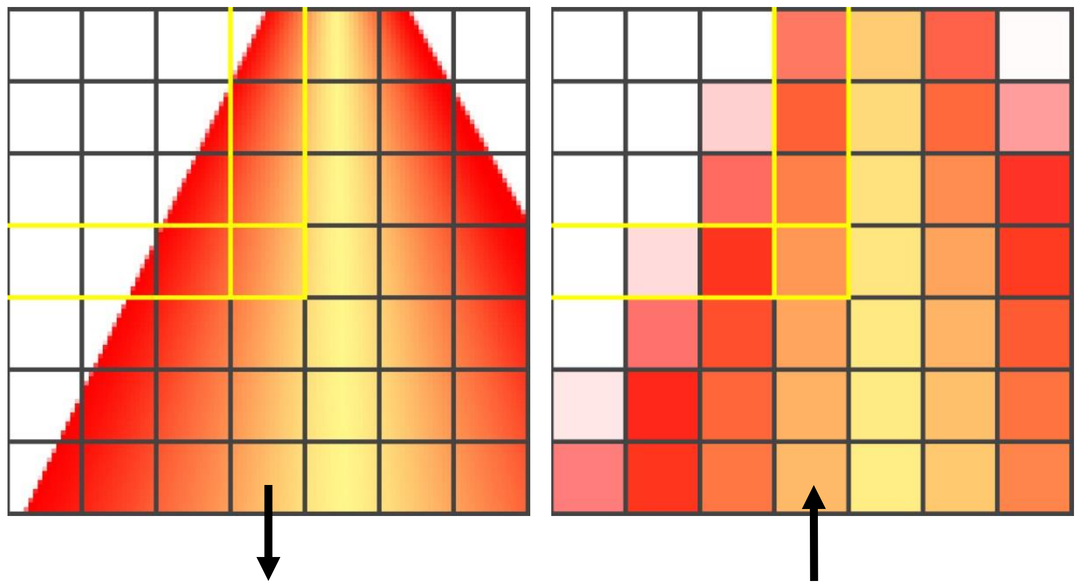
Pixelization

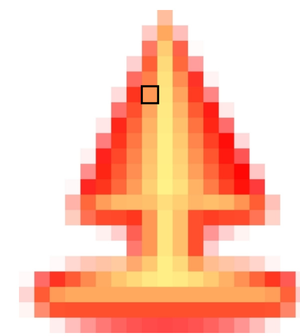
Take the average within each square.



$\mathbf{I}(\rho,\chi)$

high-res image





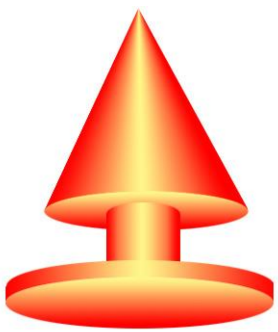
$\mathbf{I}_P(r,c)$

pixelated image

$$\mathbf{I}_{\mathrm{DS}}(r,c)=\frac{1}{\Delta^2}\sum_{\rho=r\Delta}^{(r+1)\Delta-1}\sum_{\chi=c\Delta}^{(c+1)\Delta-1}\mathbf{I}(\rho,\chi);\quad \mathbf{I}_{\mathbf{P}}=\underbrace{\mathbf{I}_{\mathrm{DS}}\uparrow\Delta}_{(upsampled)}$$

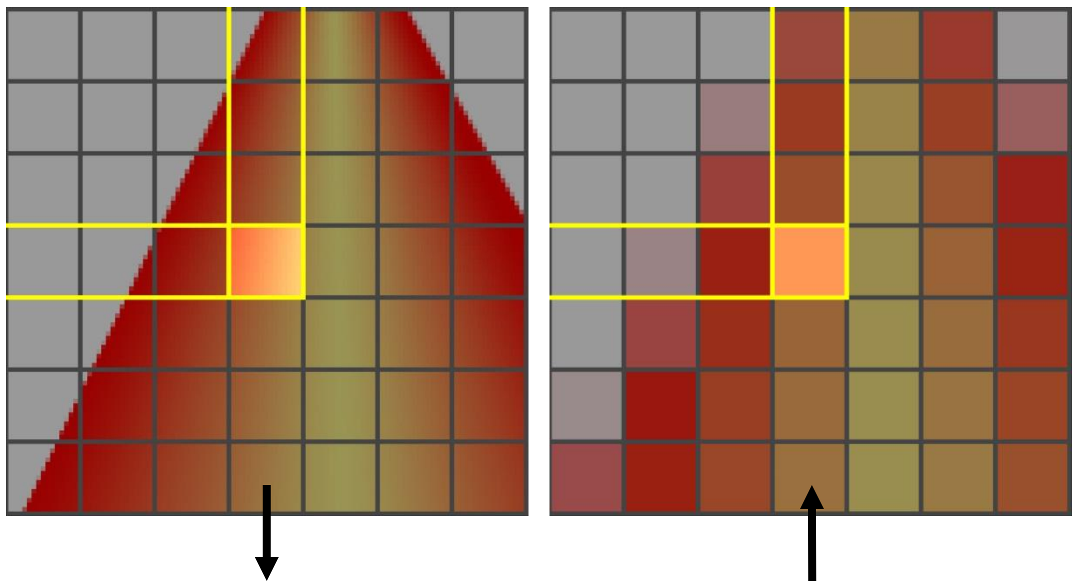
Pixelization

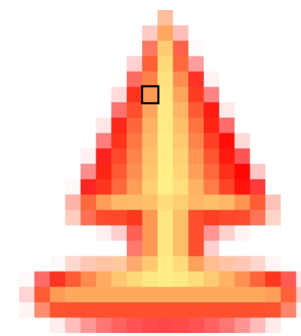
Take the average within each square.



$\mathbf{I}(\rho,\chi)$

high-res image





$\mathbf{I}_P(r,c)$

pixelated image

$$\mathbf{I}_{\mathrm{DS}}(r,c)=\frac{1}{\Delta^2}\sum_{\rho=r\Delta}^{(r+1)\Delta-1}\sum_{\chi=c\Delta}^{(c+1)\Delta-1}\mathbf{I}(\rho,\chi);\quad \mathbf{I}_{\mathbf{P}}=\mathbf{I}_{\mathrm{DS}}\uparrow\Delta$$

(*upsampled*)

Pixelization Procedure (Part 1)

To pixelize an $R\times C\times B$ image $\mathbf{I}$ by a factor, s:

Let $\mathbf{I}_{\downarrow}$ be an $\lfloor R/s\rfloor\times\lfloor C/s\rfloor\times B$ image.

Let the value of $\mathbf{I}_{\downarrow}$ at location (r,c,b) be the average value of $\mathbf{I}$ in the s-square neighborhood starting at (rs,cs,b).

$$\mathbf{I}_{\downarrow}(r,c,b) = \underset{(\rho,\chi)\,\in\mathfrak{N}_{\mathbf{I}}(r,c)}{\text{mean}}\left\{\,\mathbf{I}(\rho,\chi,b)\,\right\},$$

where

$$\mathfrak{N}_{\mathbf{I}}(r,c) = \left\{ (\rho,\chi) \,\middle|\, \begin{array}{l} \rho\in\{rs, rs+1,\ldots,(r+1)s-1\}, \\ \chi\in\{cs, cs+1,\ldots,(c+1)s-1\} \end{array} \right\}.$$

Notation:

$$\mathbf{I}_{\mathrm{DS}} = \mathbf{I}\downarrow s$$

$\mathbf{I}_{\mathrm{DS}}$ is $\mathbf{I}$ downsampled by a factor of s.

r & c are indices in the downsampled image.
ρ=rs+i & χ=cs+j are indices in the original image.

Pixelization Procedure (Part 2)

Let $\mathbf{I}_\mathrm{P}$ be an $R{\times}C{\times}B$ image.

Let the value of $\mathbf{I}_\mathrm{P}$ in neighborhood, $\mathfrak{N}(r,c)$ be $\mathbf{I}_\mathrm{DS}(r,c)$.

$$\mathbf{I}_\mathrm{P}(\rho,\chi,b) = \mathbf{I}_\mathrm{DS}(r,c,b) \quad \text{for} \quad (\rho,\chi) \in \mathfrak{N}_{\mathbf{I}_\mathrm{P}}(r,c).$$

where

$$\mathfrak{N}_{\mathbf{I}_\mathrm{P}}(r,c) = \left\{ (\rho,\chi) \,\middle|\, \begin{matrix} \rho \in \{rs, rs+1, \ldots, (r+1)s-1\}, \\ \chi \in \{cs, cs+1, \ldots, (c+1)s-1\} \end{matrix} \right\}.$$

Notation:

$$\mathbf{I}_\mathrm{P} = \mathbf{I}_\mathrm{DS}\!\uparrow s$$

$\mathbf{I}_\mathrm{P}$ is $\mathbf{I}_\mathrm{DS}$ upsampled by a factor of s.

r & c are indices in the downsampled image. $\rho=rs+i$ & $\chi=cs+j$ are indices in the upsampled image.

Pixelization

8 of 8: 256x256

What is the scene in this picture?

Pixelization

7 of 8: 128x128

What is the scene in this picture? A room with a window?

Pixelization

What is the scene in this picture? Earth and sky?

Pixelization

What is the scene in this picture? A sign pointing [☞]at a bright spot?

Pixelization

4 of 8: 16x16

What is the scene in this picture? A bucolic landscape with a barn?

Pixelization

3 of 8: 8x8

A bucolic landscape with a barn? Yes and a fine autumn day, too.

Pixelization

2 of 8: 4x4

Pixels are still visible at 4×4.

Pixelization

1 of 8: 2x2

Pixels are pretty much invisible at 2×2. But the resolution is wanting.

Pixelization

original image

Switch back and forth between this slide and the previous one to see.

Pixelization by Factor 32

Cross-fade 1/5

This 5-step cross-fade between the original and …

Pixelization by Factor 32

Cross-fade 2/5

… a 32×32 pixelization shows…

Pixelization by Factor 32

Cross-fade 3/5

… the averaging of …

Pixelization by Factor 32

Cross-fade 4/5

… the underlying pixels.

Pixelization by Factor 32

Cross-fade 5/5

Completed crossfade to a 32×32 pixelization.

Pixelization by Factor 32

original image

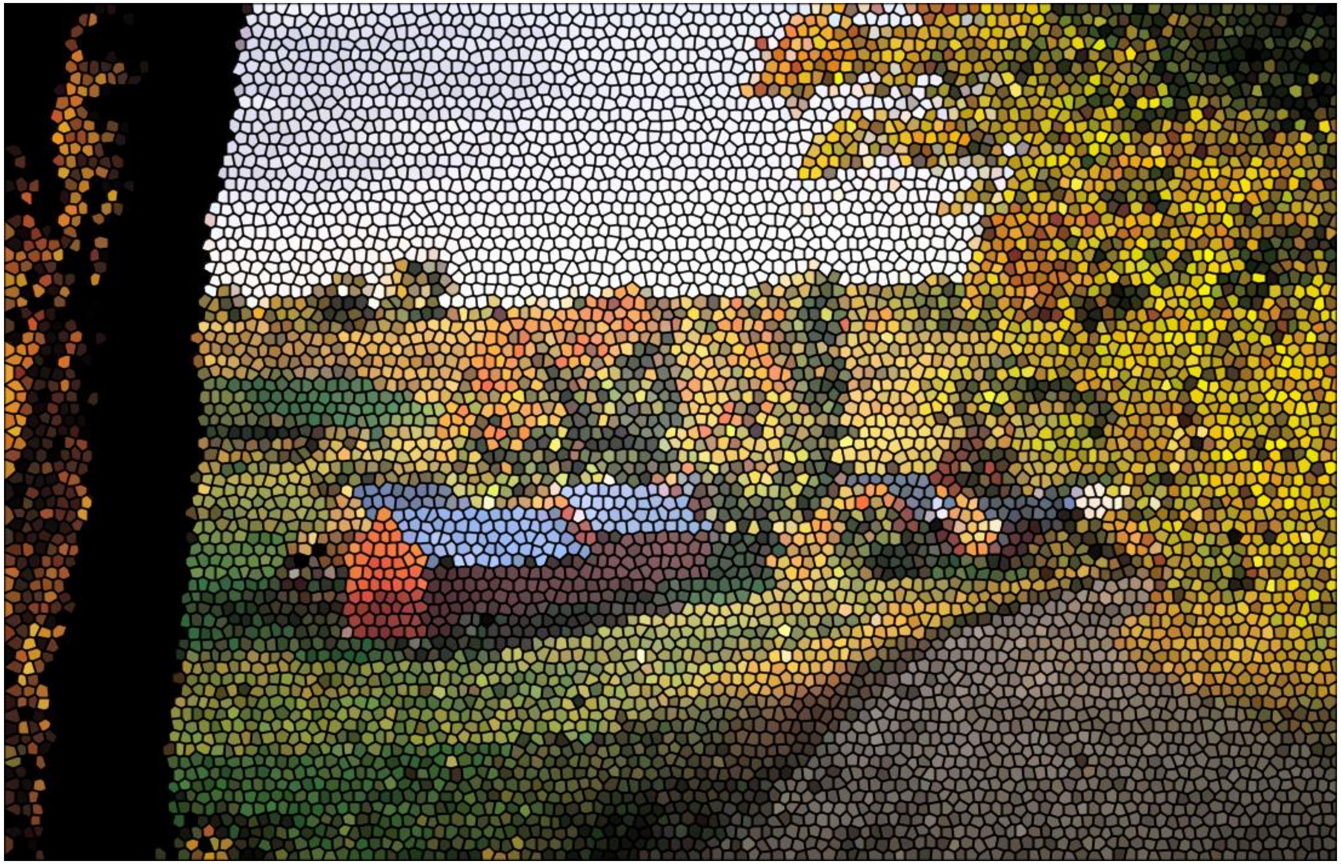
Switch back and forth between this slide and the previous one to see.

