# Basic Image Compression
# or
# Compression 101

Bernie Brower

NSES-Kodak

beranrd.brower@kodak.com

Derived from tutorial from Majid Rabbani

# BWC 101 Outline

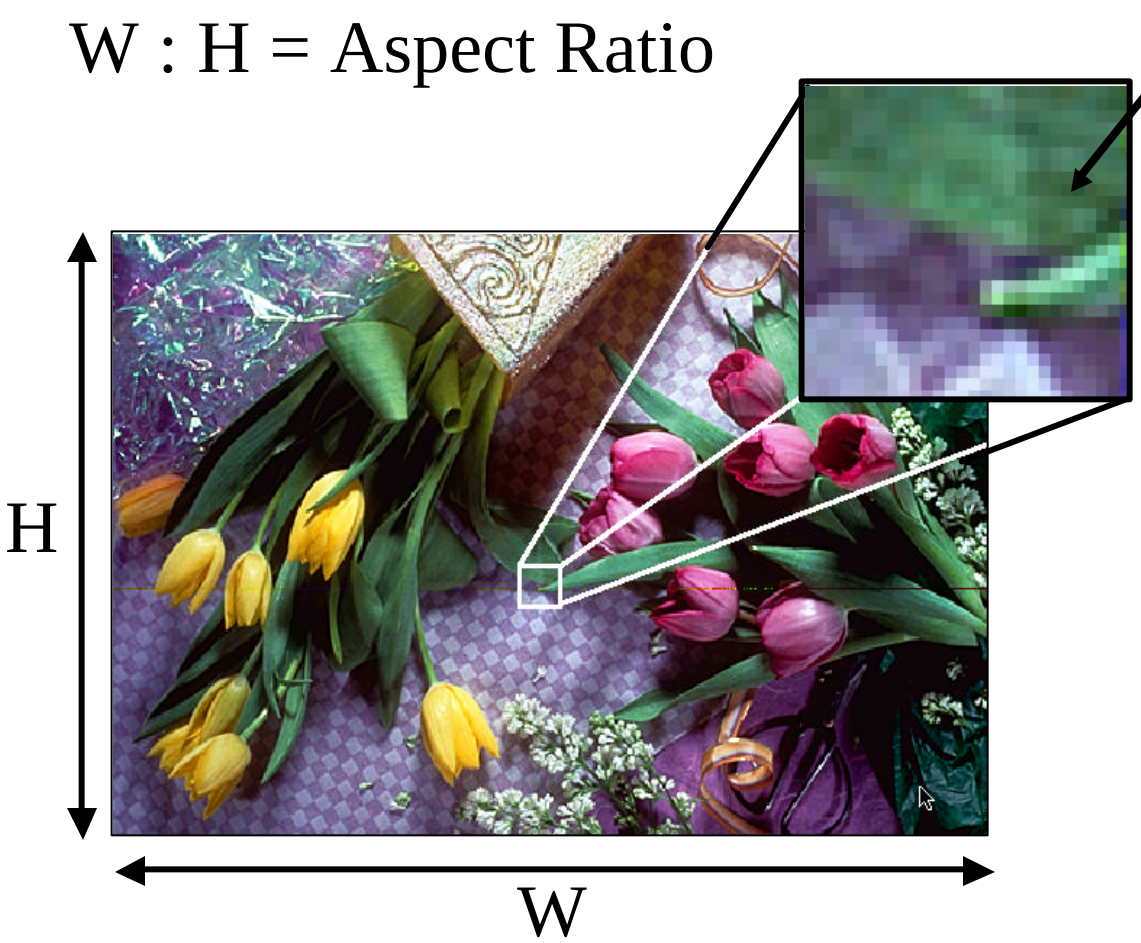
- Motivation for image compression
  - Digital images
  - Storage and transmission media
- Why images can be compressed
  - Redundancy
  - Irrelevancy
- Image compression basics
  - Transform (DPCM, DCT, Wavelet)
  - Quantization
  - Encoding (Huffman, arithmetic)
  - Rate Control
  - Color and Multidimensional transforms
- Selecting a compression algorithm
- Image compression standards
- Image compression systems
  - JPEG DCT
  - JPEG 2000
- Current Dissemination of Imagery
  - USIGS dissemination compression algorithms
- Migration of USIGS to JPEG 2000

# Digital Images

- Digital images are produced by:
  - Remote sensing satellites and aircraft
  - Digitized film and paper
  - Handheld cameras
  - Synthetic imaging (computer generation)
- Regardless, digital images are sampled in;
  - Space ⇨ Resolution (GSD, DPI)
  - Amplitude ⇨ Bit depth (bits per pixel)
  - Spectral ⇨ Resolution (# of bands/color)
- The area coverage or the size of the image "footprint" is dependent on the field of view of the camera system
- [High resolution] x [large bit depth] x [large size] x [large # of bands] = Storage and Transmission challenges

# Digital Image Representation

W : H = Aspect Ratio




<u>Pixel</u>

Red = 15

Green = 95

Blue = 27

<u>24 bits per Pixel</u>

R = 0 → 255

G = 0 → 255

B = 0 → 255

# Bits and Bytes

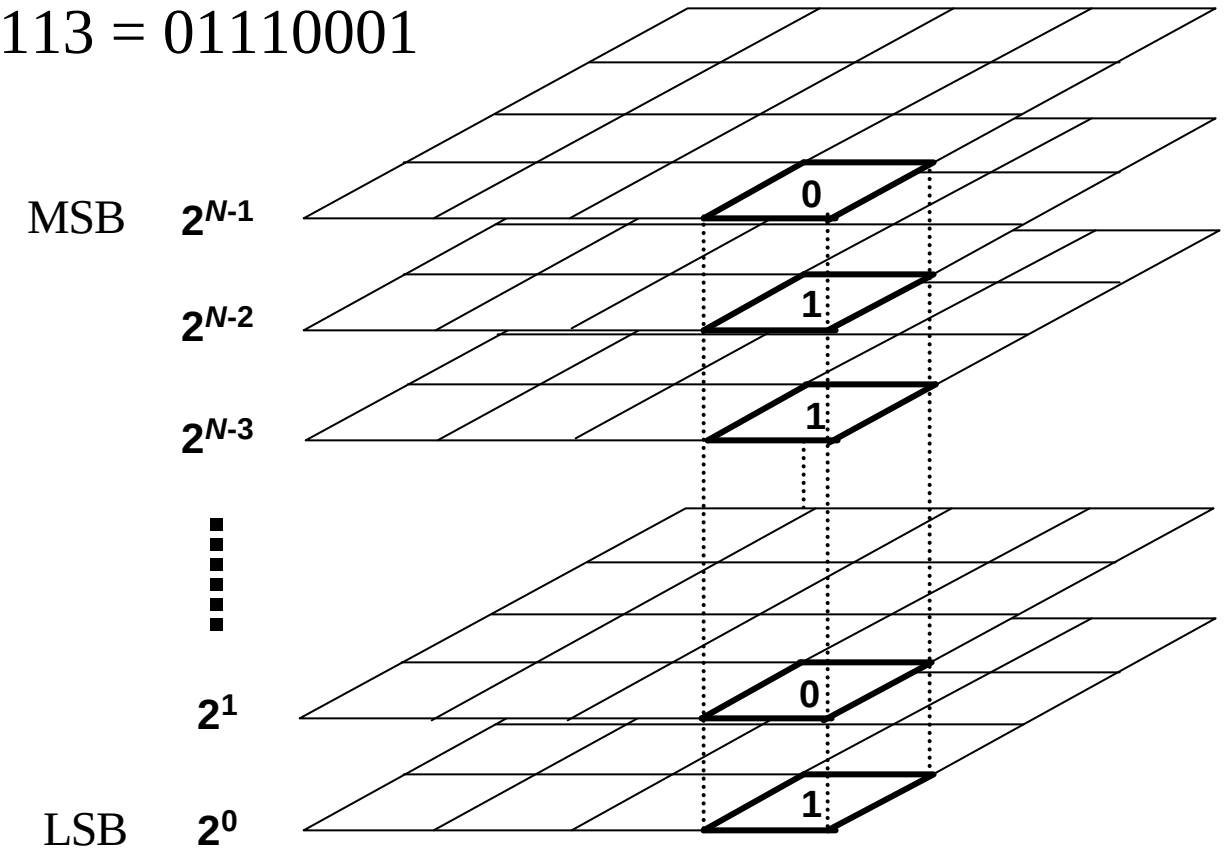
The following terminology is often used when referring to digital image sizes (**bit** is abbreviation for binary digit):

| | | |
|---|---|---|
| **bit (b)** | 1 bit | 1 bit |
| **byte (B)** | 8 bits | 8 bits |
| **kilobyte (KB)** | $2^{10}$ bytes | $10^3$ + 2.4% |
| **megabyte (MB)** | $2^{20}$ bytes | $10^6$ + 4.9% |
| **gigabyte (GB)** | $2^{30}$ bytes | $10^9$ + 7.4% |
| **terabyte (TB)** | $2^{40}$ bytes | $10^{12}$ + 10% |

