CENG 477
Introduction to Computer Graphics

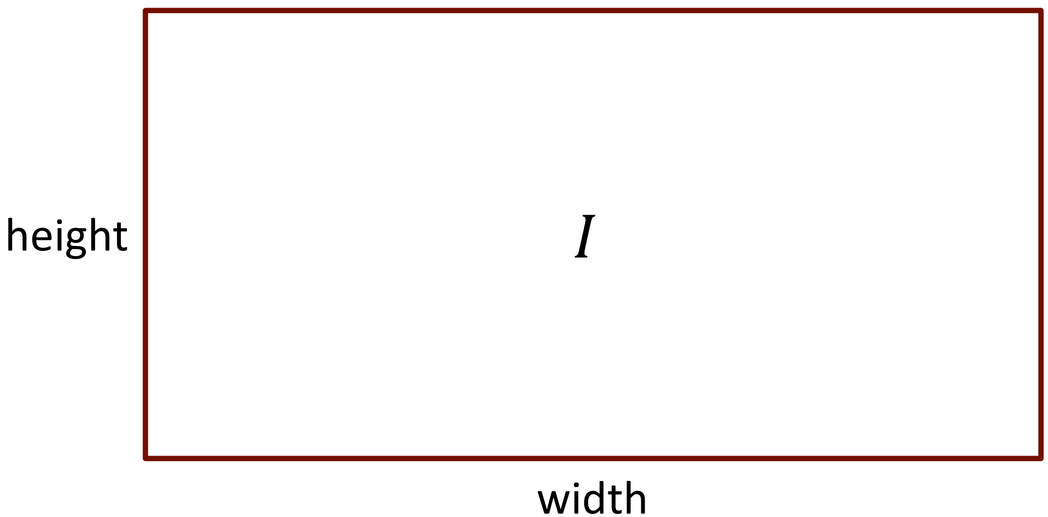
Images, Cameras, Displays

Images and Displays

- Computer graphics is all about creating and displaying images
- A video is nothing but an image sequence
- A computer game is nothing but many images rendered at rapid succession
- As such, we should first understand what an image is and how it is displayed

Image

- An image, or a digital image, is an intensity distribution over a bounded two dimensional region
- More formally, $I: \mathbb{R}^2 \rightarrow \ldots$

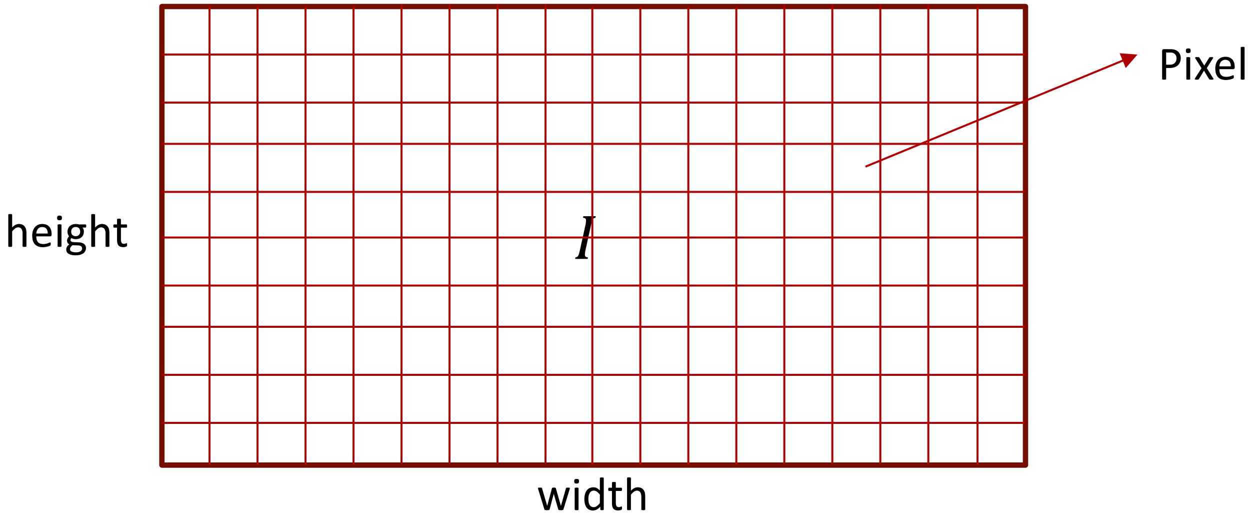


Image

- In practice, we place two restrictions in order handle images on a computer:
  - Discretization
  - Data type

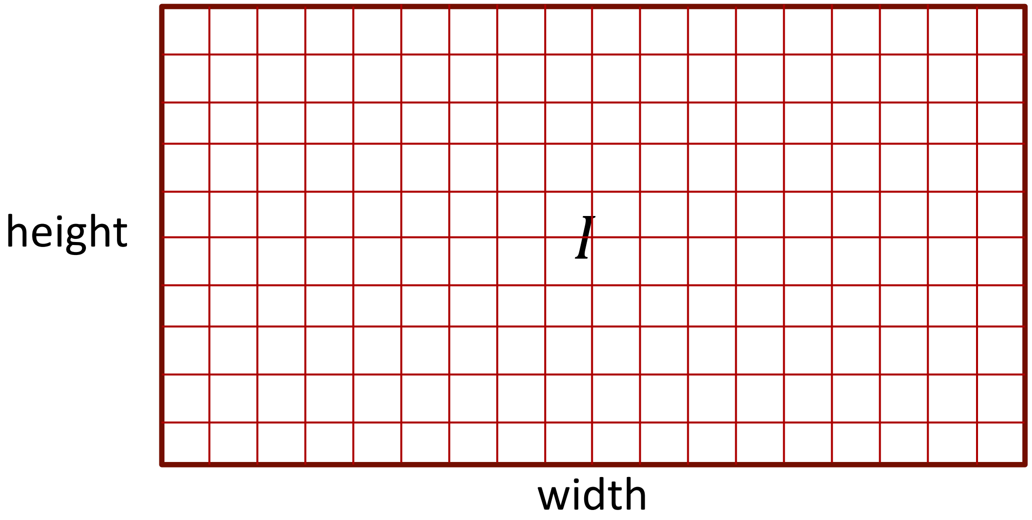
Discretization

- Discretization is the partitioning of the image region to a non-overlapping grid
- Each cell is called a pixel (short for picture element)