Other kinds of pixelization

photoshop “facet”

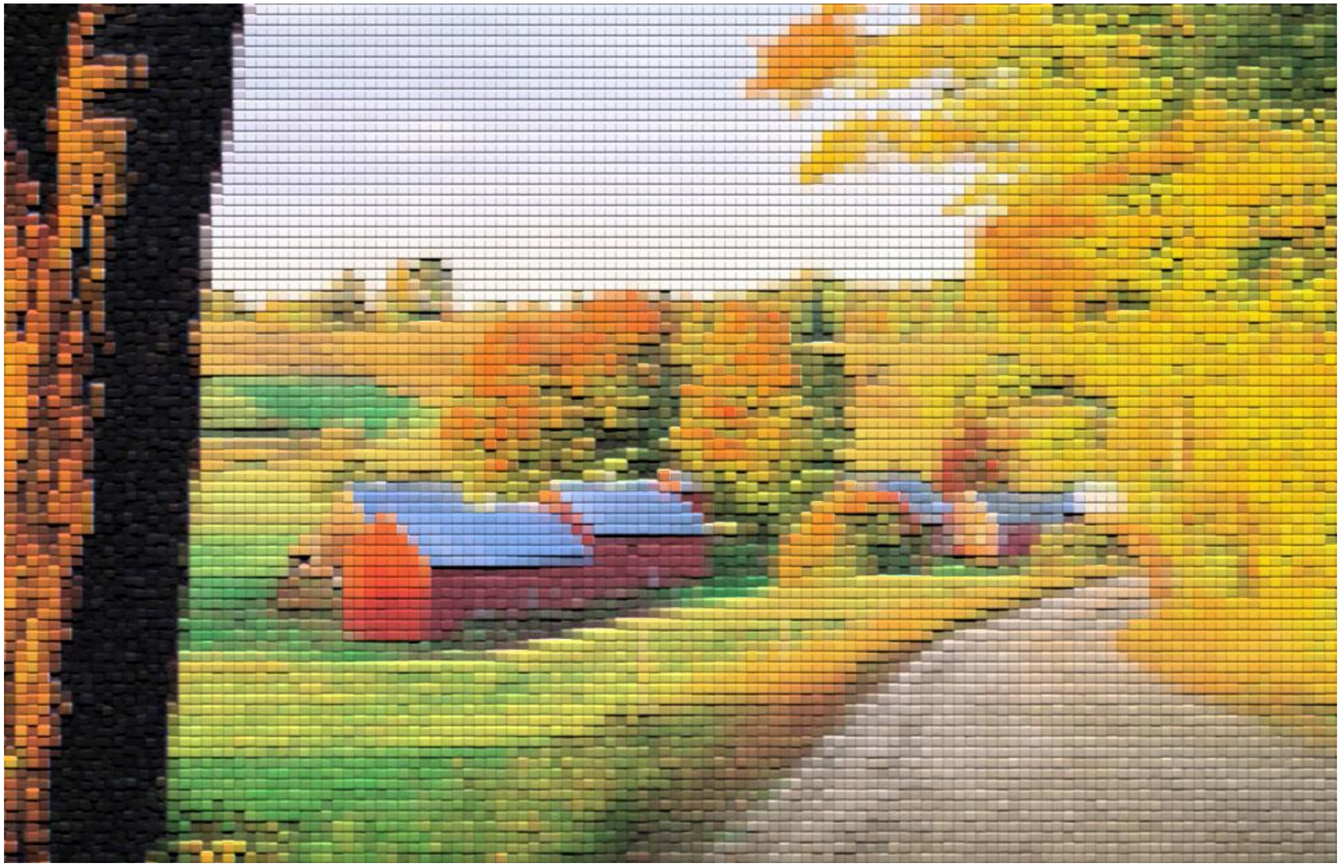
Other kinds of pixelization

photoshop "stained glass"



Other kinds of pixelization

photoshop “patchwork”



Other kinds of pixelization

photoshop "pointilized"

Other kinds of pixelization

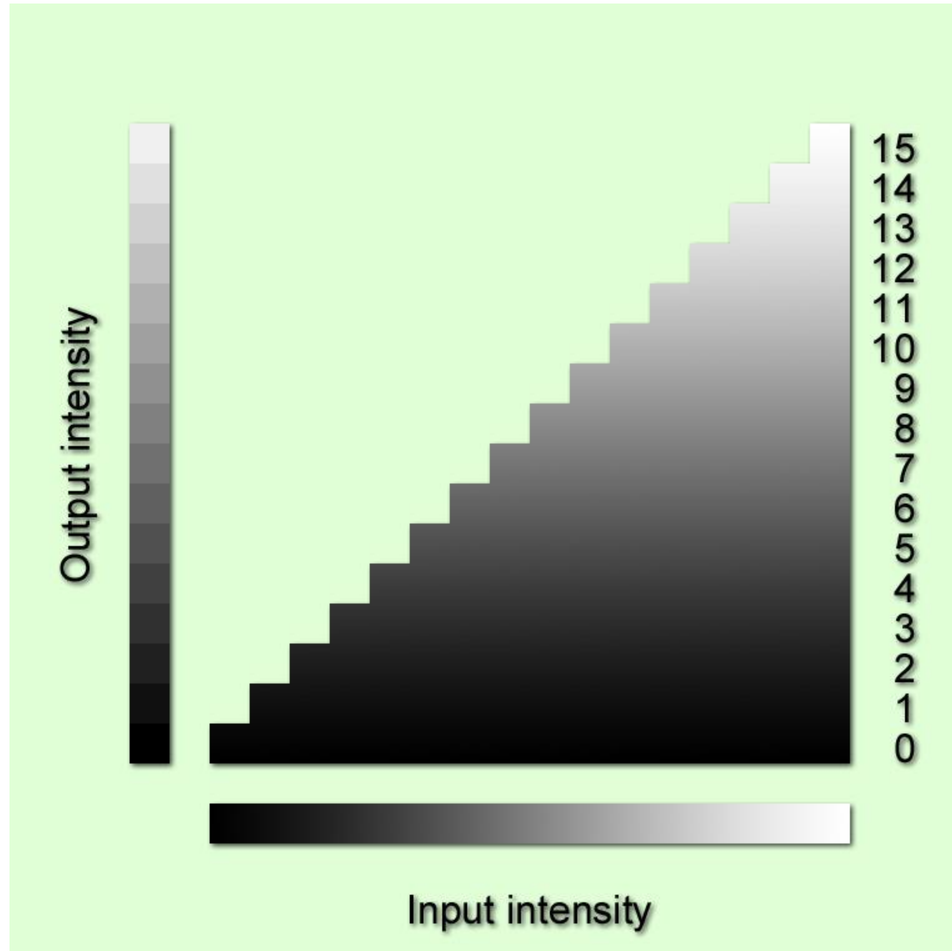
photoshop “mezotint”