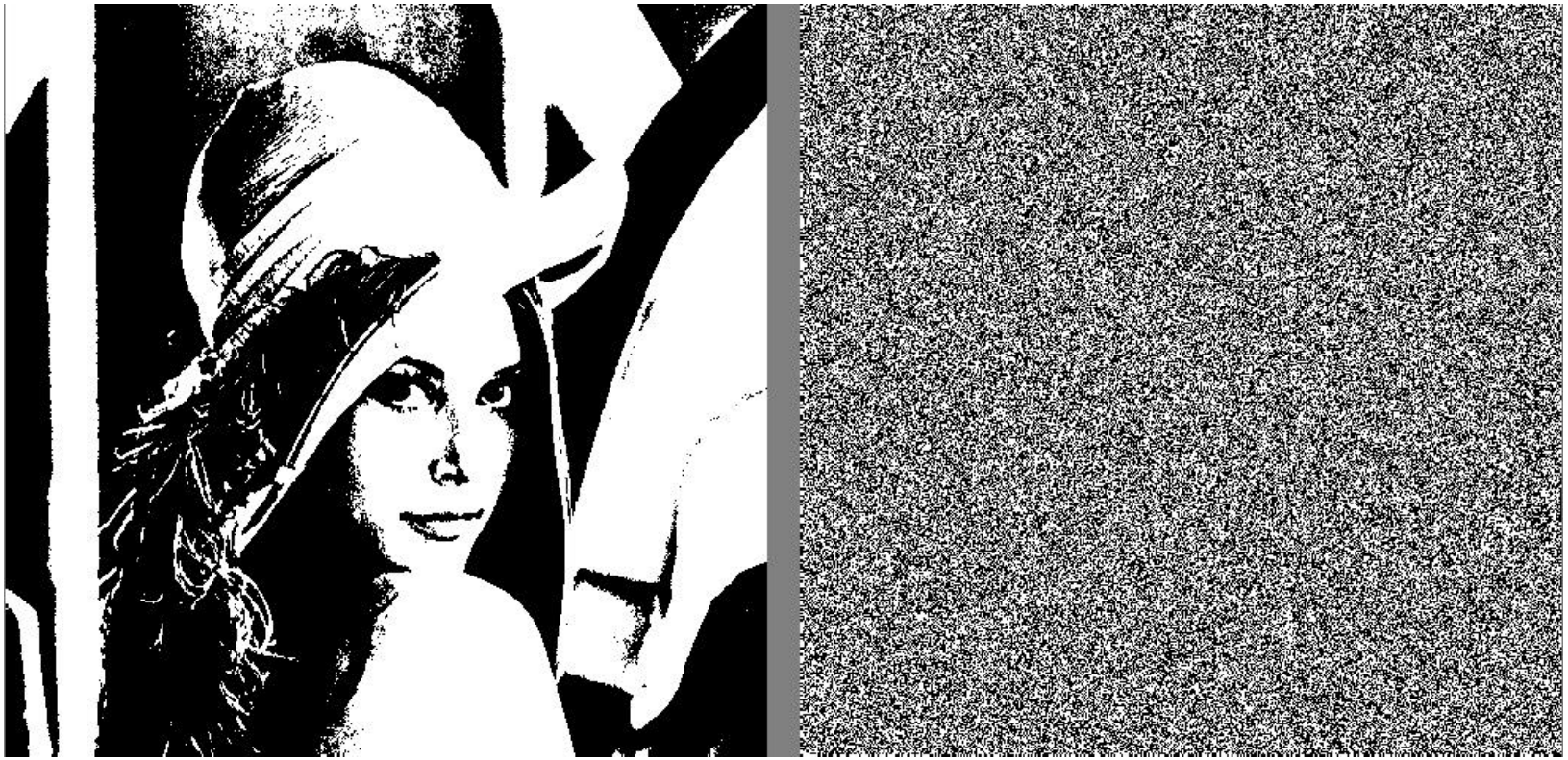
# Bit Plane Representation

An image with $n$ x $m$ pixels each with a bit-depth of $N$ bits can be represented by $N$ binary bit planes of size $n$ x $m$ ranging from the most significant bit (MSB) to the least significant bit (LSB).

$x(k,l) = 113 = 01110001$



# Example: Lena MSB and LSB Planes



Most significant bit plane  Least significant bit plane

# Example Images

- **Very Low Resolution Images**
  - **160 x 120** (4:2:2) **-** DCF standard; used for storing icon images in digital cameras.
  - **176 x 144** (4:2:0) **-** QCIF (Quarter Common Intermediate Format); used for video phones and visual telephony.
  - Many web-page images fall in this category.

- **Low Resolution Imagery**
  - **352 x 240** (4:2:0) **-** SIF (Source Image Format) @ 30 Hz picture rate (used in CD-I for movies on CD-ROM).
  - **352 x 288** (4:2:0) **-** CIF Format; also SIF @ 25 Hz picture rate (used for video teleconferencing).
  - Suitable for VHS-quality digital video; video-teleconferencing; or sharing pictures with e-mail.

# Example Images

- **Medium Resolution**
  - **640 x 480 -** VGA resolution
  - **800 x 600 -** SVGA resolution
  - **720 x 480** (4:2:0) **-** CCIR 601, DVD movies
  - **600 x 400** (4:2:0) **-** Kodak "Picture Disk" (24-exposure film scanned and stored on a floppy)
  - Suitable for NTSC or PAL Television viewing; 4R photographic prints; low- resolution digital cameras; PalmPix and PC cameras.
- **High Resolution**
  - **1536 x 1024** (4:2:0) **-** Kodak "Picture CD" (35mm film scanned and stored on a CD)
  - **1280 x 720** (4:2:0) **-** HDTV progressive @ 60 Hz (frames/s)
  - **1920 x 1080** (4:2:0) **-** HDTV interlace, @ 30 frames/s
  - **1760 x 1168 -** Kodak DC280 (2 megapixel) Digital Camera
  - Suitable for 8" x 10" photographic prints, high-definition monitors, digital cinema.

# Very High-Resolution Images

- **3060 x 2036** - Kodak DCS 460 Professional digital camera
- Approaching the the resolution limit of the 35mm film; high-end professional cameras; very high-quality or large size printing.
- Some professional applications scan film at twice this resolution (e.g., Cineon)

# Examples of Digital Still Images

| Application | Pixels | Lines | bpp | Filesize |
|---|---|---|---|---|
| Facsimile | 1728 | 1100 | 1 | 240 KB |
| Icons | 192 | 128 | 24 | 72 KB |
| Kodak Picture Disk | 600 | 400 | 24 | 700 KB |
| Still-Video | 768 | 512 | 24 | 1.1 MB |
| DC 280 (Kodak) | 1760 | 1168 | 24 | 6 MB |
| Kodak Picture CD | 1536 | 1024 | 24 | 4.5 MB |
| DCS-465 (Kodak) | 3072 | 2048 | 24 | 18 MB |
| Kodak Photo CD | 3072 | 2048 | 24 | 18 MB |

# Examples of Digital Video Sequences

| Application | Pixels | Lines | bpp | f/s | Data Rate |
|---|---|---|---|---|---|
| Video Phone 4:2:0 | 176 | 144 | 12 | 15 | 540 KB/s |
| SIF – 4:2:0 | 352 | 240 | 12 | 30 | 3.6 MB/s |
| CCIR 601 - 4:2:0 | 720 | 480 | 12 | 30 | 15 MB/s |
| CCIR 601 - 4:4:4 | 720 | 480 | 24 | 30 | 30 MB/s |
| HDTV (Interlace) | 1920 | 1080 | 24 | 30 | 180 MB/s |
| HDTV (progressive) | 1280 | 720 | 24 | 60 | 160 MB/s |
| Cineon | 3656 | 2664 | 30 | 24 | 1 GB/s |

# Examples of Storage Media

## Optical

## Magnetic

## Solid State

# Examples of Storage Media

| Media | Type | Capacity |
|---|---|---|
| Floppy Disk | Magnetic | 1.4 MB |
| Zip Disk | Magnetic | 100 & 250 MB |
| Jaz Disk | Magnetic | 1 & 2 GB |
| 8mm Cartridge | Magnetic | Up to 70 GB |
| D2C | Magnetic | 25 GB |
| CD-ROM | Optical | 650 MB |
| DVD-120mm | Optical | 4.7 GB |
| DVD-80mm | Optical | 1.9 GB |
| Compact Flash | Solid State | 1-200 MB |
| Memory Stick | Solid State | 32 & 64 MB |