Discretization

- The total number of pixels in an image called image resolution
- The same term is used for display devices as well

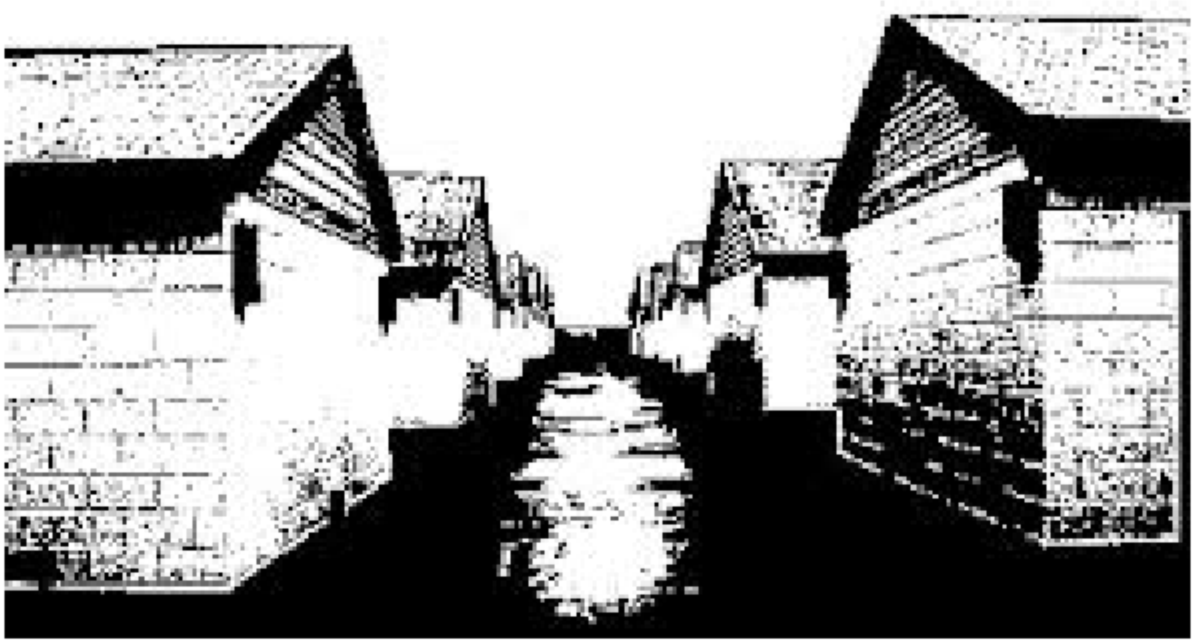


Data Type

- Data type represents what can be stored in a pixel
  - Bitmaps: $I: \mathbb{R}^2 \rightarrow \{0,1\}$
  - Grayscale: $I: \mathbb{R}^2 \rightarrow \{0,1,\dots,255\}$
  - Color: $I: \mathbb{R}^2 \rightarrow \{0,1,\dots,255\}^3$
  - Color (generalized): $I: \mathbb{R}^2 \rightarrow \mathbb{R}^3$

Bitmap

- A sample bitmap image (1 bpp):



Grayscale

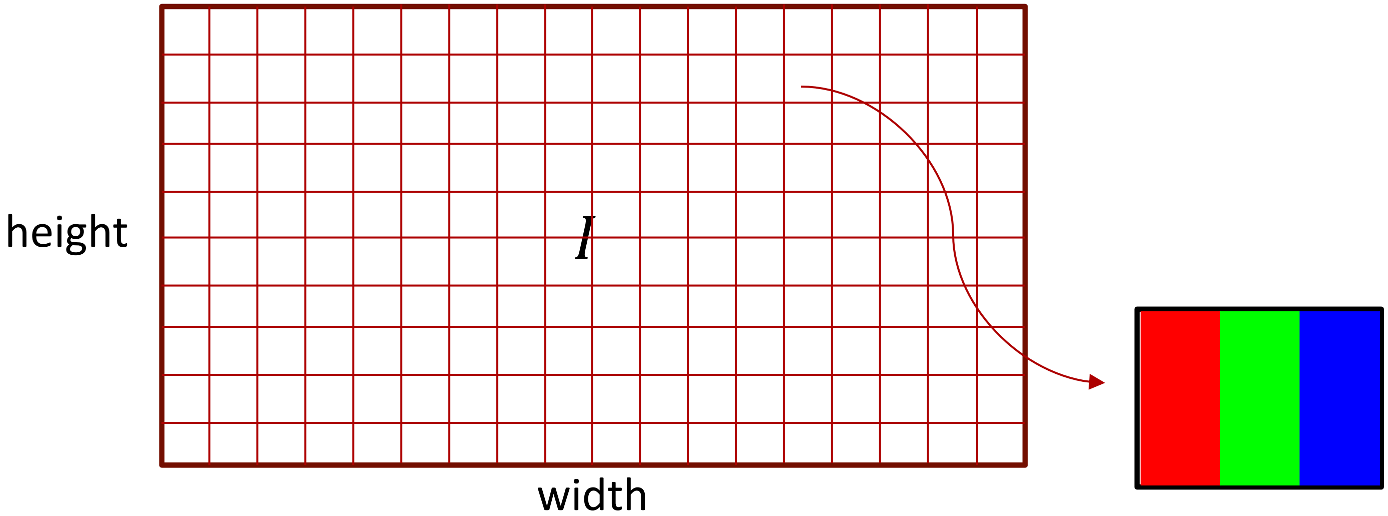
- A sample grayscale image (8 bpp):