Quantization

Quantization

16 million colors

16 colors



Quantization

8 bits 256 levels

7 bits 128 levels

6 bits 64 levels

5 bits 32 levels

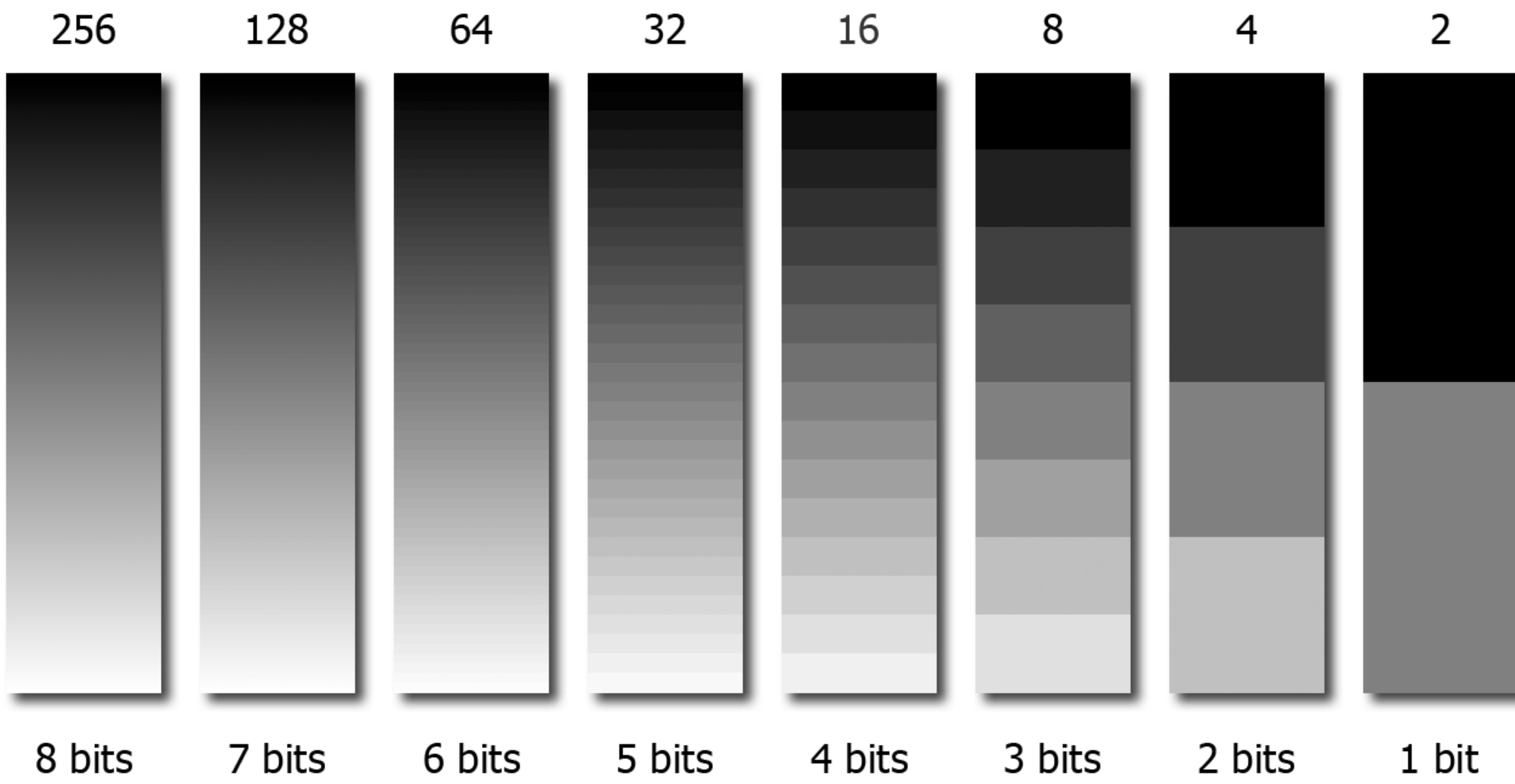
4 bits 16 levels

3 bits 8 levels

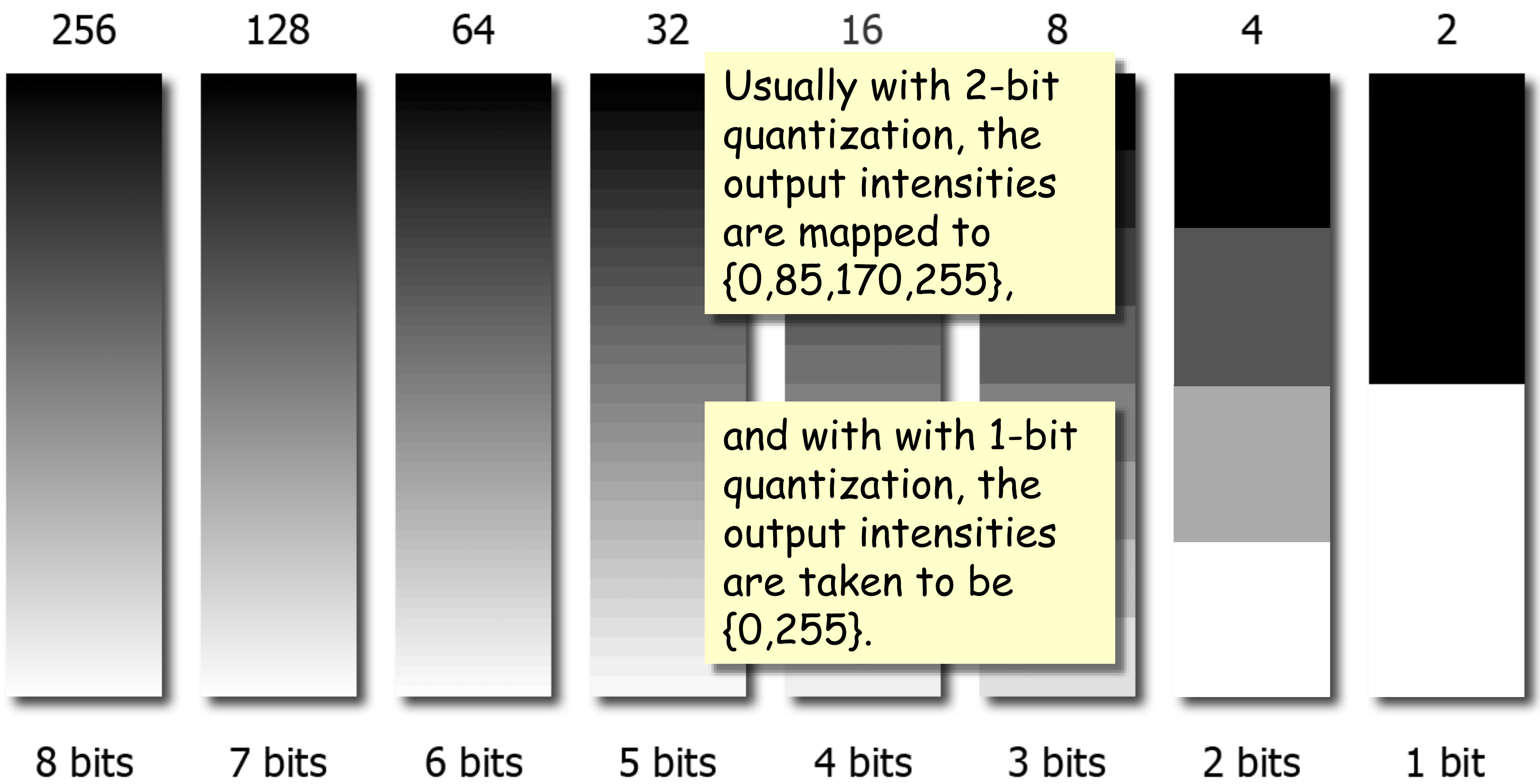
2 bits 4 levels

1 bit 2 levels

Intensity Quantization



Intensity Quantization



Usually with 2-bit quantization, the output intensities are mapped to {0,85,170,255},

and with with 1-bit quantization, the output intensities are taken to be {0,255}.

Enhancement of an 8-bit image


a. original


b. contrast enh.


b. dark enhanced


b. bright enh.

Enhancement of a 16-bit image

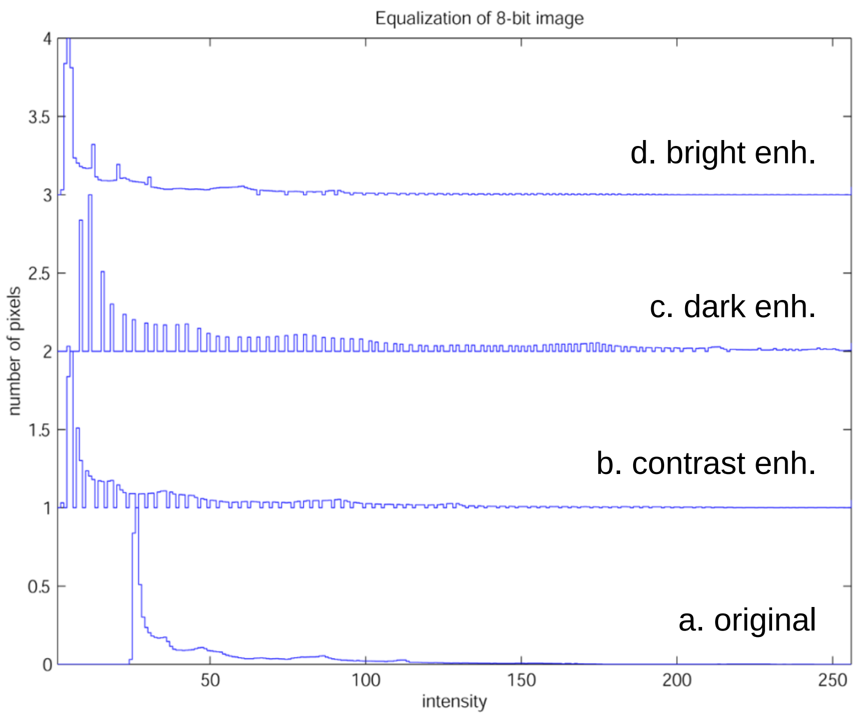
a. original

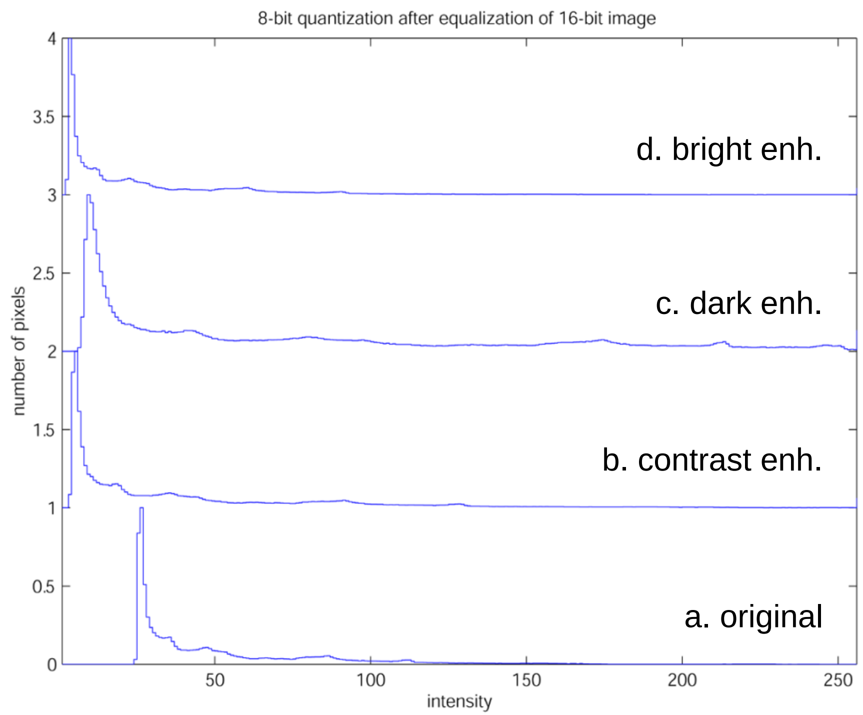
b. contrast enh.

b. dark enhanced

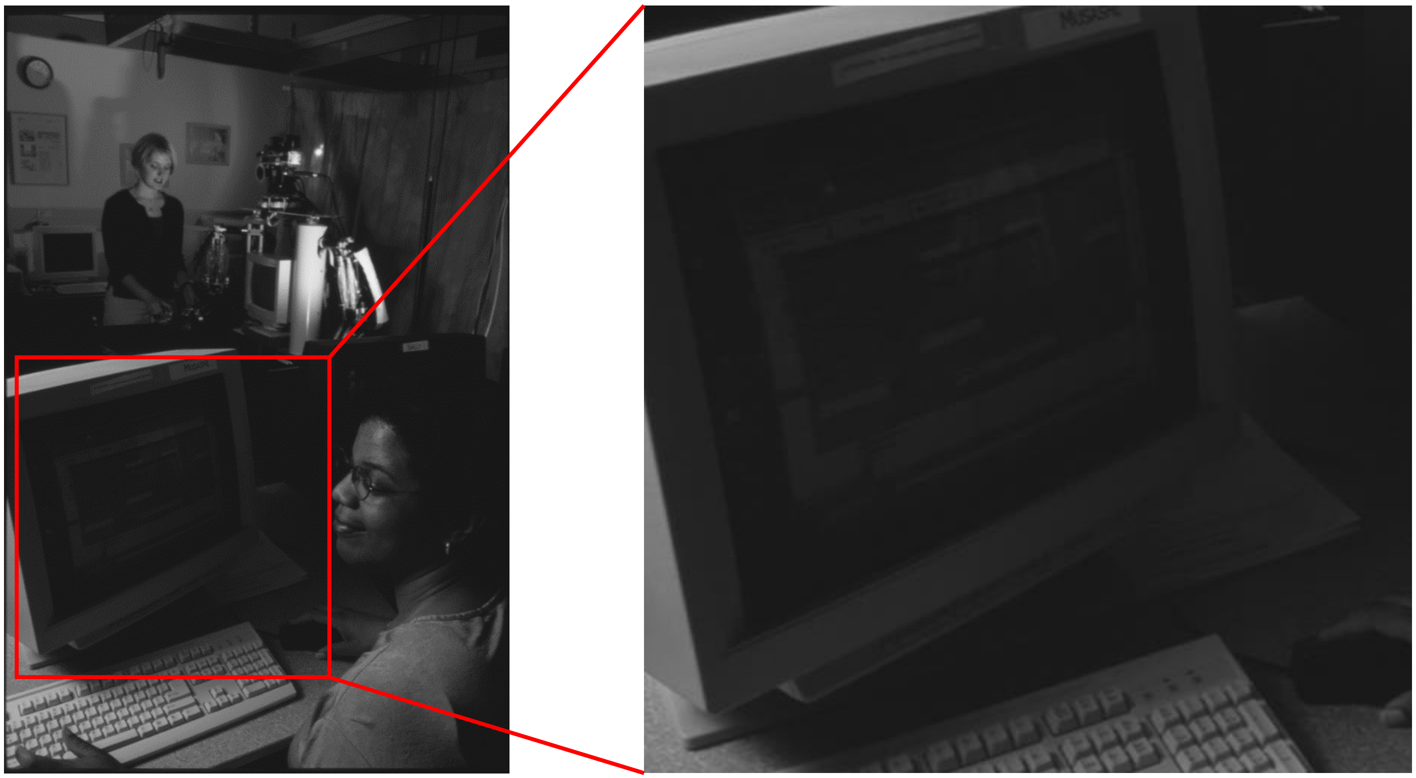
b. bright enh.