# Examples of Transmission Media

| Media | Bandwidth |
|---|---|
| Dial-Up Telephone | 33.6-56 Kb/s |
| ISDN (Integrated Services Digital Network) | 64 Kb/s |
| T1 (24 x ISDN) | 1.544 Mb/s |
| Ethernet | 10 Mb/s |
| Fast Ethernet | 100 Mb/s |
| Ultra-Fast Ethernet | 1 Gb/s |
| Cable Modem | 1-2 Mb/s |
| FDDI (Fiber Distributed Data Interchange) | 100 Mb/s |

# Examples of Transmission Media

| Media | Bandwidth |
|---|---|
| Cell Phone (US) | 9.6 – 14.4 Kb/s |
| IR (Infra-Red)<br>Line-of-sight | 115 kb/s – 16 Mb/s |
| Bluetooth RF | 400 Kb/s |
| Bluetooth RF<br>(Asymmetric) | 741 Kb/s Downstream<br>56 Kb/s Upstream |
| Kodak RF | 16 Mb/s |
| DSL<br>(Asymmetric) | 384 Kb/s – 1.5 Mb/s Downstream<br>128 Kb/s – 750 Kb/s Upstream |

# Image Transmission Example

| Media | Time seconds |
|---|---|
| Cell Phone | 417 |
| 28.8 Modem | 139 |
| ISDN | 62 |
| Asymmetric DSL (Downstream) | 10 |
| Bluetooth | 5.5 |
| Cable Modem (1 Mb/s) | 4 |
| IR (4 Mb/s) | 1 |
| RF (16 Mb/s) | 1/4 |

For an uncompressed VGA 640 x 480 (4:2:0) image ~500KB

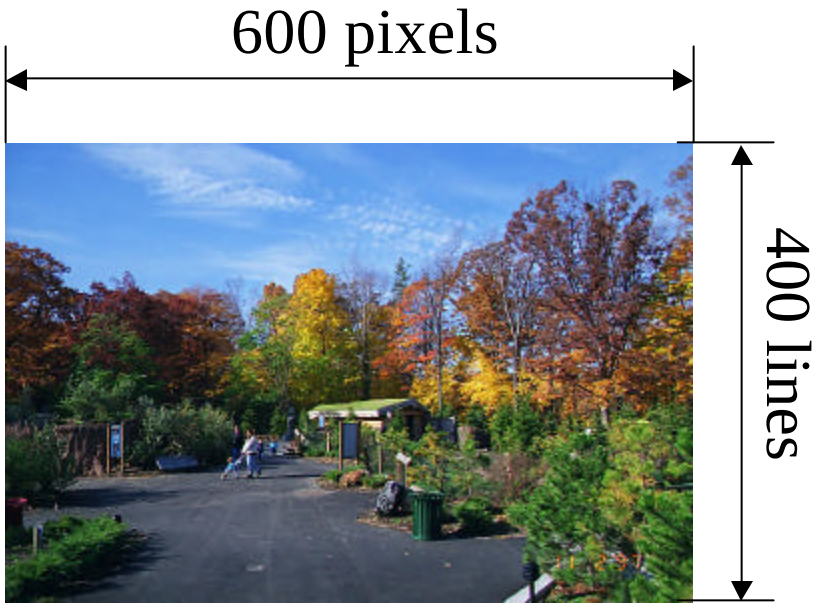
# Kodak Picture Disk

- Scanned images from a 24-exposure roll are stored in a floppy disk with a 1 MB of useful space.

Filesize for a single image: $600 \times 400 \times 3 = 720$ KB

$720 \text{ KB} \times 24 \text{ exp.} = 16.5 \text{ MB}$

A compression ratio of 17:1 is needed to achieve this goal.

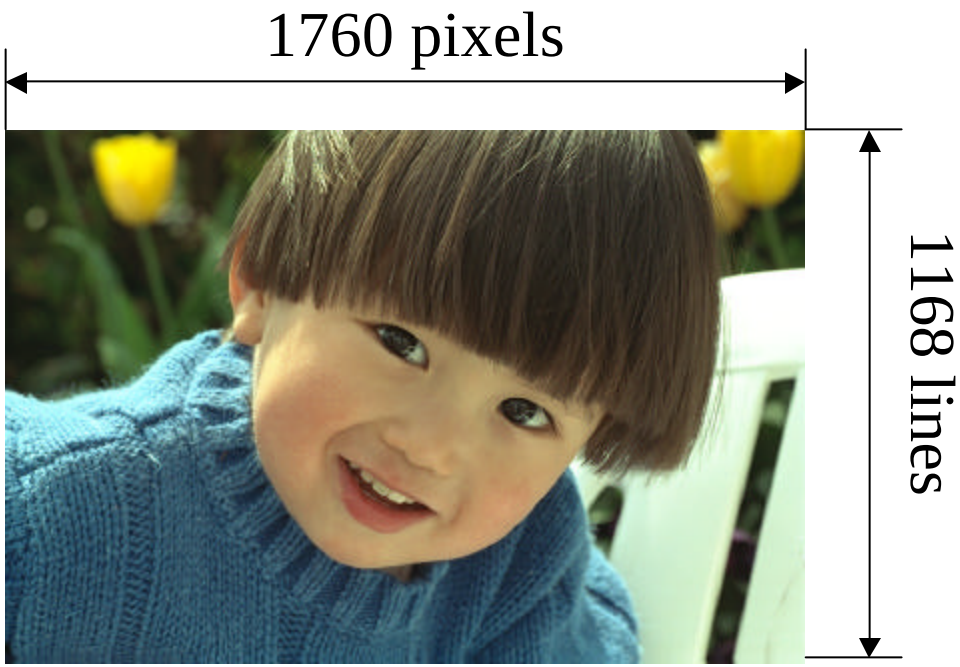


# Kodak Picture CD

- Scanned images from film are written on a CD @ 600 KB/s (4X write speed).
- A single uncompressed image takes 7.5 seconds to write; a 36-exposure roll takes 270 seconds.

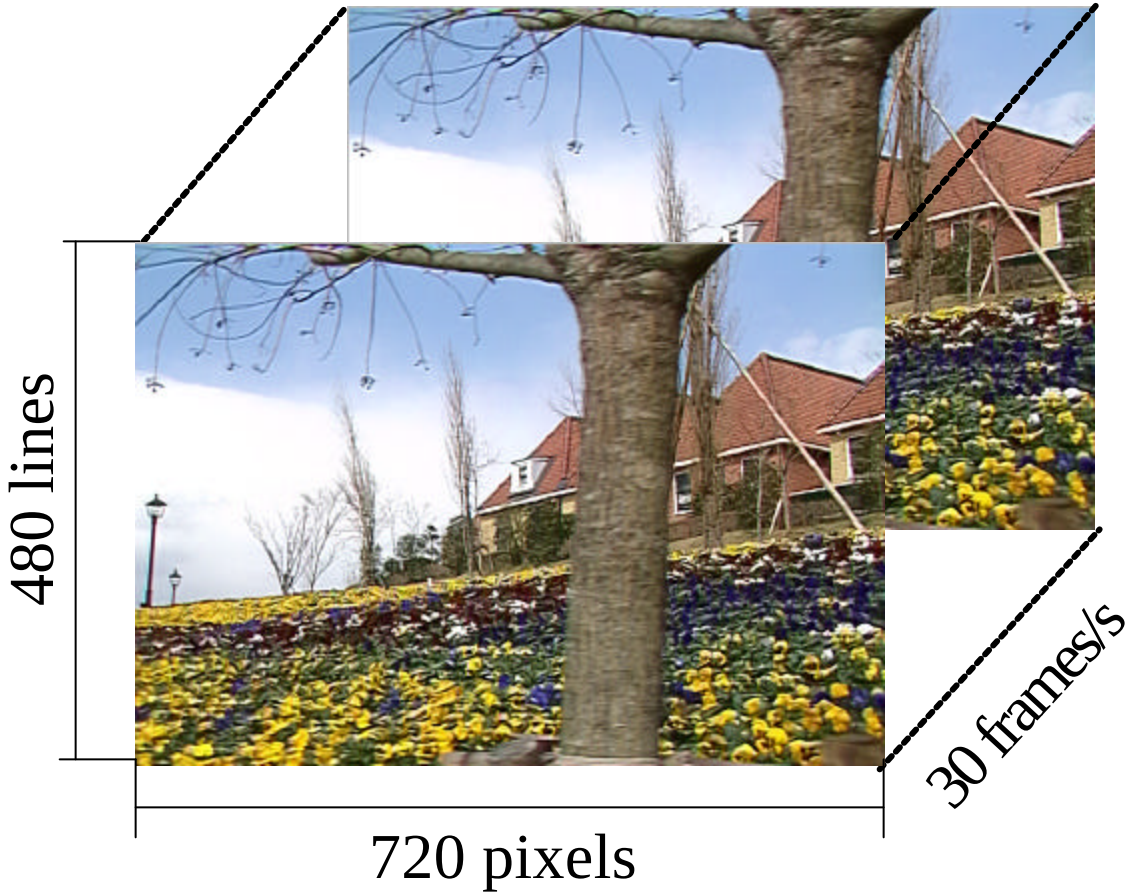
# Digital Camera

- Kodak DC280 digital camera creates a 6 MB image after color interpolation.
- An 64 MB compact flash card will hold about 10 images.