Color

- A sample color image (24 bpp):

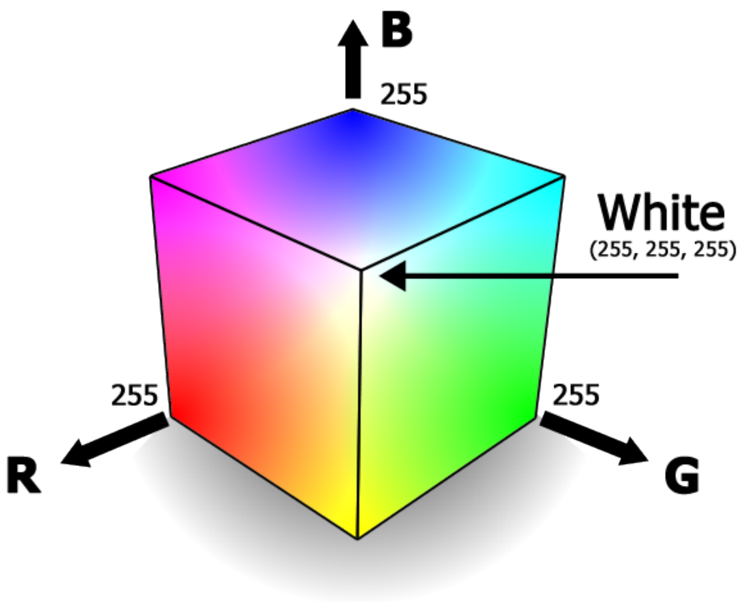
Color

- In color images, each pixel has three components: red, green, blue
- Their relative contribution determines the actual color



Color

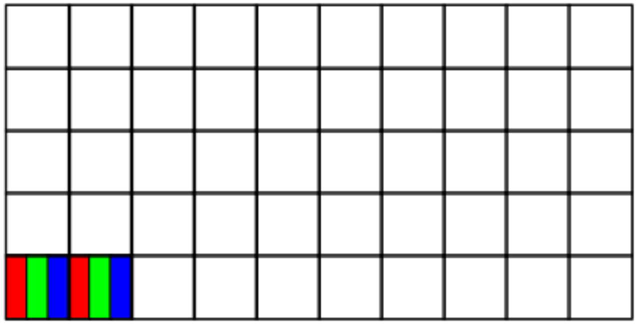
- Typically, each color value is an 8-bit integer in [0, 255] range
- This corresponding space is called the RGB color cube



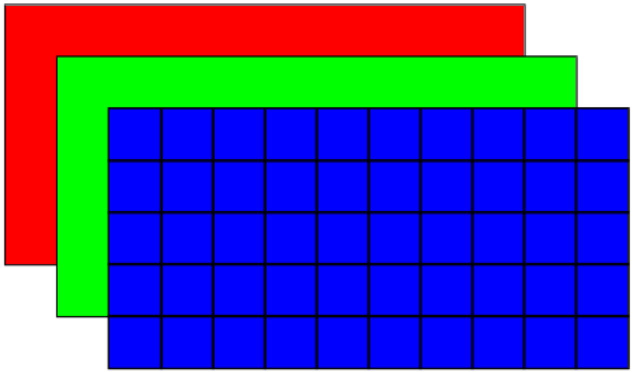
medialooks.com

Storage

- These colors can be stored as interleaved or as planar in an image file



Interleaved



Planar

Image Formats

- Images generated by a CG program can be sent to a display device or written to an image file