Effect of Quantization on Equalization





Effect of Quantization on Equalization



Effect of Quantization on Equalization

enhanced 8-bit

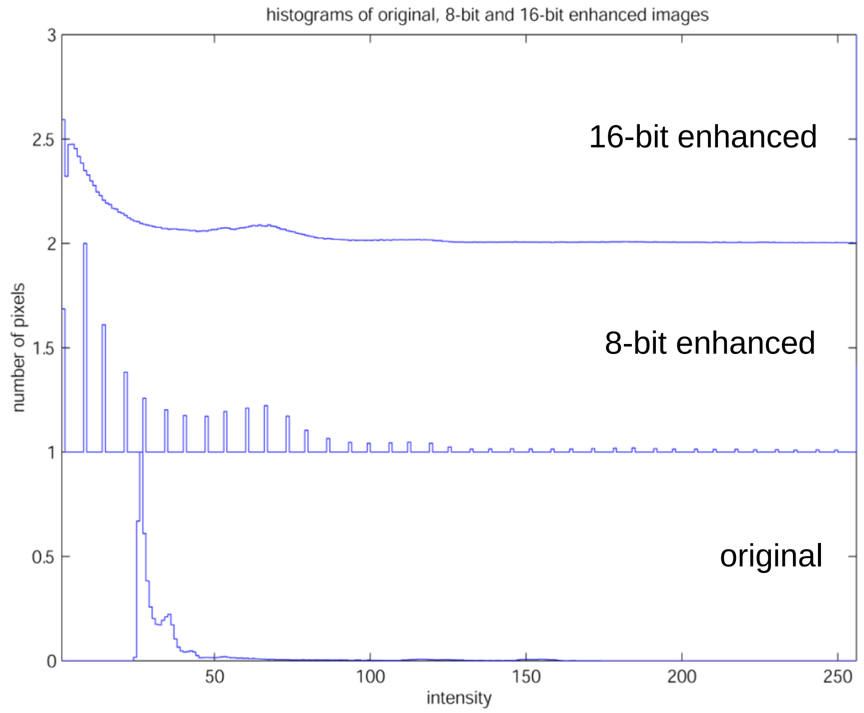
enhanced 16-bit

Effect of Quantization on Equalization

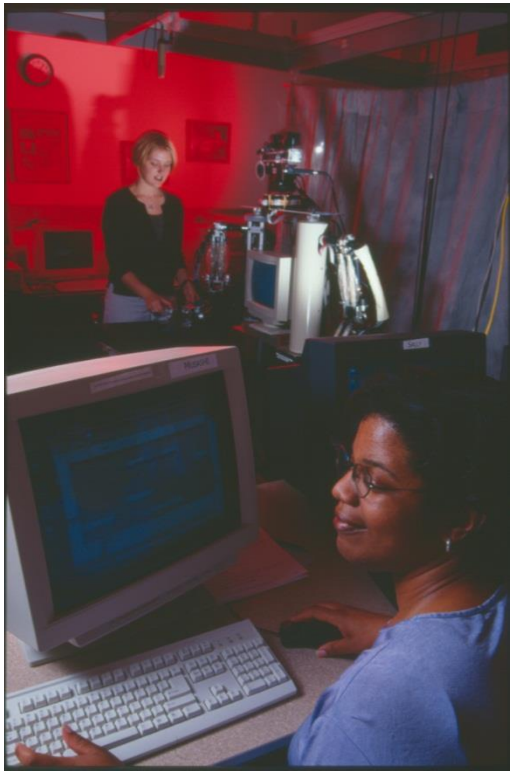
enhanced 16-bit

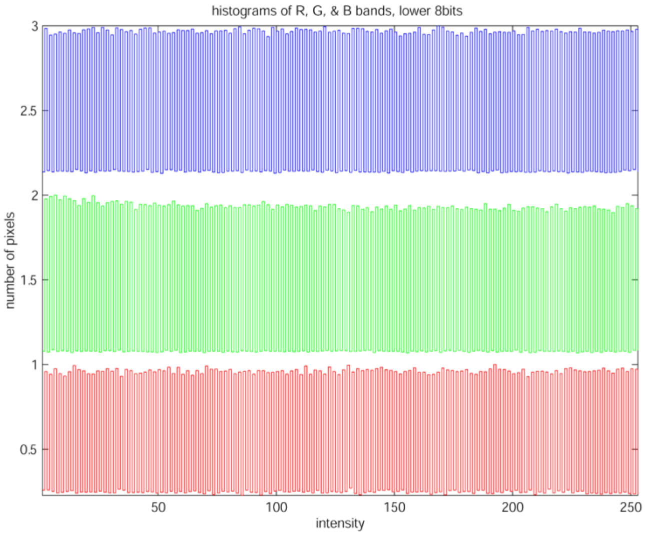
enhanced 8-bit

Effect of Quantization on Equalization



What's in the lower eight bits?



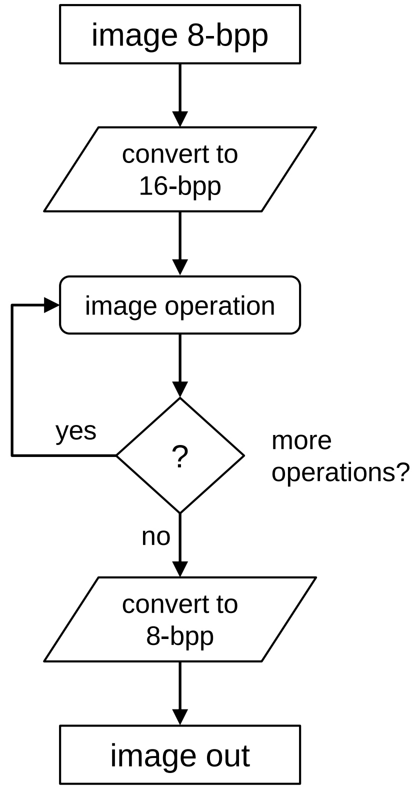


Use of 16-bit images as intermediates.

When performing operations on an image that will change intensity levels, either locally or globally, sometimes better results can be had by converting the image into a 16-bit format, performing the operations, and then converting it back.

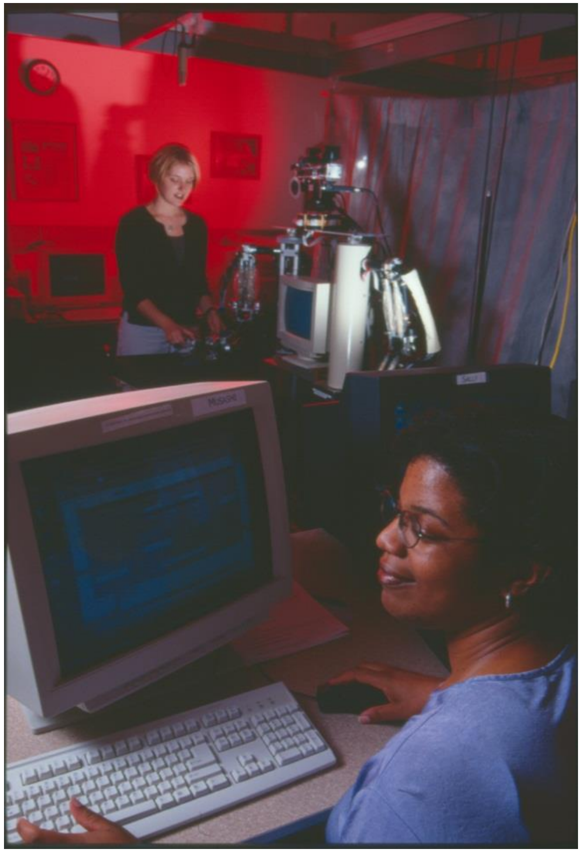
This happens frequently (and sometimes automatically) in Matlab except that each value is converted to 64-bit floating point. So this applies to other IP programs like Photoshop or gimp.

Workflow:

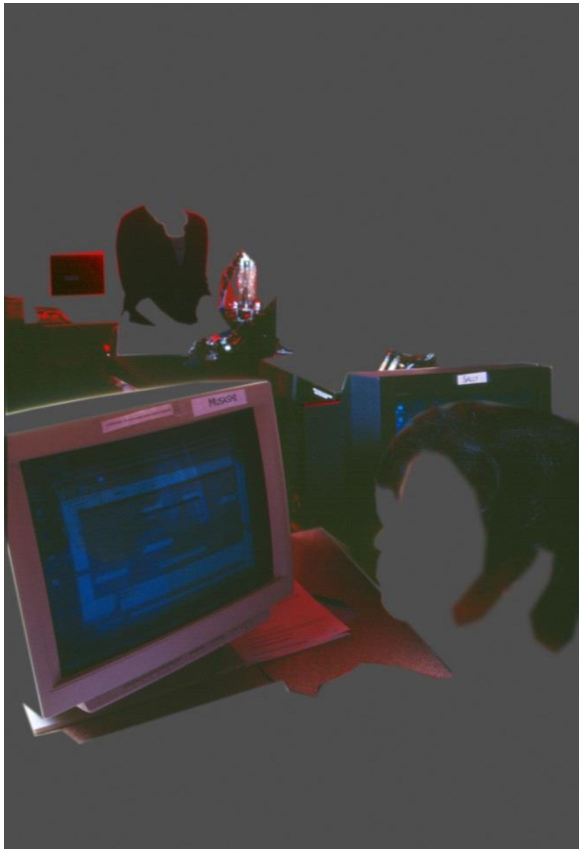


This is a crude form of HDR imaging…

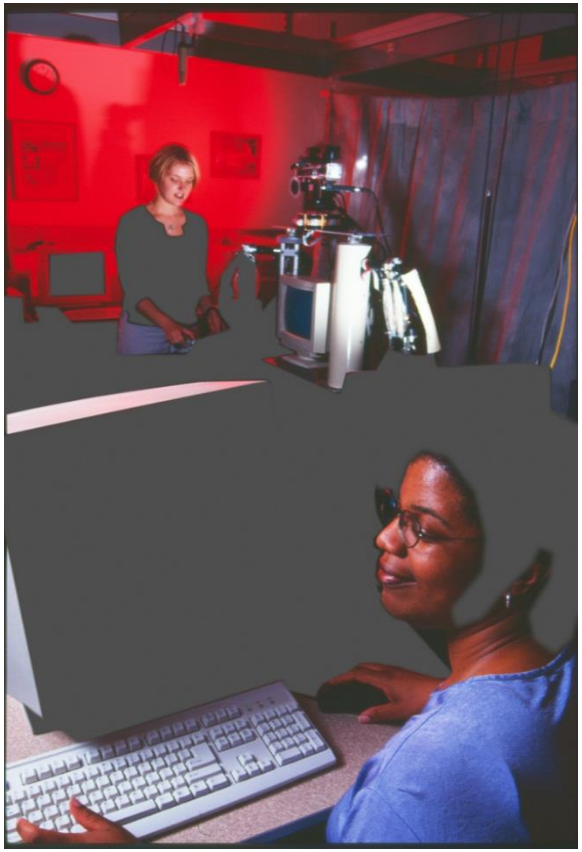
Separate EQ of Dark and Light Regions in 16-bit Images



original 16-bit image

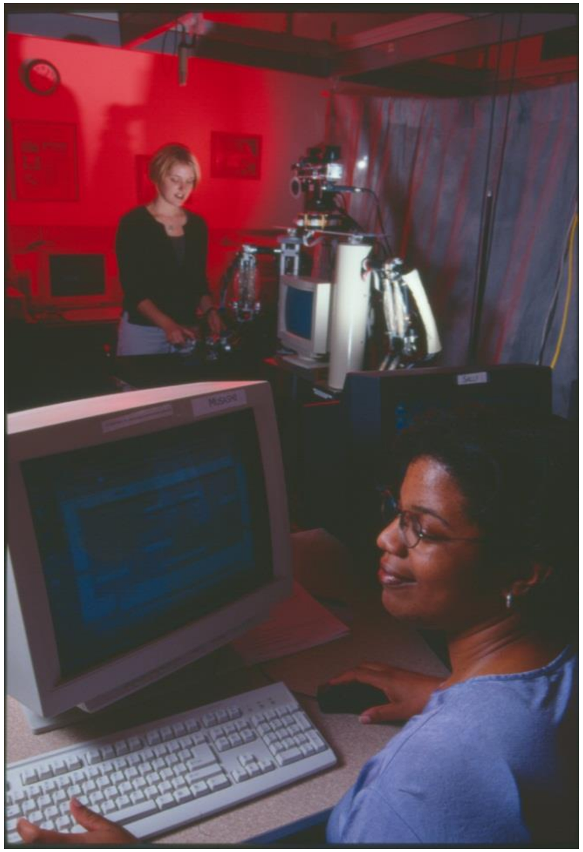


contr. stretched dark reg.