# Movies on DVD

- The full resolution RGB uncompressed DVD movie has a rate of ~60 MB/sec, i.e., a DVD disc holds ~1 minute of uncompressed video!



# Aerial Photograph

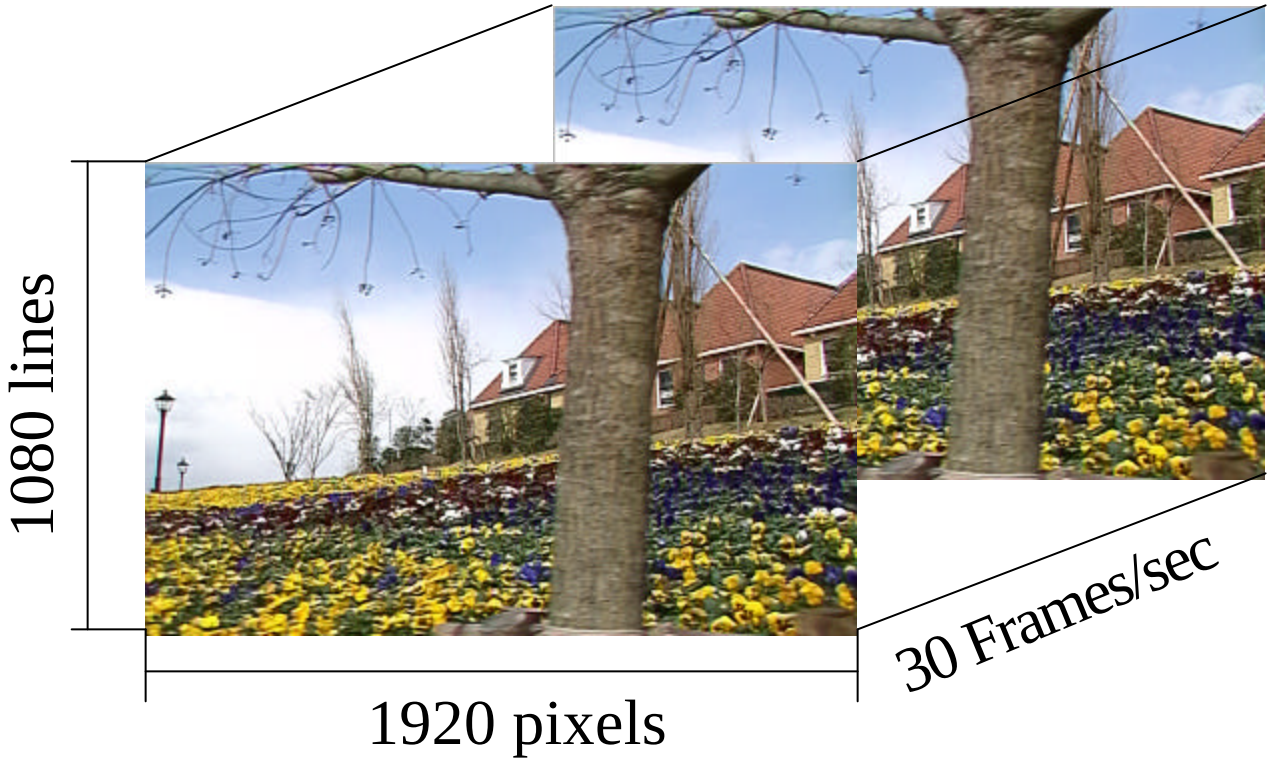
- 10” Aerial Mapping Camera at about 6” resolution
- 2.35 Square Miles of Coverage (about 1.5 Miles on a side)
- 16,000-by-16,000 pixels, 3 bands, 8 bits per band
- 730 MB uncompressed image does not fit on CD

# Satellite Image

- IKONOS or Digital Globe Images
- 10K-by-10K, 5 bands, 10 bits per pixel

# HDTV Transmission

- 1920 pixels × 1080 lines × 3 colors × 30 f/s ~ 180 MB/s
- At 18 Mb/s, a compression ratio of ~80:1 is required.



# Need For Image Compression

| Application | Size / Rate | CR | Method |
|---|---|---|---|
| Digital Camera | 1-10 MB | >10 | JPEG |
| Facsimile | 240 KB | 20 | G3 & G4 |
| CD-I (SIF 4:2:0) | 3.6 MB/s | 25 | MPEG 1 |
| DVD (CCIR 601 4:2:0) | 15 MB/s | 25 | MPEG 2 |
| HDTV | 89 MB/s | 70 | MPEG 2 |
| Teleconferencing | 9 MB/s | 50 | H.261 |
| Video Phone (QCIF) | 0.54 MB/s | 80 | H.263 |

# Image Compression

- Aims at finding methods for reducing the number of bits needed to represent a digital image without compromising the required image quality for a given application.
- Image compression is used to:
  - Reduce memory for image storage.
  - Reduce the bandwidth/time required for image transmission.
  - Increase effective data transfer rate.

# Why images can be compressed

# What is digital image compression

- Image compression is the art/science of finding efficient representations for digital images in order to:
  - Reduce the memory required for their storage,
  - Reduce the effective data access time when reading from storage devices,
  - Reduce the bandwidth and/or the time required for their transfer across communication channels.

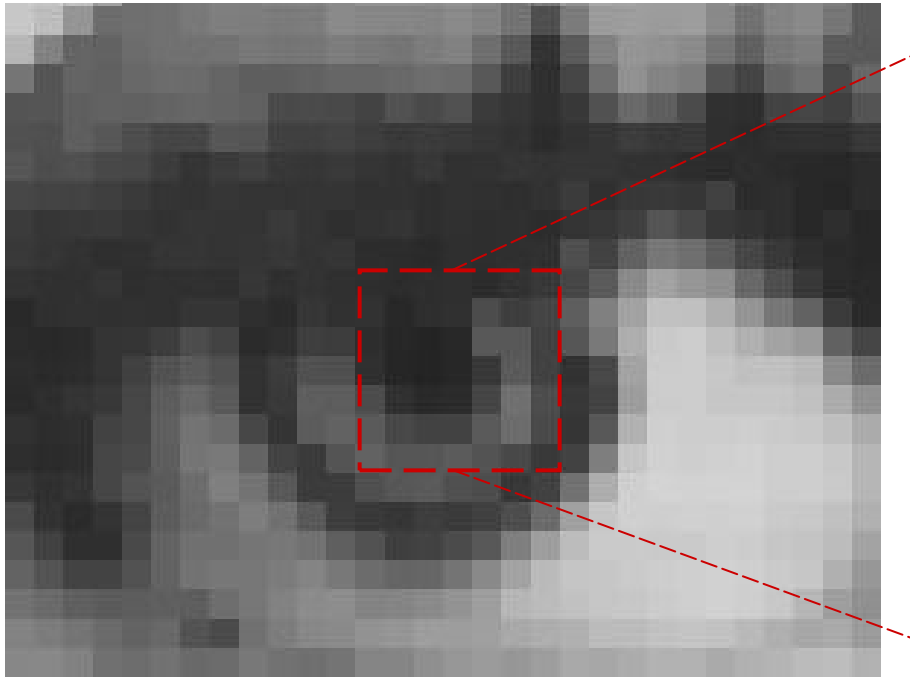
- The goal is to achieve the desired bit rate without compromising the image quality required for a given application.

# Why can images be compressed?

- Image compression can be achieved because image data are often highly redundant and/or irrelevant. The redundancy or irrelevancy exist in **spatial**, **spectral**, and **temporal** forms.
  - **Redundancy** relates to the statistical properties of an image (e.g., pixel-to-pixel correlation, spectral (RGB) correlation, frame-to-frame similarity, etc.) and is a function of resolution, bit-depth, image noise, and image detail.
  - **Irrelevancy** relates to an observer viewing an image (HVS spatial and temporal CSF, visual masking, etc.) and is a function of image resolution, noise, detail, and viewing conditions.