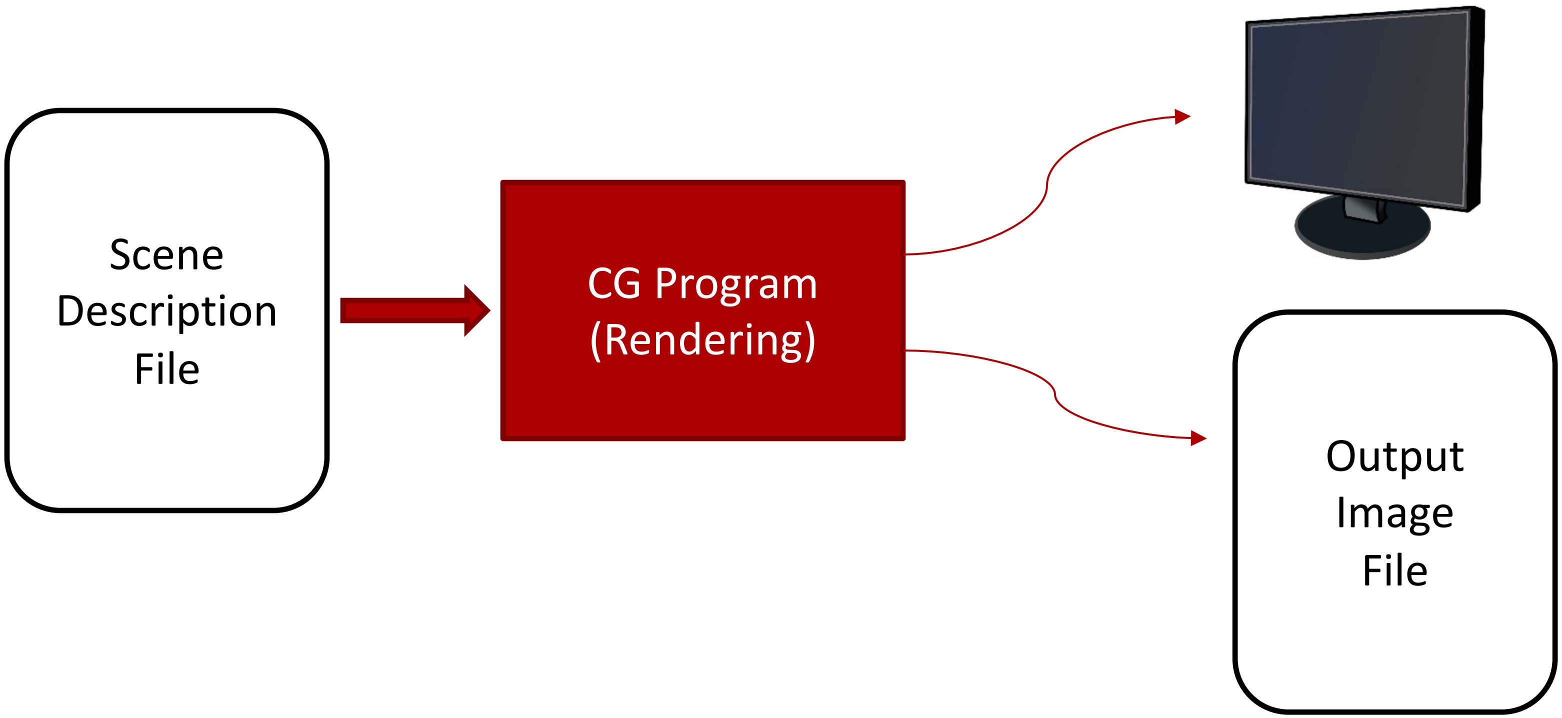


Image Formats

- There are hundreds of image formats perhaps the best well-known being the JPEG format
- A very simple image format is the PPM format:

```
P3
# simple.ppm
4 4
255
128 128 128   128 128 128   128 128 128   255   0 255
128 128 128     0 255 255   128 128 128   128 128 128
255   0   0   128 128 128   128 128 128   128 128 128
  0   0 255   128 128 128   128 128 128   128 128 128
```

Image Formats

- Despite being simple, the PPM format is very inefficient due to lack of compression
- How many MBs would an 18 megapixel (MP) plain PPM image would occupy?

$$\frac{18 * 1024 * 1024 * 3 * 3.57}{1024 * 1024} \cong 193\ MBs$$

Image Formats

- 3.57 in this formula comes from the expected number of bytes that each component will occupy:

$$\frac{10 \; * 1 + 90 \; * 2 + 156 \; * 3}{256} + 1 \cong 3.57$$

- The last +1 is for the whitespace between the components

Image Formats

- If we used binary PPM (each component is 1 byte and there is no white space) this produce a file size of 54 MBS for an 18 MP image (still too much)
- For this reason, compressed image formats are available
  - Lossless compression
  - Lossy compression

Lossless Compression

- With lossless compression, a decoder will read the exact information that an encoder wrote to a file
- Various lossless compression techniques are used such as Huffman encoding, run-length encoding, etc.
- A well-known lossless image format is the PNG format
- Efficient for computer generated images but not for natural (photographic) images due to presence of noise

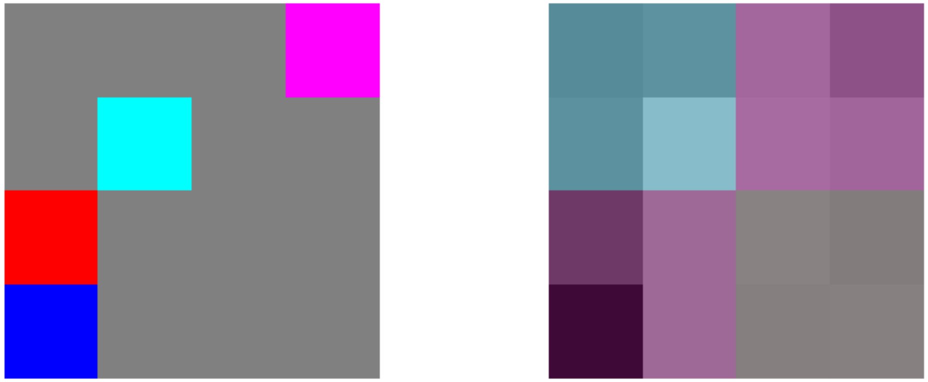
Lossy Compression

- In lossy compression, numerical match between the input and output is not required
- Some information is lost to improve compression efficiency
- However, lossy formats can still be visually lossless
- The most well-known lossy format is the JPEG format

Lossy vs Lossless

- Assume we encode and decode this data as PPM and JPEG:

```
P3
# simple.ppm
4 4
255
128 128 128   128 128 128   128 128 128   255   0 255
128 128 128     0 255 255   128 128 128   128 128 128
255   0   0   128 128 128   128 128 128   128 128 128
  0   0 255   128 128 128   128 128 128   128 128 128
```



PPM (or PNG)　　　　JPEG

JPEG Quality

- A JPEG image with different quality settings:

Image Capture

- We defined a color image as $I: \mathbb{R}^2 \rightarrow \{0,1,\ldots,255\}^3$
- The light intensity (more precisely *luminance*) in the world is not restricted to such a set
- Larger and smaller values are clamped (saturated) and all values are quantized
- Which values get saturated depends on the exposure setting of the camera

Image Capture

- A low exposure image:

Image Capture

- A high exposure image:

Dynamic Range

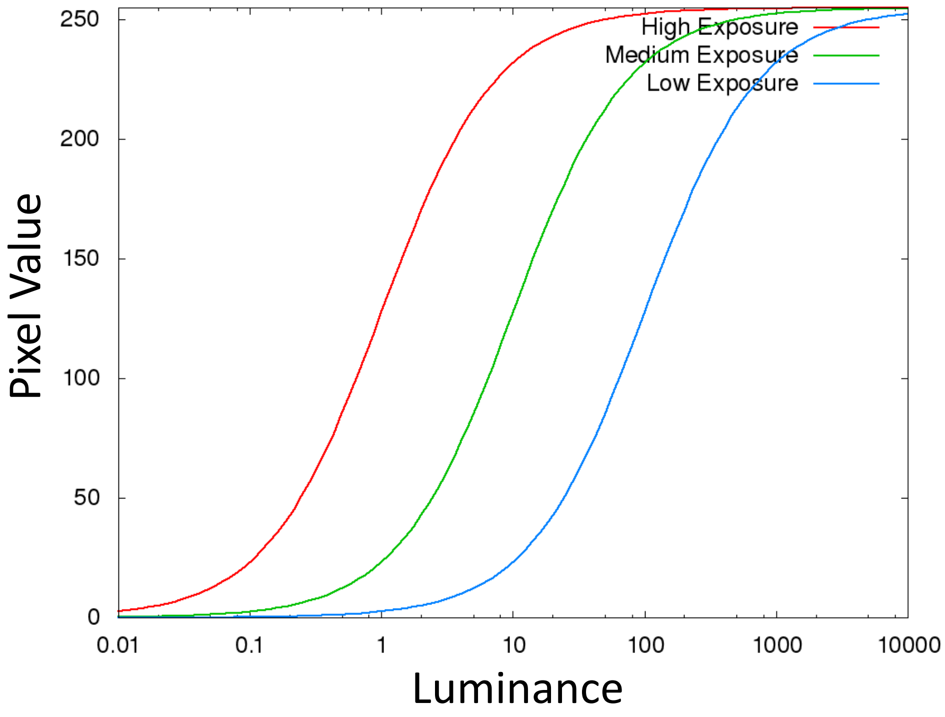
- Dynamic range (DR) is defined as the ratio of the highest luminance to the lowest luminance in a given scene

$$DR = \frac{L_{max}}{L_{min}}$$

L_{max} L_{min}

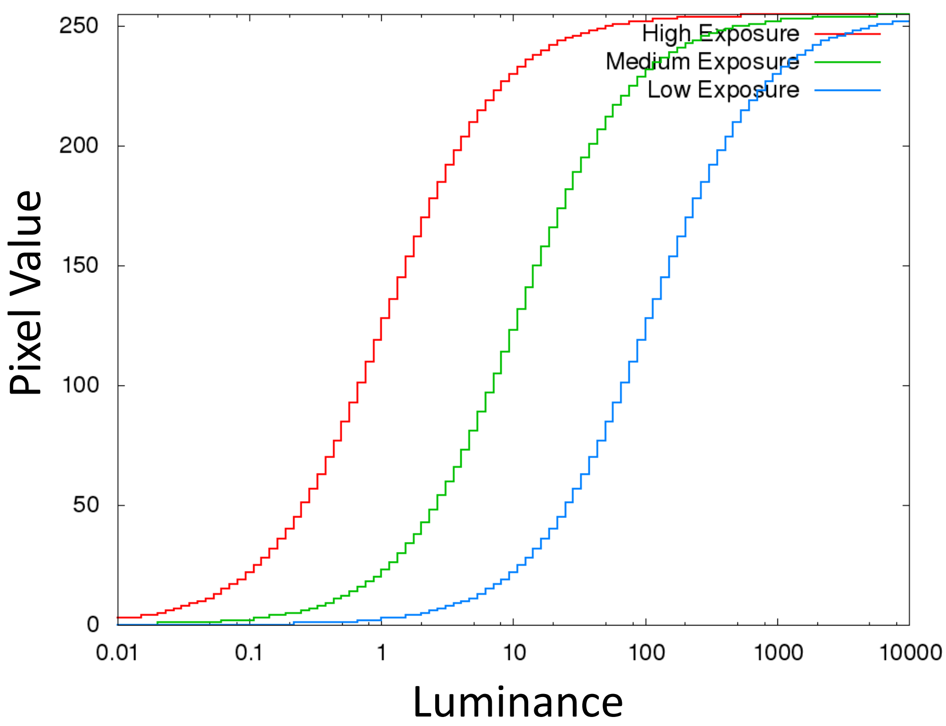
Exposure Control

- Cameras control their exposure to decide on a proper range:



Quantization

- With quantization, world luminance to pixel value mapping looks like this:



Rendering

- Why this matters for CG?
- In CG, we generate images just like a camera captures images
- Our artificial scene may have luminance values not limited to [0, 255] range
- As such, we have to mimic what the camera does

HDR

- What if we want to capture (or render) the world as it is without mapping to [0, 255] range?
- We can capture multiple exposures and merge them to create an HDR image

1/1000 s.

1/500 s.

1/250 s.

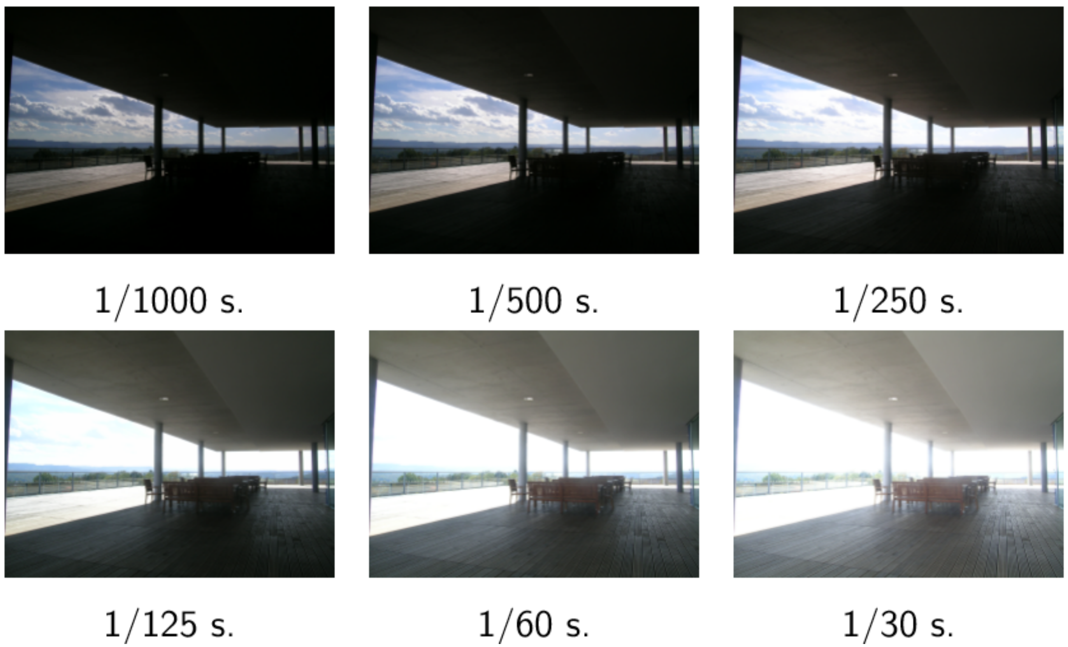
1/125 s.