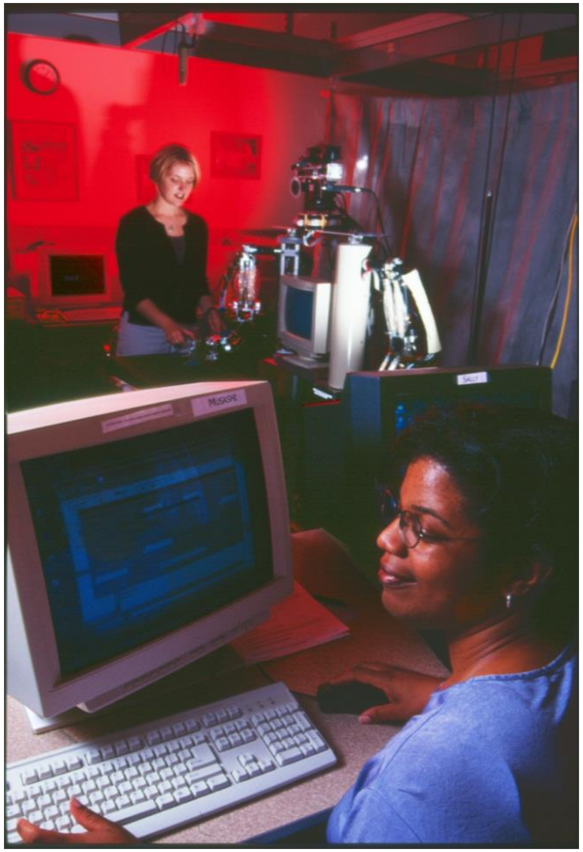


contr. stretched light reg.

Separate EQ of Dark and Light Regions in 16-bit Images



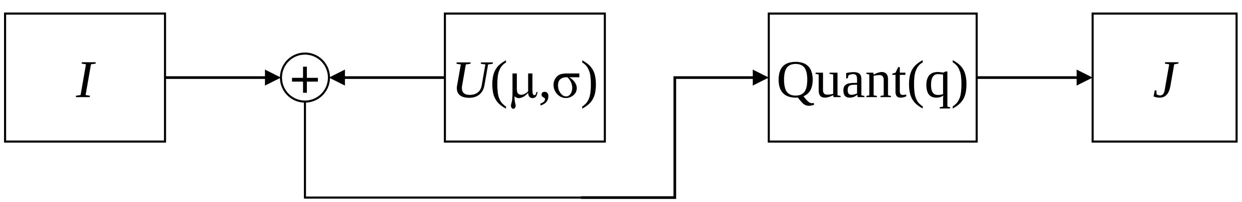
original 16-bit image



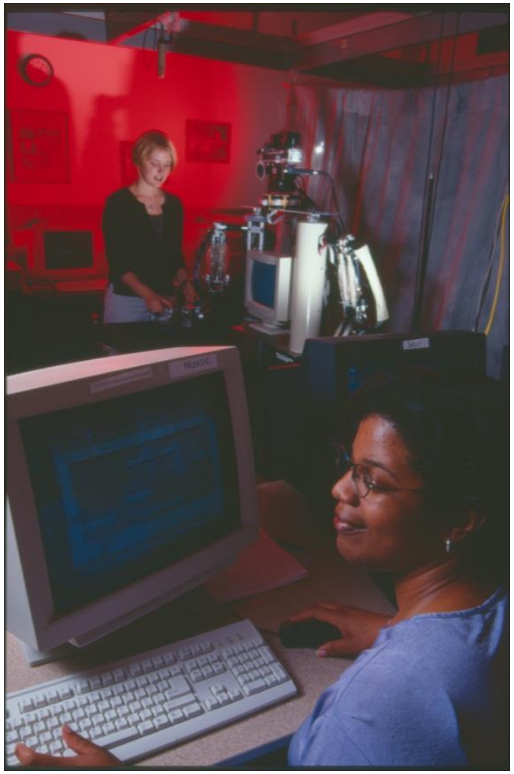
contr. stretched light + dark reg.

Dithering: Noise Improves Quantization

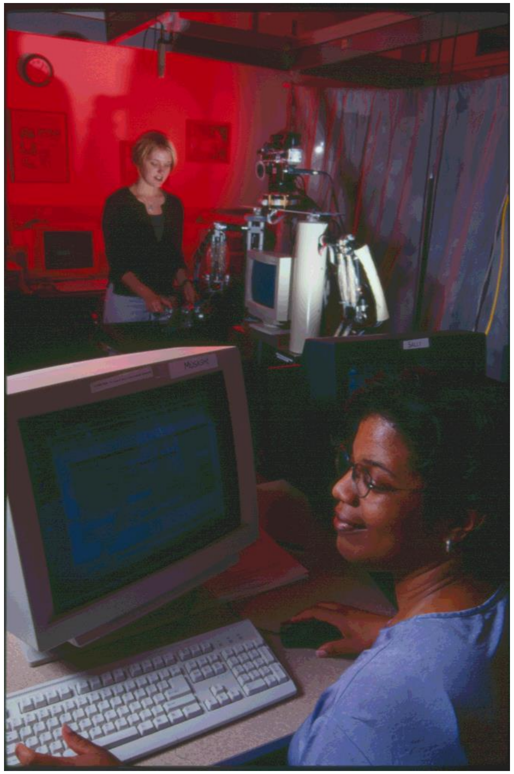
- Quantizing an image into 1, 2, or 3 bits can introduce false contours.
- The addition of signed noise to the image *before* quantization can improve the appearance of the result. This is called *dithering*.
- The noise usually should have $\mu = 0$.
- The σ of the noise must be determined through experimentation since it depends on the image being quantized. A reasonable first choice for uniformally distributed noise in the interval $(-\frac{1}{2},\frac{1}{2})$ is $\sigma = \frac{1}{4}\,M/q$, where M is the maximum intensity value in the image (*e.g.* 255) and q is the number of bits in the quantized image.



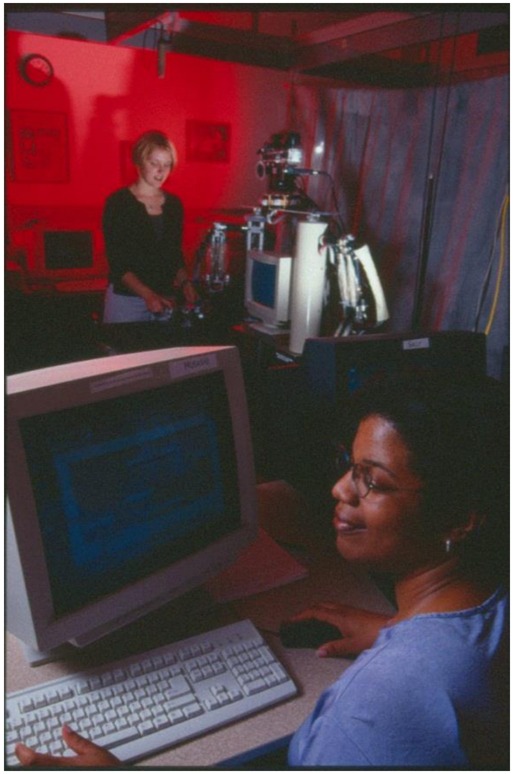
Dithering: use noise to reduce quant. error



8 bits

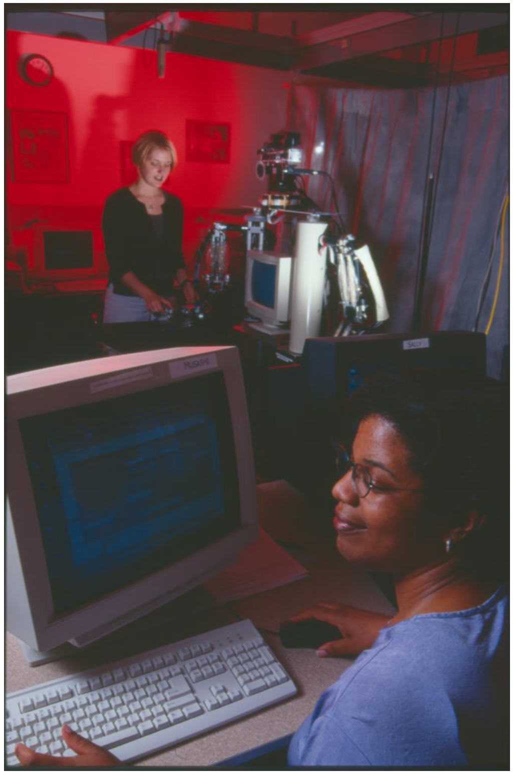


4 bits



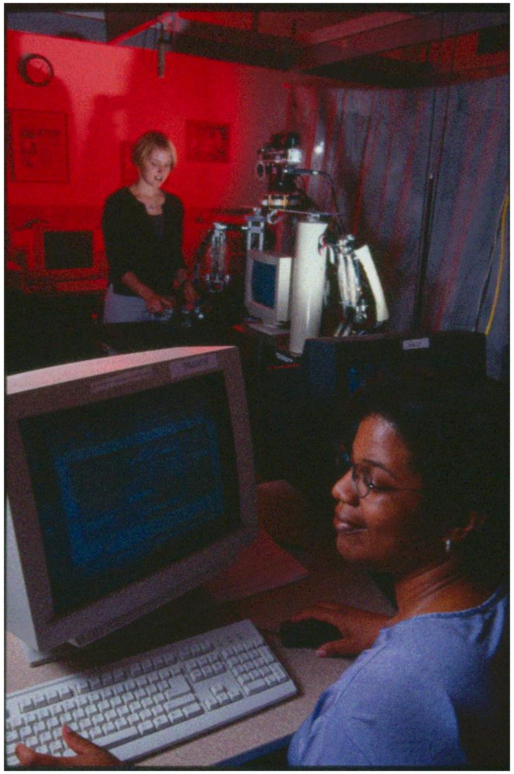
4 bits + noise

Dithering: use noise to reduce quant. error



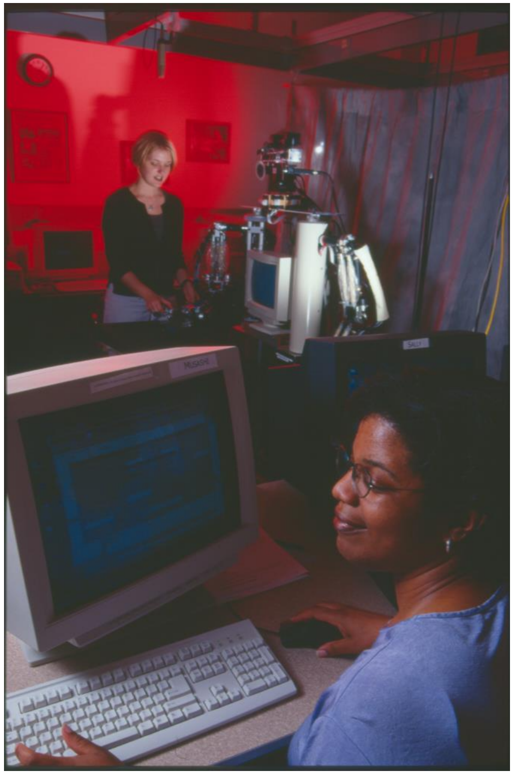
8 bits

3 bits

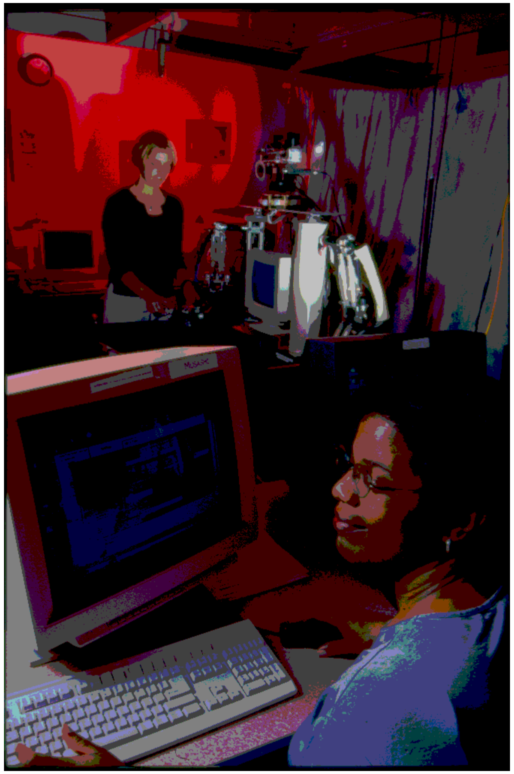


3 bits + noise

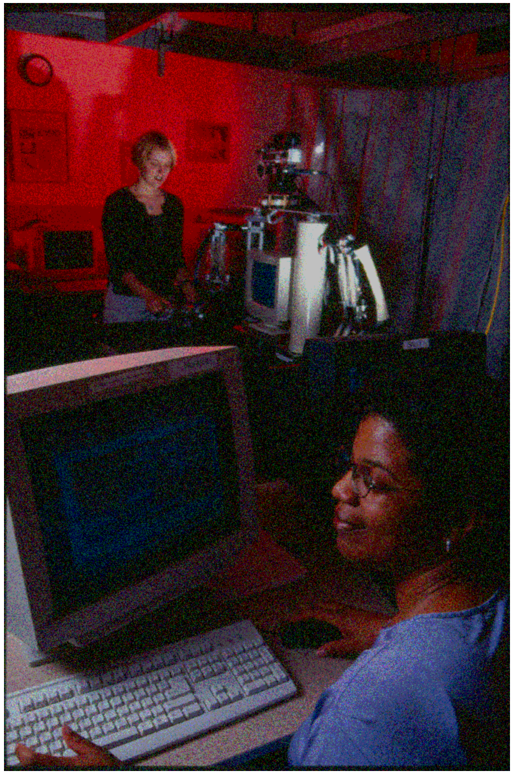
Dithering: use noise to reduce quant. error