# Spatial Redundancy And Irrelevancy

- What is the value of the missing pixel? **(39)**
- How critical is its exact reproduction?



| | | | | | | |
|---|---|---|---|---|---|---|
| 46 | 44 | 46 | 47 | 44 | 50 | 56 |
| 50 | 40 | 46 | 48 | 76 | 62 | 69 |
| 45 | 39 | 36 | 40 | 88 | 87 | 65 |
| 48 | 38 | 36 | ? | 56 | 90 | 65 |
| 76 | 48 | 41 | 43 | 69 | 112 | 77 |
| 90 | 72 | 66 | 66 | 90 | 108 | 74 |
| 98 | 86 | 86 | 91 | 83 | 72 | 57 |

# Example: Original and Difference Images

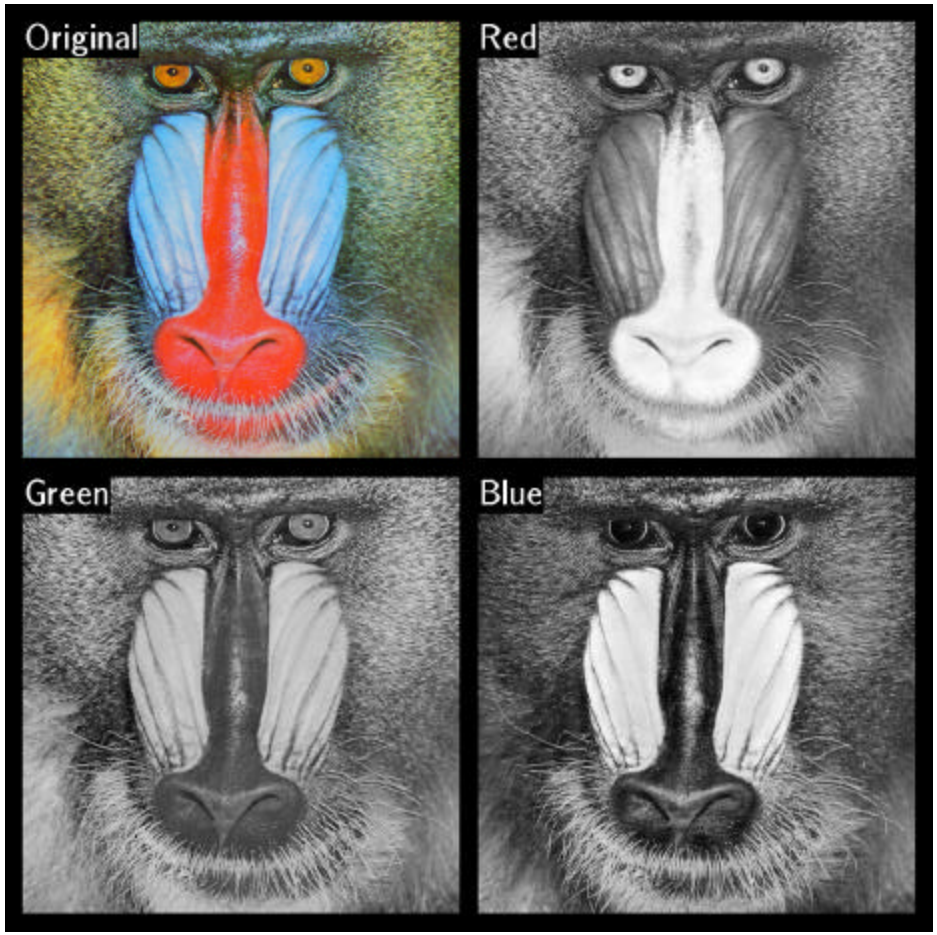
| | | | | | | | |
|---|---|---|---|---|---|---|---|
| 139<br>139 | 144<br>+5 | 149<br>+5 | 153<br>+4 | 155<br>+2 | 155<br>0 | 155<br>0 | 155<br>0 |
| 144<br>+5 | 151<br>+7 | 153<br>+2 | 156<br>+3 | 159<br>+3 | 156<br>-3 | 156<br>0 | 156<br>0 |
| 150<br>+6 | 155<br>+5 | 160<br>+5 | 163<br>+3 | 158<br>-5 | 156<br>-2 | 155<br>0 | 155<br>0 |
| 159<br>+9 | 161<br>+2 | 162<br>+1 | 160<br>-2 | 160<br>0 | 159<br>-1 | 159<br>0 | 159<br>0 |
| 159<br>0 | 160<br>+1 | 161<br>+1 | 162<br>+1 | 162<br>0 | 155<br>-7 | 155<br>0 | 155<br>0 |
| 161<br>+2 | 161<br>0 | 161<br>0 | 161<br>0 | 160<br>-1 | 157<br>-3 | 157<br>0 | 157<br>0 |
| 162<br>+1 | 162<br>0 | 161<br>-1 | 163<br>+2 | 162<br>-1 | 157<br>-5 | 157<br>0 | 157<br>0 |
| 162<br>0 | 162<br>0 | 161<br>-1 | 161<br>0 | 163<br>+2 | 158<br>-5 | 158<br>0 | 158<br>0 |

# Spatial Redundancy

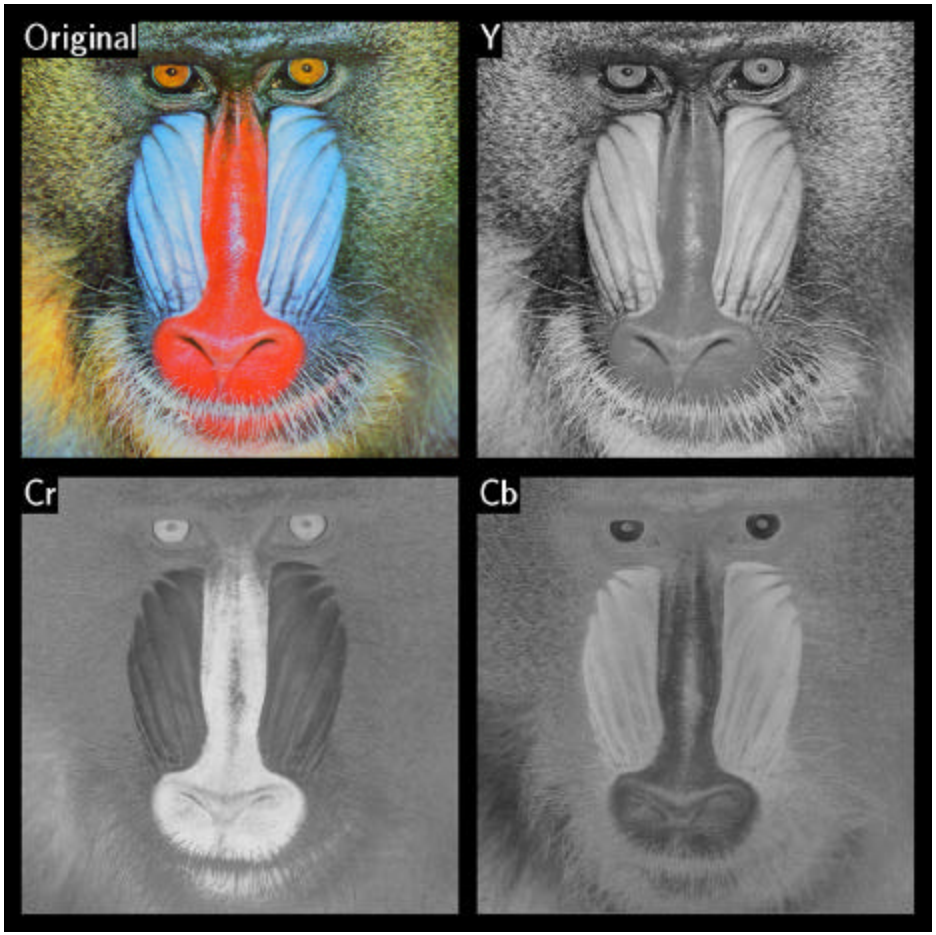
- The difference between two adjacent pixels has a very skewed distribution centered around zero.