8 bits

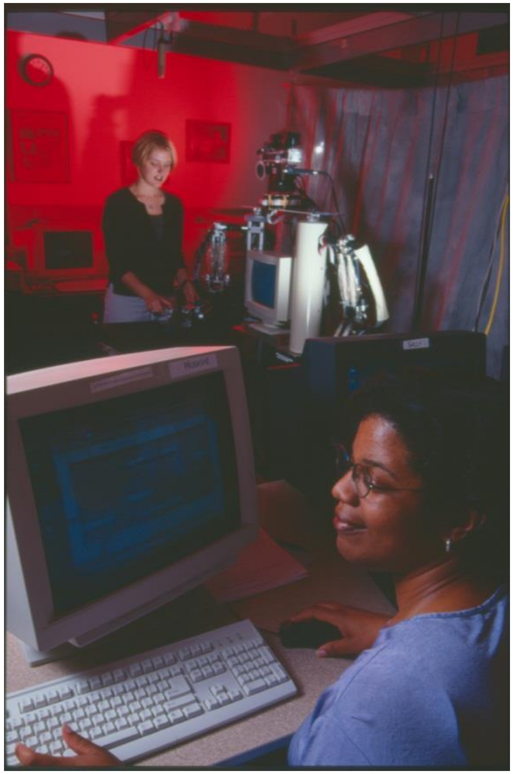


2 bits

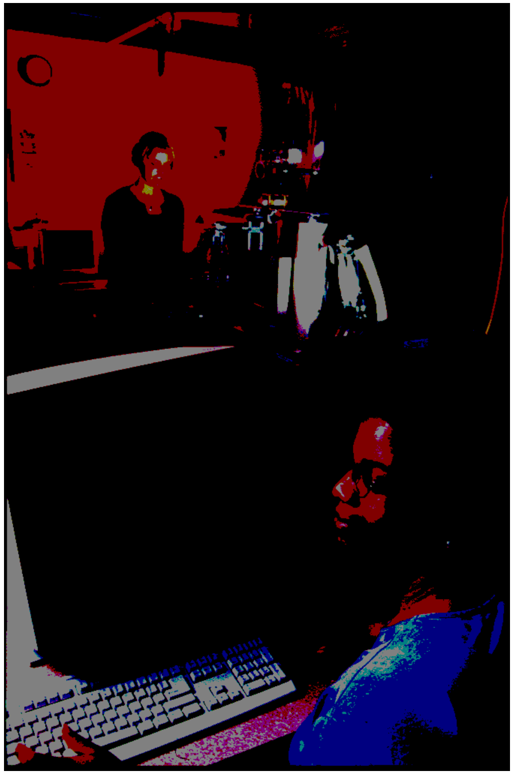


2 bits + noise

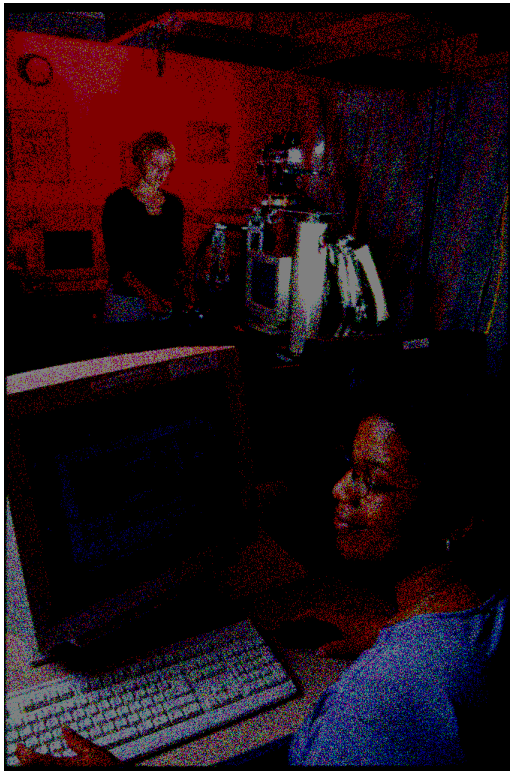
Dithering: use noise to reduce quant. error



8 bits



1 bit



1 bit + noise

Steganography

8-bit-per-band, 3-band, "original" image

Application of Quantization: Steganography

Pieter Bruegel (the Elder, ca. 1525-69), *The Peasant Dance*, 1568, Oil on oak panel, 114x164 cm, Kunsthistorisches Museum Wien, Vienna

If an image is quantized, say from 8 bits to 6 bits and redisplayed it can be all but impossible to tell the difference visually between the two.

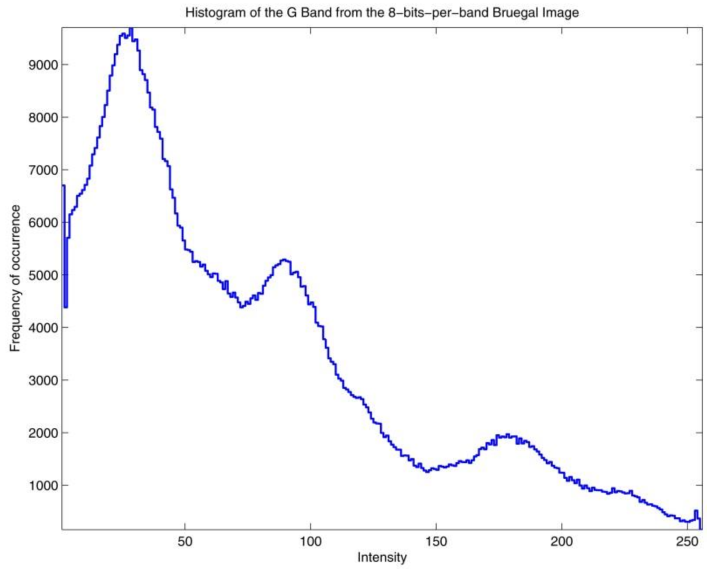
Application of Quantization: Steganography

Pieter Bruegel (the Elder, ca. 1525-69), *The Peasant Dance*, 1568, Oil on oak panel, 114x164 cm, Kunsthistorisches Museum Wien, Vienna

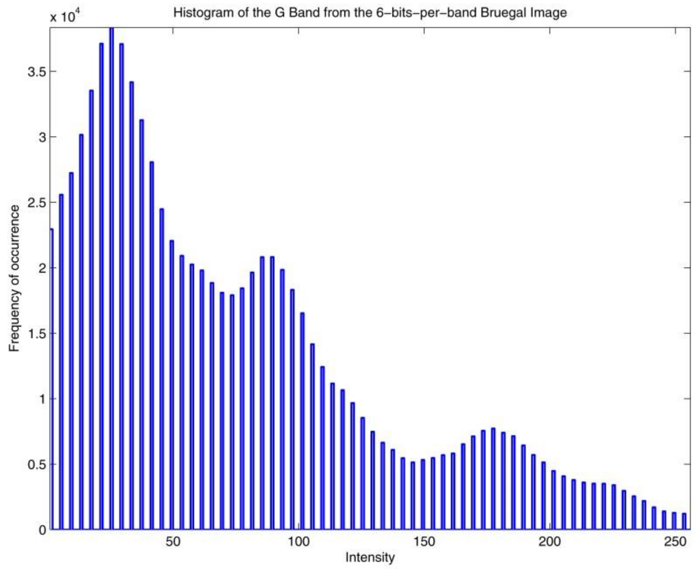
If an image is quantized, say from 8 bits to 6 bits and redisplayed it can be all but impossible to tell the difference visually between the two.

Application of Quantization: Steganography

green-band histogram of 8-bit image



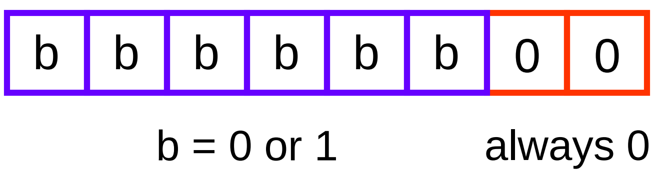
green-band histogram of 6-bit image



With simple image analysis, it is easy to tell the difference: The histograms of the two versions indicate which is which. If the 6-bit version is displayed as an 8-bit image it has only pixels with values 0, 4, 8, … , 252.

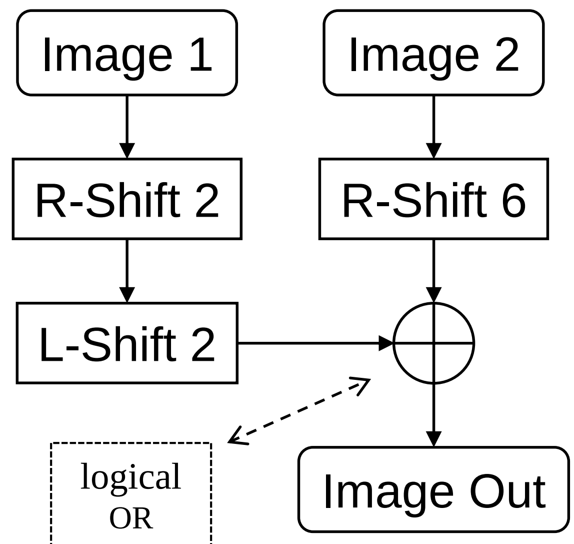
Application of Quantization: Steganography

If the 6-bit version is displayed as an 8-bit image then the 8-bit pixels all have zeros in the lower 2 bits:



This introduces the possibility of encoding other information in the low-order bits.

That other information could be a message, perhaps encrypted, or even another image.



X-Shift *n* = logical left or right shift by *n* bits.

Image 1 in upper 6-bits.
Image 2 in lower 2-bits.

Application of Quantization: Steganography

Pieter Bruegel (the Elder, ca. 1525-69), *The Peasant Dance*, 1568, Oil on oak panel, 114x164 cm, Kunsthistorisches Museum Wien, Vienna

The second image is invisible because the value of each pixel is between 0 and 3. For any given pixel, its value is added to the to the collocated pixel in the first image that has a value from the set {0, 4, 8, … , 252}. The 2^{nd} image is noise on the 1^{st}.

Image 1 in upper 6-bits.
Image 2 in lower 2-bits.

Application of Quantization: Steganography

Pieter Bruegel (the Elder, ca. 1525-69), *The Peasant Dance*, 1568, Oil on oak panel, 114x164 cm, Kunsthistorisches Museum Wien, Vienna

L-Shift 6

?

To recover the second image (which is 2 bits per pixel per band) simply left shift the combined image by 6 bits.