# Spectral Redundancy

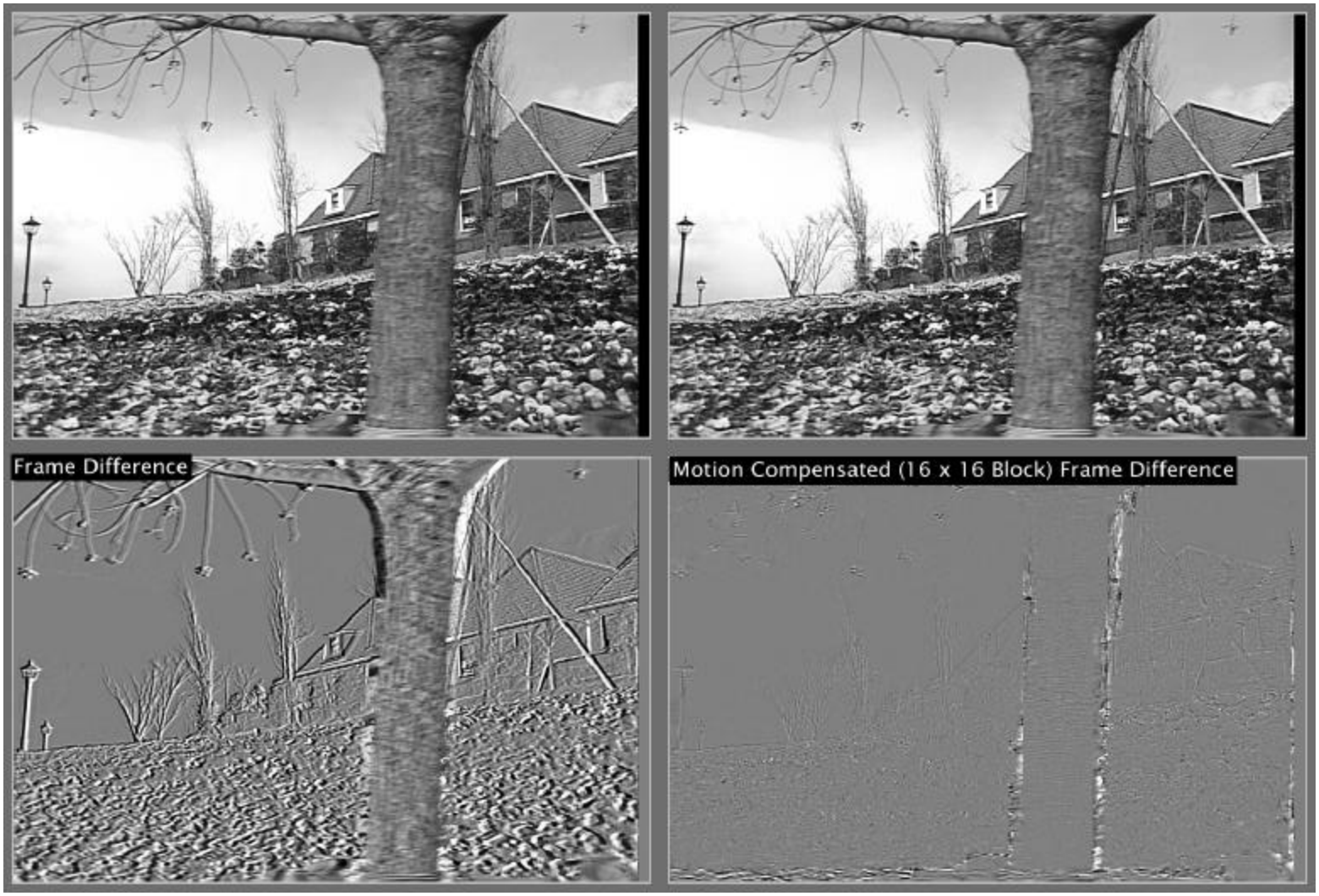
## Original RGB




## Transformed YCrCb



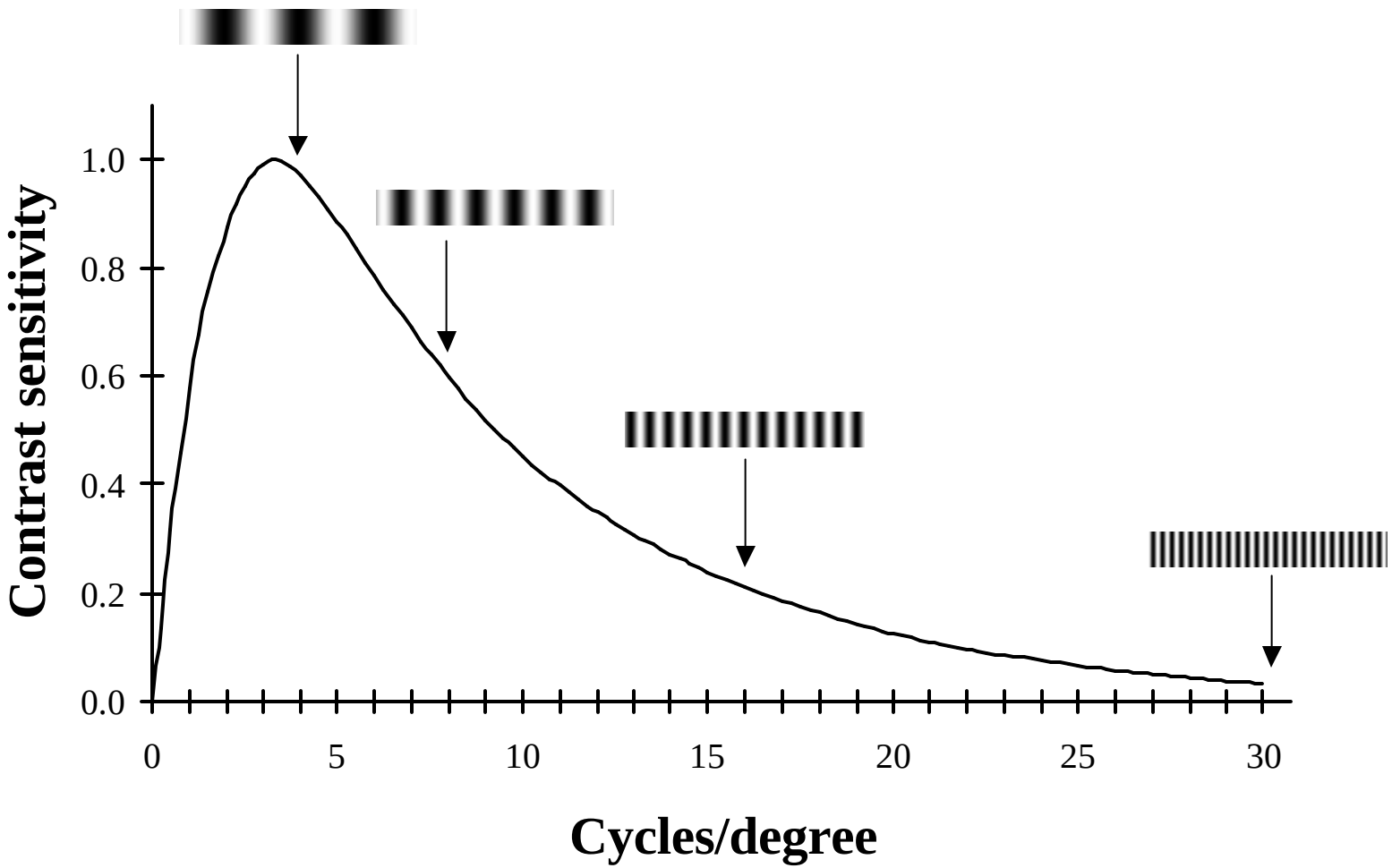
# Temporal Redundancy



# The Human Visual System CSF

- The frequency-dependent behavior of the human visual system (**HVS**) can be characterized by its response to harmonic (sinusoidal) functions.
- For each sinusoid with a given frequency, the amount of contrast needed to elicit a criterion level of response from a neuron is called the **contrast threshold**.
- The inverse of the contrast threshold is called the **contrast sensitivity** and when plotted as a function of frequency is referred to as the **contrast sensitivity function (CSF)**.
- The luminance CSF peaks at around 5 cycles/degree, and rapidly drops off to almost zero at 50 cycles/degree. The chrominance CSF drops even faster.