Image 2 in upper 2-bits.
Image 1 shifted out

Application of Quantization: Steganography

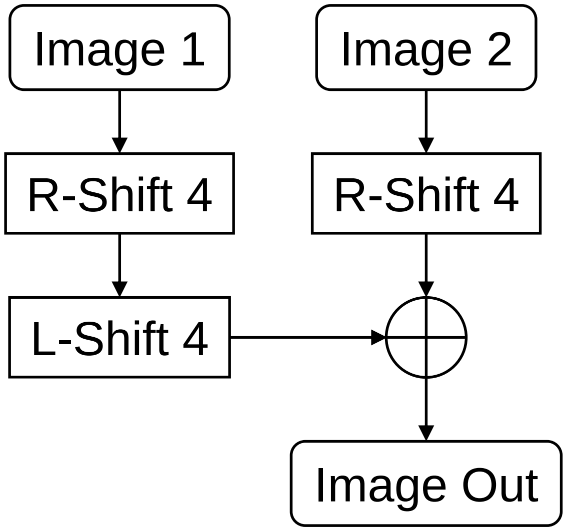
From the video game, *ZeroWing*, by Toaplan.
See http://en.wikipedia.org/wiki/All_your_base

To recover the second image (which is 2 bits per pixel per band) simply left shift the combined image by 6 bits.

Application of Quantization: Steganography

This is so effective that two 4-bit-per-pixel images can be superimposed with only the image in the high-order bits visible. Both images contain the same amount of information but because one takes on values between 0 and 15, the other takes on values from {16, 32, 48, … , 240}, and the smaller values are added to the larger, the image in the low-order bits is effectively invisible

Images 1 and 2 each have 4-bits per pixel when combined.



Application of Quantization: Steganography

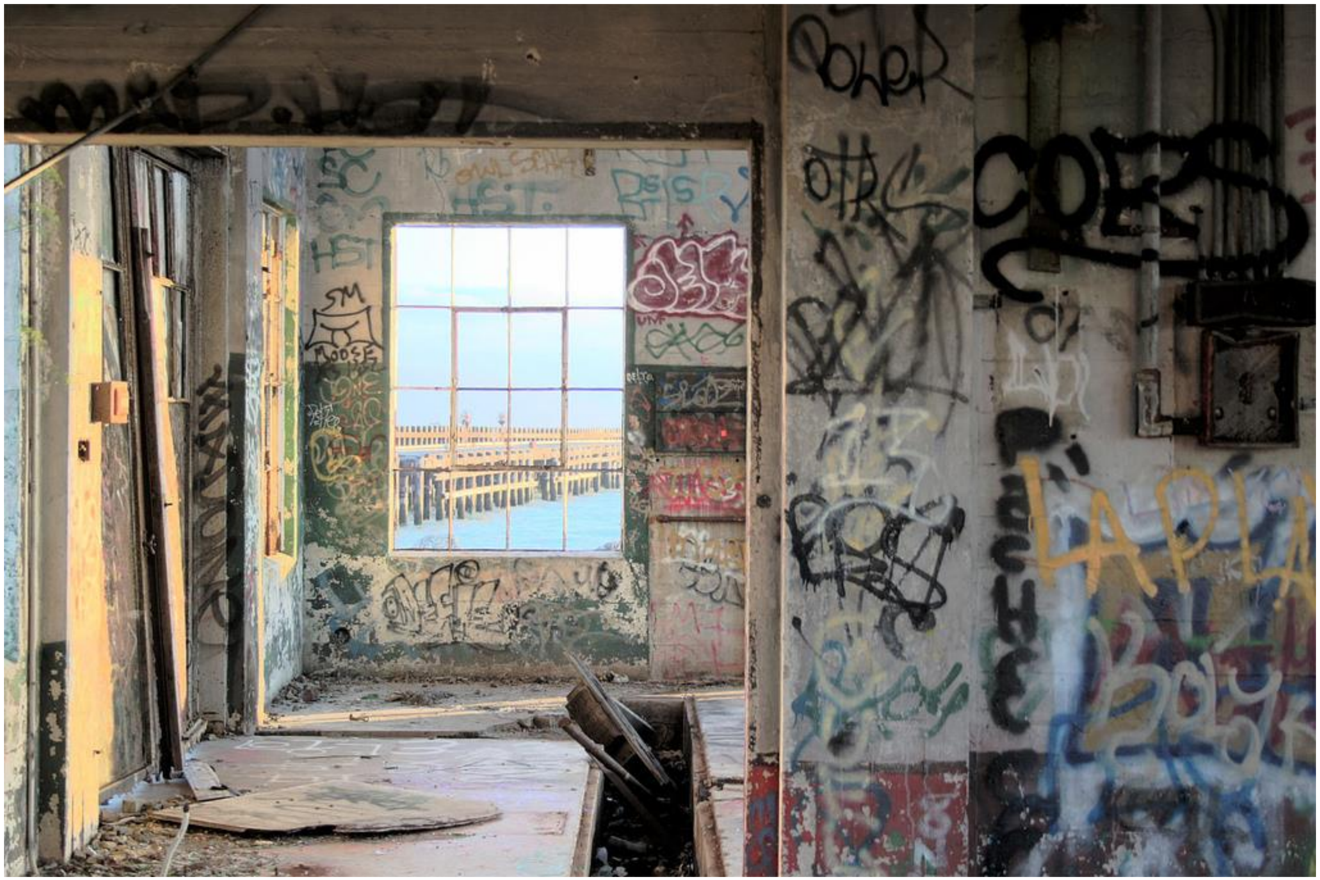


Photo: CypherOne
http://www.flickr.com/people/cypherone/

Image quantized to 4-bits per pixel.

Application of Quantization: Steganography

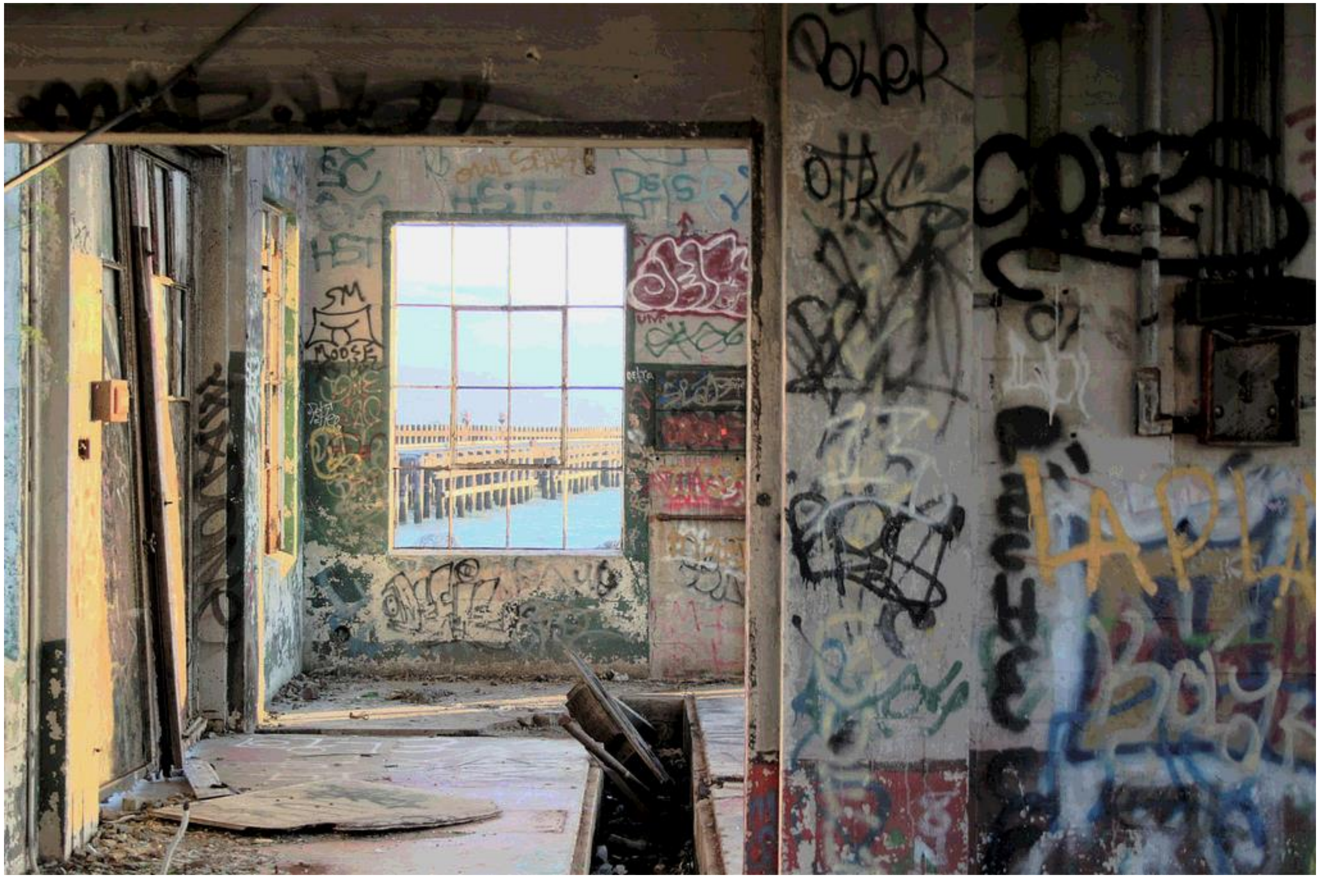


Photo: CypherOne
http://www.flickr.com/people/cypherone/

Image 1 in upper 4-bits.
Image 2 in lower 4-bits.

Application of Quantization: Steganography

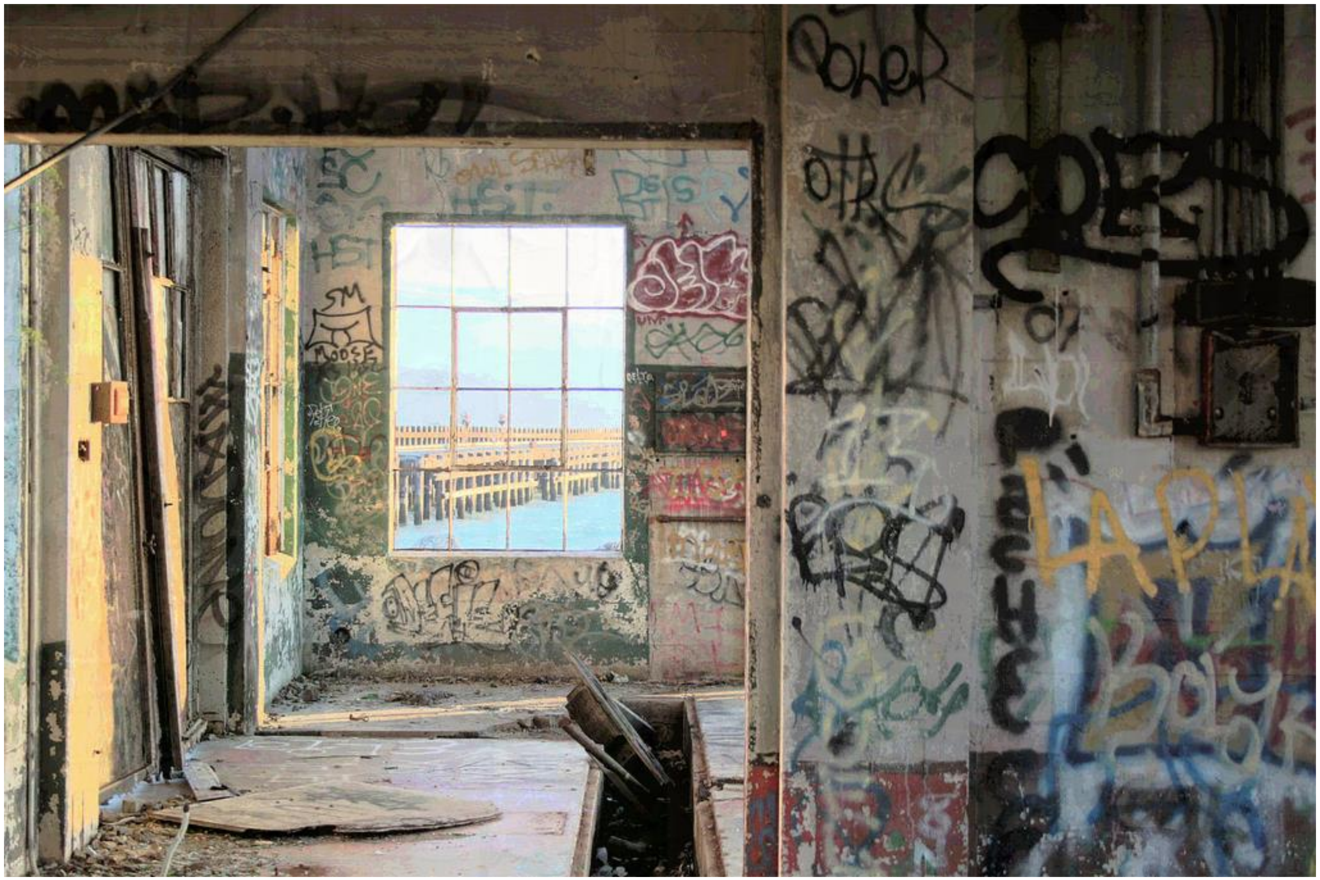
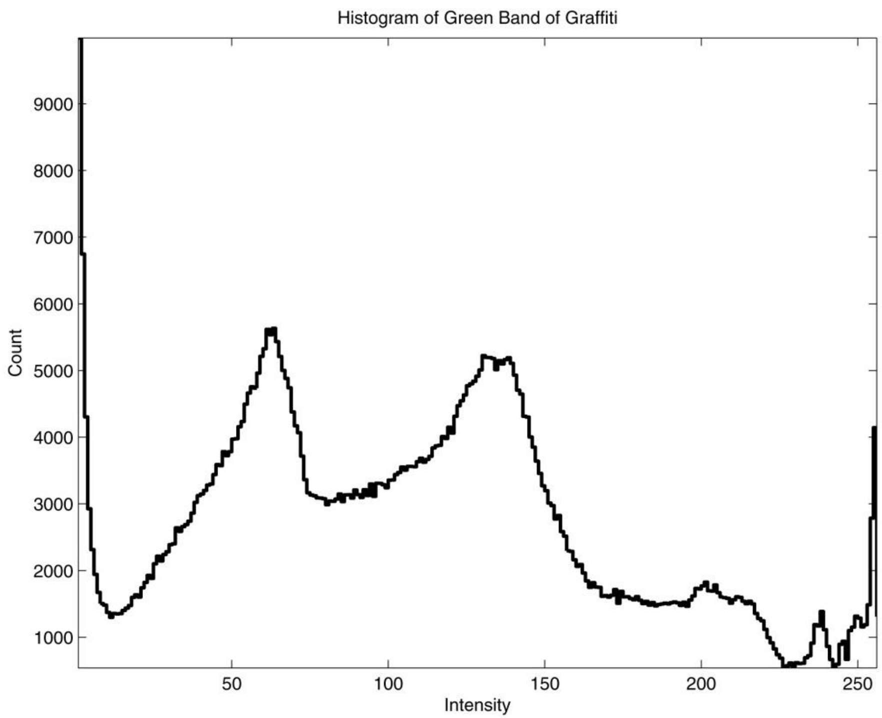