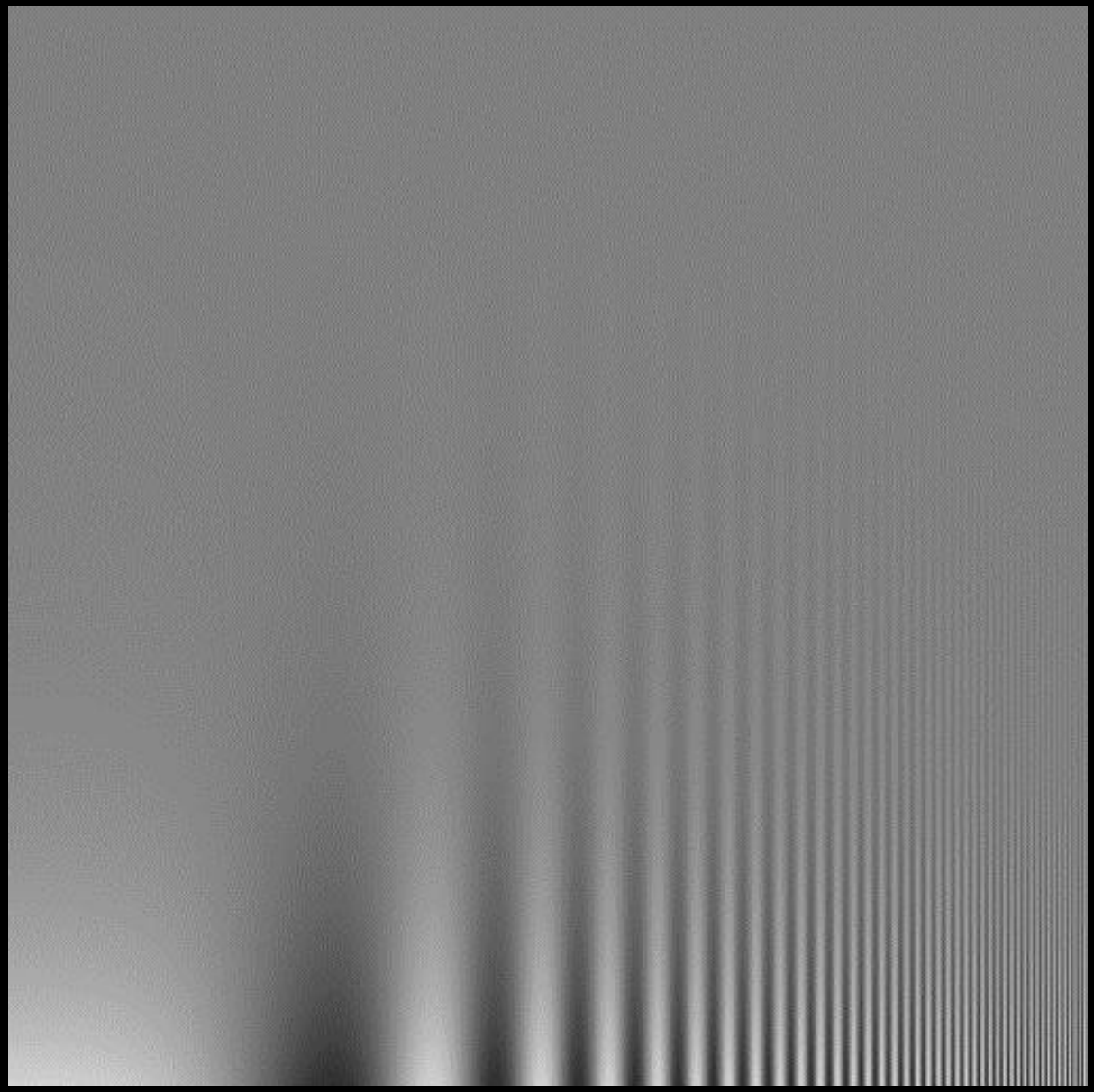
# Example of Luminance CSF



NIMA

Systems Engineering Services

Kodak



# Visual Masking

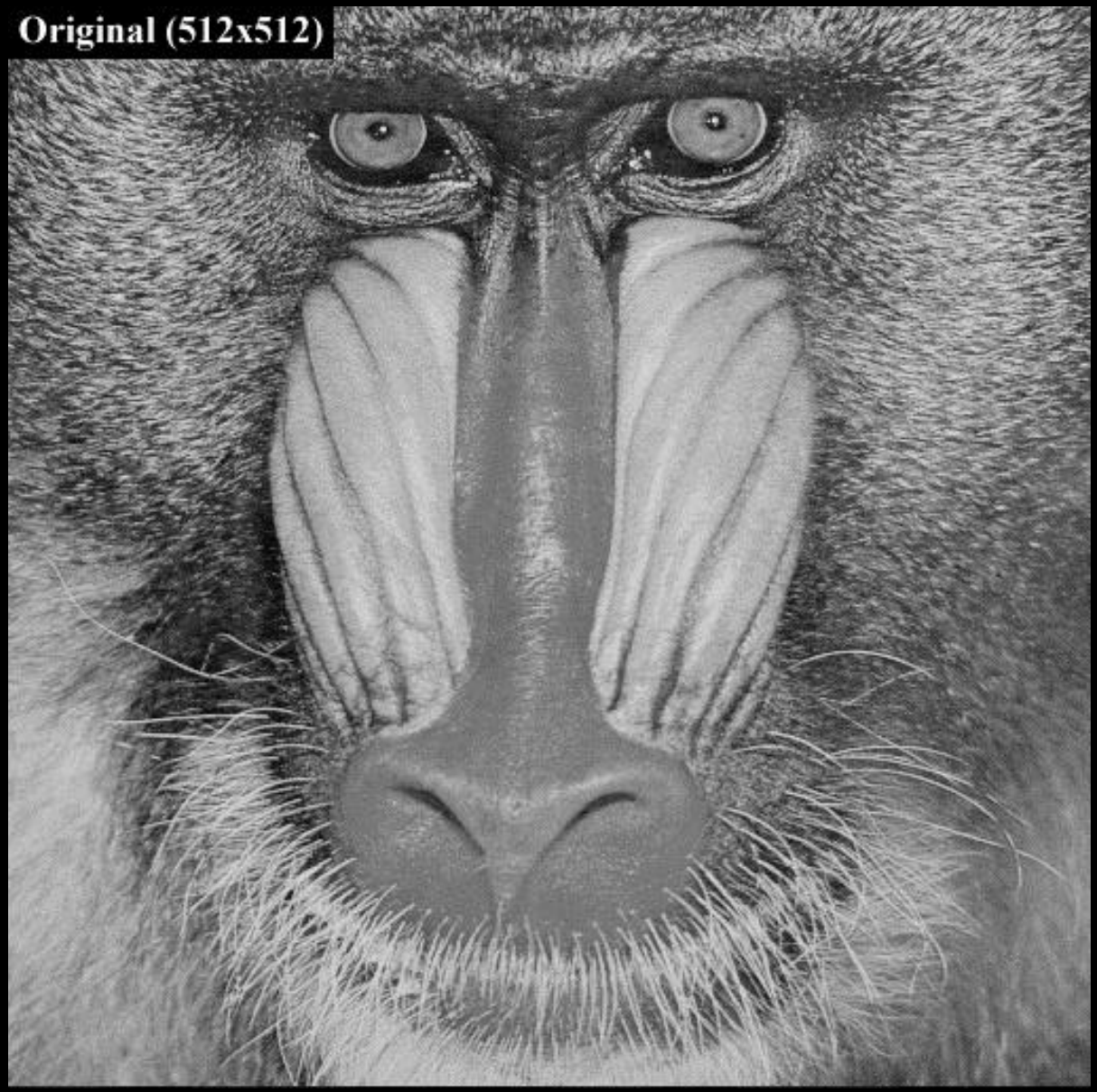
- **Visual masking** refers to the decreased visibility of a signal due to the presence of a supra-threshold background.
  - The HVS is fairly sensitive to changes in flat areas and rather insensitive to changes in busy or detailed regions.
  - The HVS is more tolerant of noise in busy areas compared to flat areas.
- Visual masking can be utilized in JPEG2000 and MPEG to introduce more compression errors in the busy regions of an image compared to the flat regions.

NIMA
Systems Engineering Services

Kodak

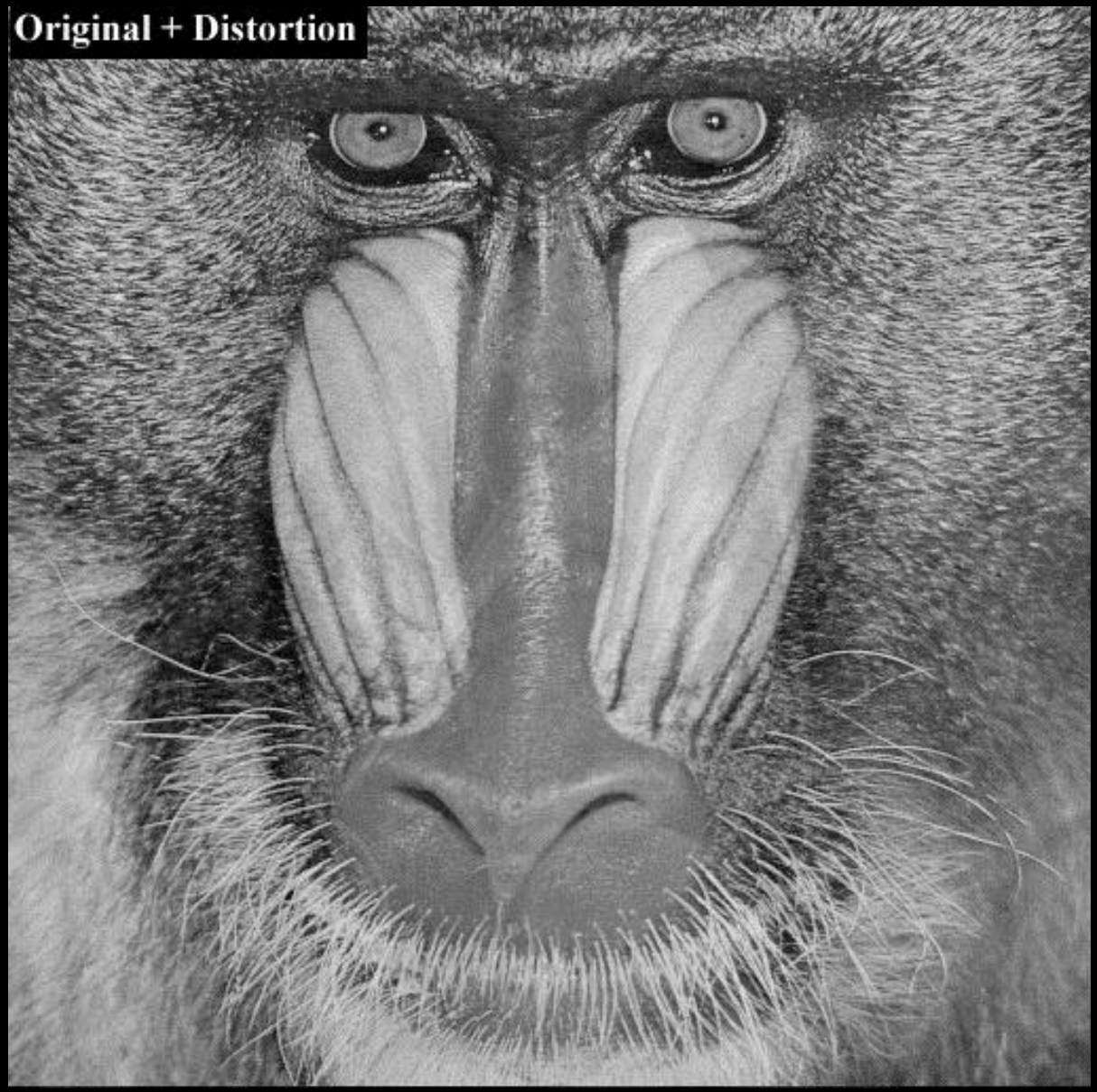
NIMA
Systems Engineering Services

Kodak



NIMA
Systems Engineering Services

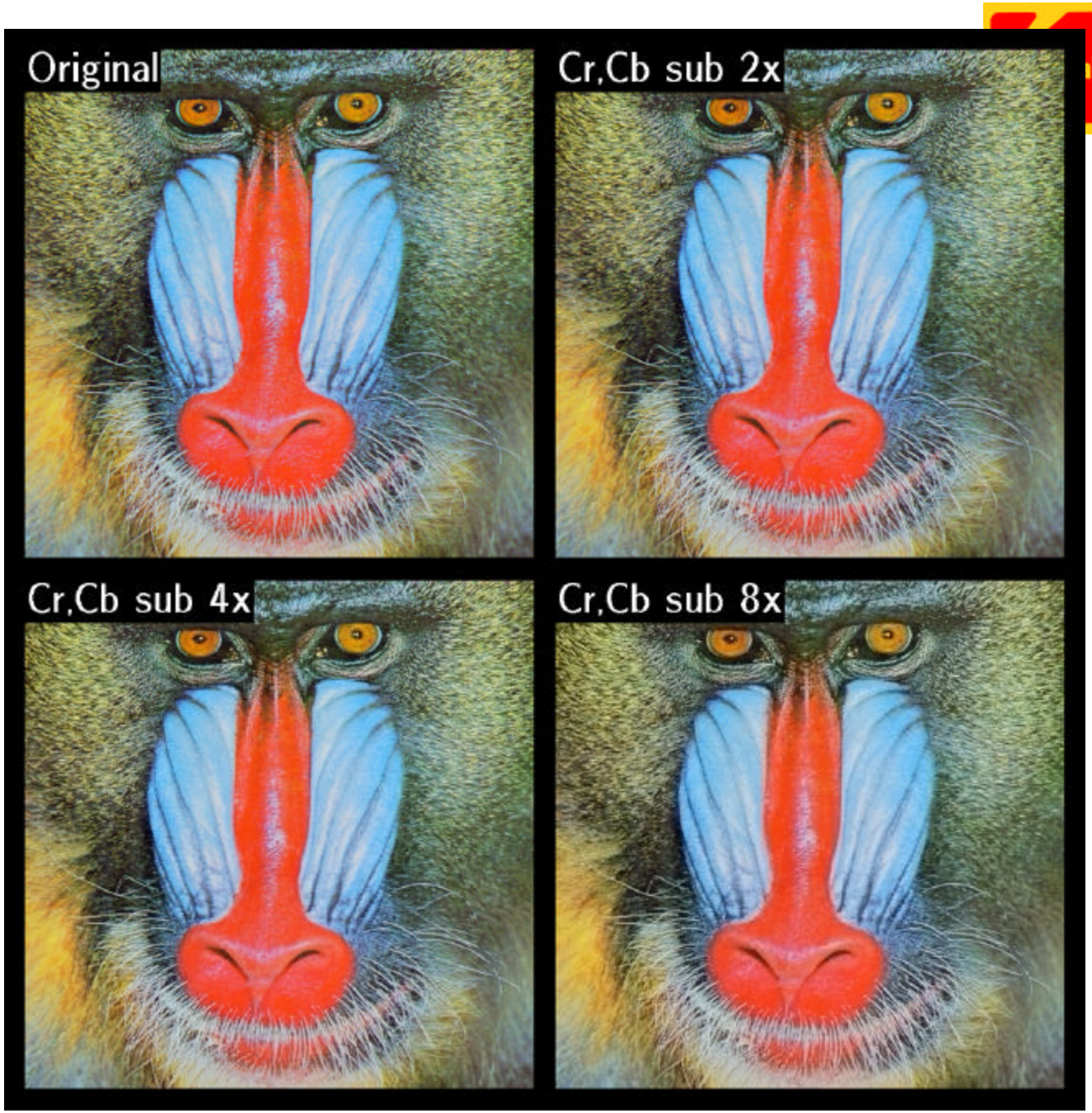
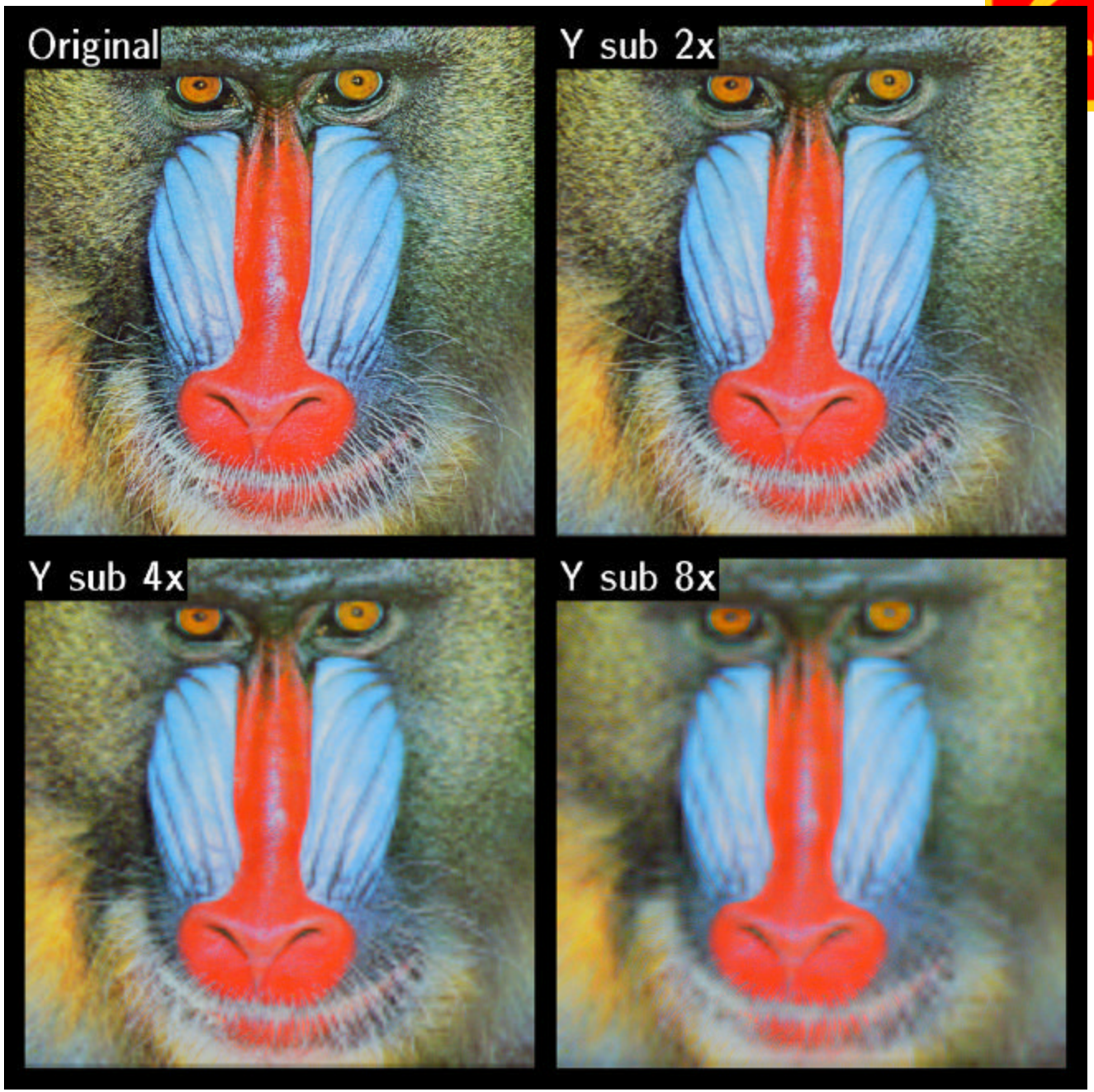
Kodak



NIMA
Systems Engineering Services

Kodak

# Chrominance Sub-sample



# Intensity Sub-sample