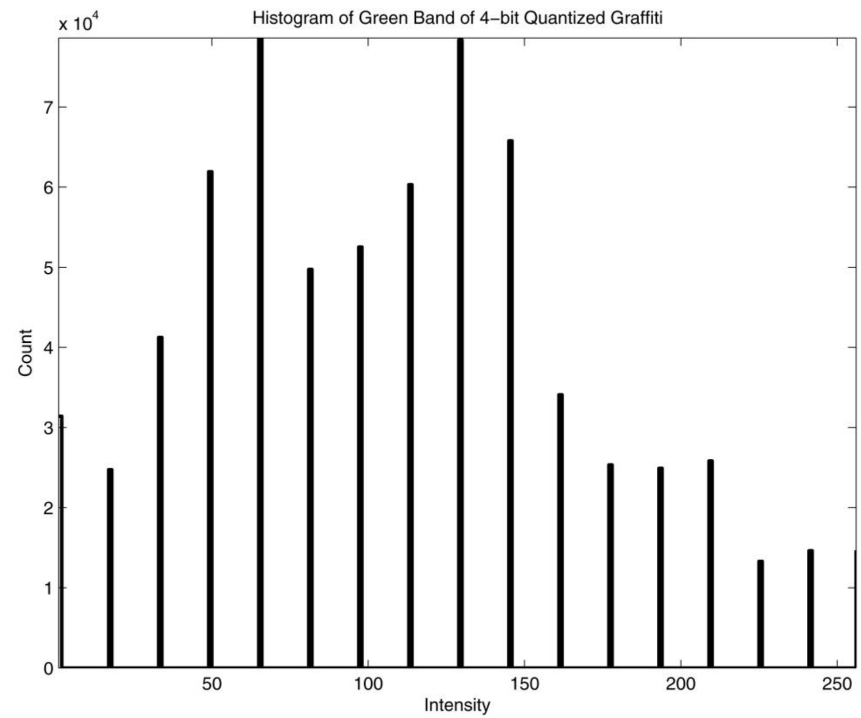
Photo: CypherOne
http://www.flickr.com/people/cypherone/

Application of Quantization: Steganography

Phototographer Unknown

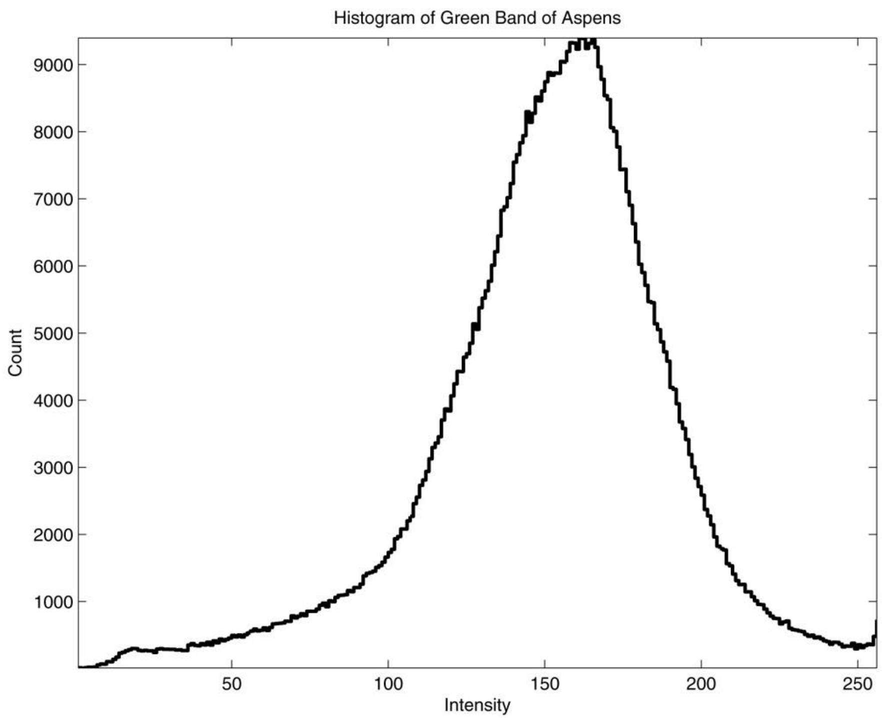
Histograms of Steganographs

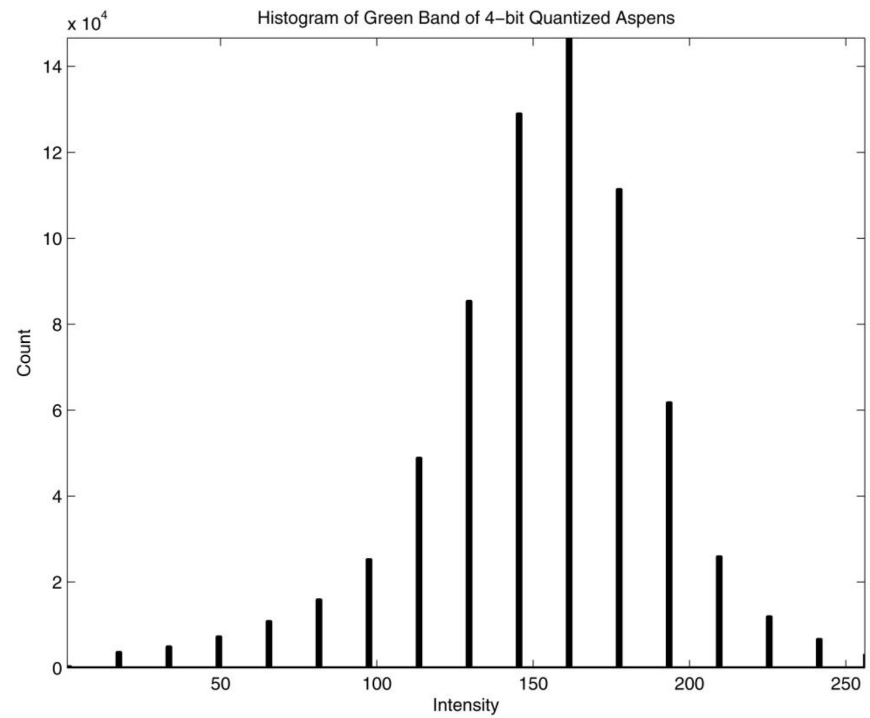




Graffiti image: although the histogram of the 4-bit quantized image (right) has gaps of 16 between adjacent nonzero bins, its overall shape is similar to the original (left).

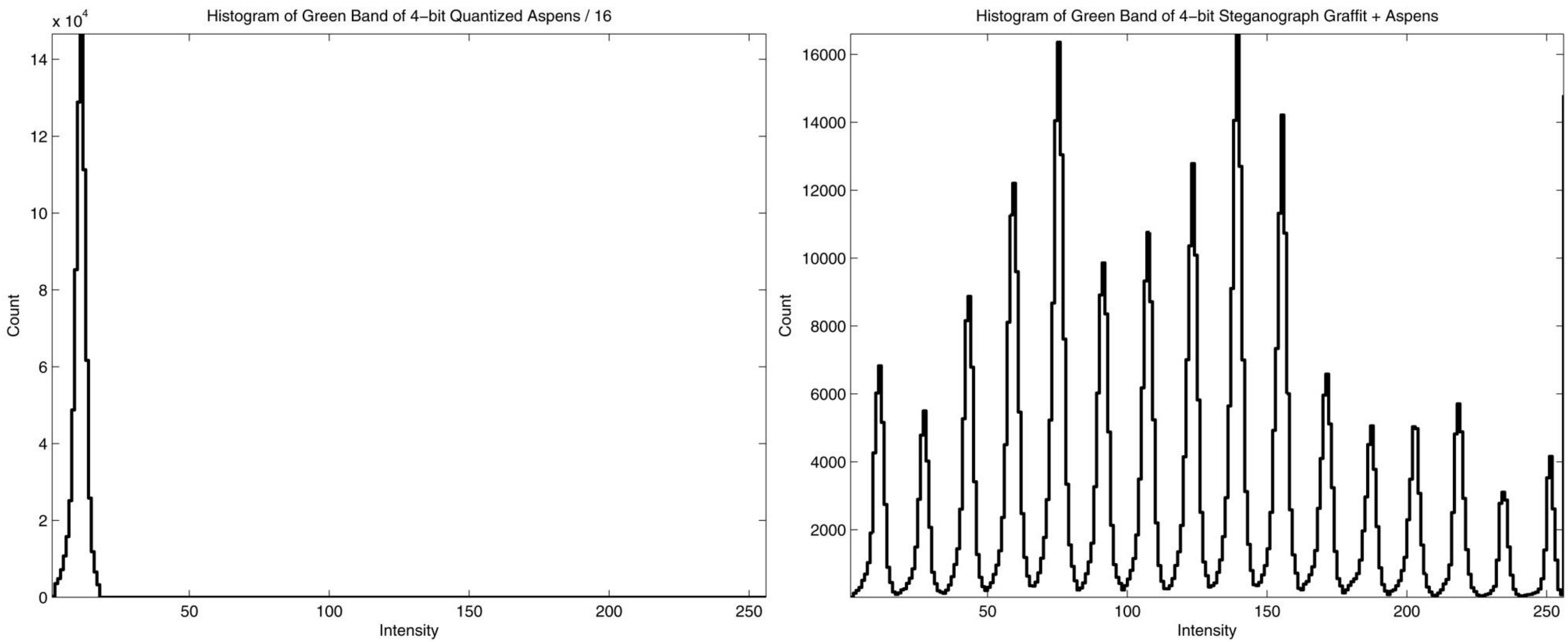
Histograms of Steganographs





Aspens image: again there are gaps of 16 between pixel values but the overall shape is preserved. Note the bell-shaped distribution. That is typical of natural scenes.

Histograms of Steganographs



Steganograph image: since the Aspens image's values are "riding on top" of the Graffiti images values, Aspen's pdf appears to be repeated at every nonzero bin of Graffiti.