1/60 s.

1/30 s.

HDR

- HDR image capture process:



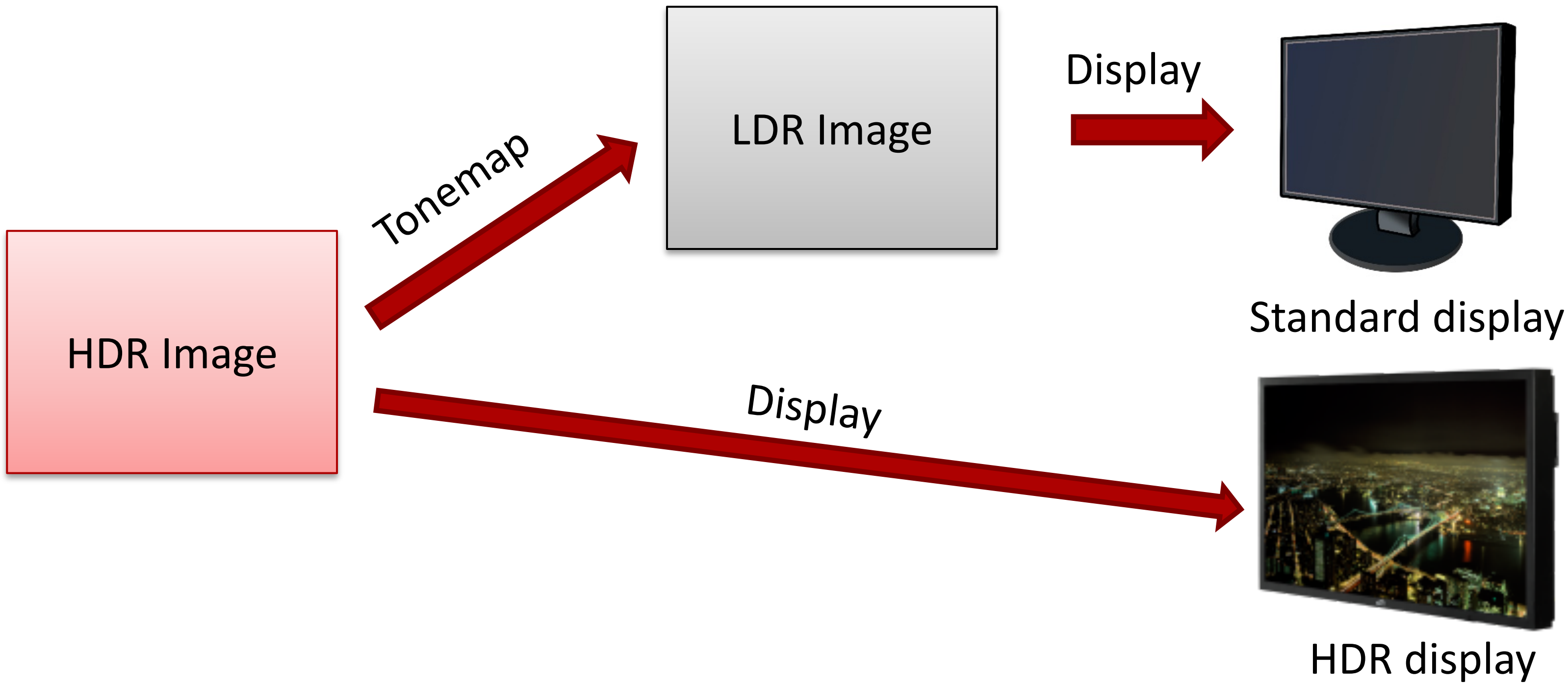
Merge → HDR Image

HDR

- Unfortunately, HDR images cannot be directly displayed on standard display devices
- They must be tonemapped first (see Chapter 23 in our textbook):

HDR

- HDR images can also be saved in HDR file formats such as .hdr and .exr
- Novel HDR displays allow direct display of HDR imagery:



HDR

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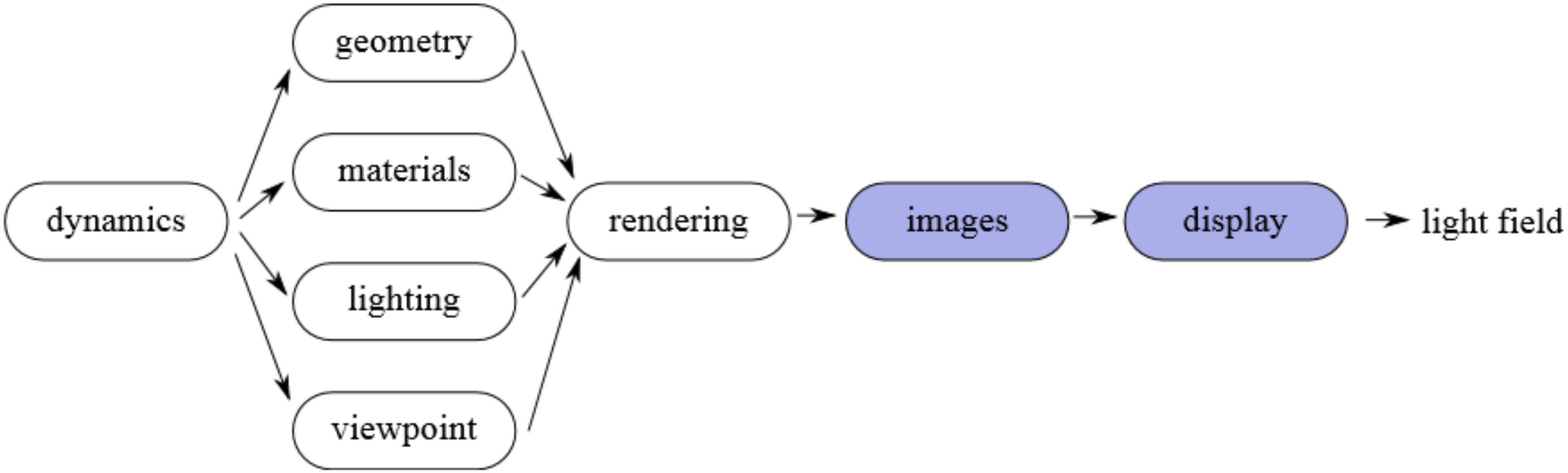
See http://hdr.sim2.it/ for more info on HDR displays

Display Devices



- Generated images are sent to a display device via the video card
- Therefore, understanding the basic properties of display devices is important

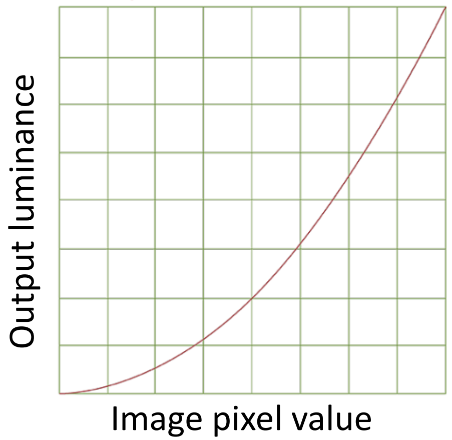
Display Devices

- CRT
- Plasma
- LCD
- LED
- OLED
- E-ink
- …

- There are numerous types of display devices
- But they all share some basic properties

Display Devices

- The digital RGB signals sent from the video card are translated into analog voltages in the display device
- These voltages determine the luminance emitted from each pixel
- However, voltage to luminance relationship is nonlinear



Gamma

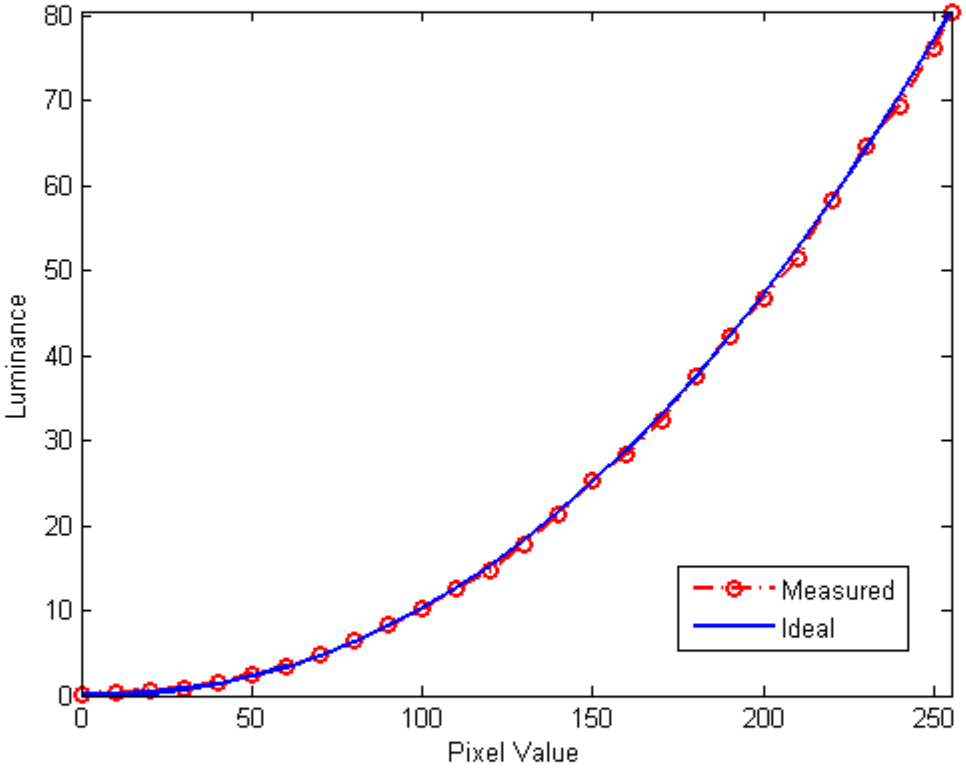
- This nonlinearity is called the display gamma
  - E.g. twice the pixel value (twice the voltage) does not result in twice the luminance
- Also, zero RGB value does not mean zero luminance due to leaking light and reflections off the screen
- A simplified display model is:

$$L_{out} = cV^{\gamma} + b$$

Output luminance Contrast Voltage Gamma Brightness

Gamma

- Measured gamma of a NEC Spectraview 241 monitor calibrated to the sRGB profile:

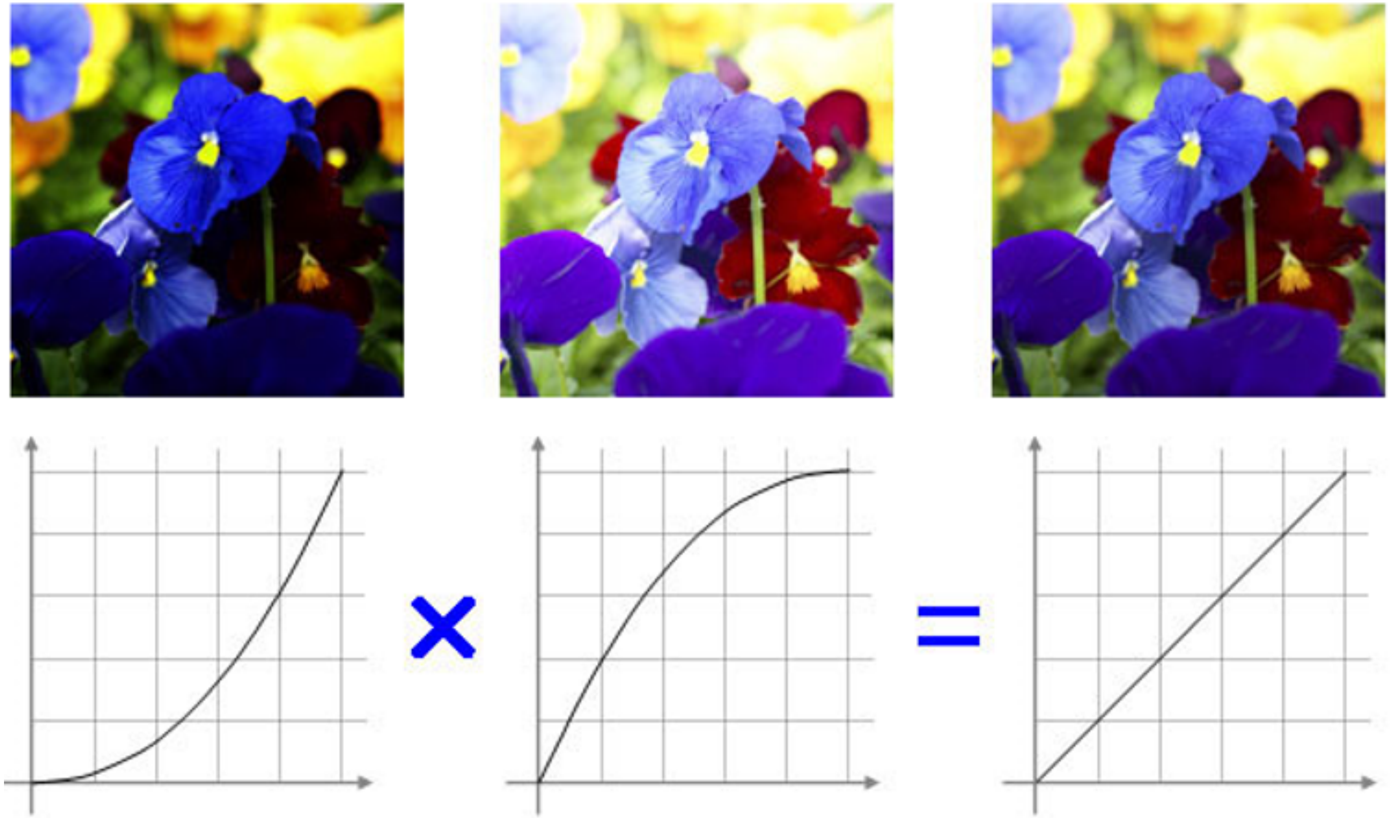


- Measurements are taken at intervals of 10
- Ideal is a gamma value of 2.2

Gamma Correction

- Most display devices have a gamma value around 2.2
- Gamma correction is performed to account for this non-linearity:
  - The input signal is raised to the power $1/\gamma$ before being stored
  - Typically cameras do this for us unless capturing in RAW format
- This makes the luminance emitted by a display device linear

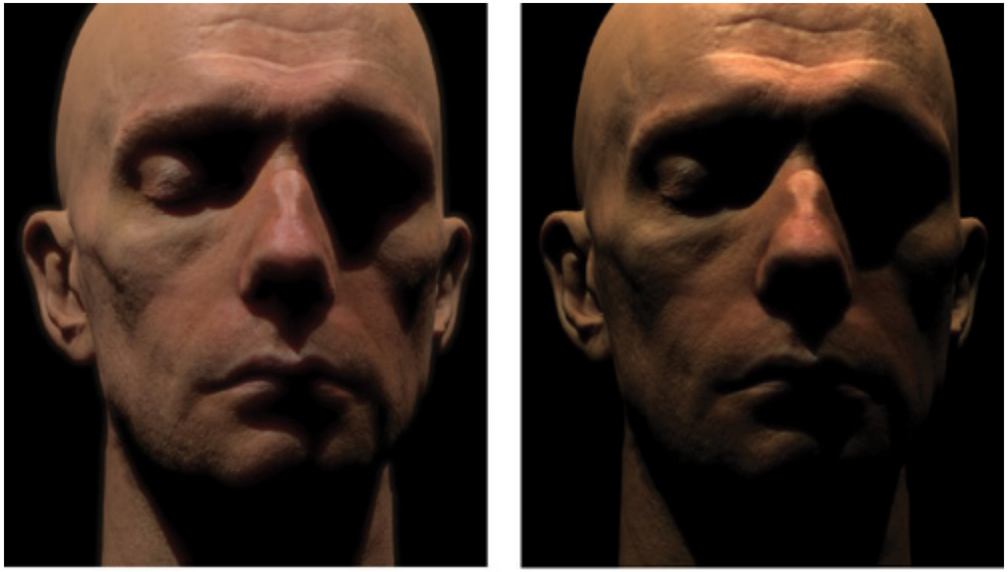
Gamma Correction



Gamma characteristics of monitors × *Color information adjusted to match gamma characteristics* = *Color handling approaching the "y = x" idealcs*

Gamma Correction

- In CG, we must also apply gamma correction as the last step of the rendering process
- Without gamma correction, we may obtain unnaturally dark images



(a) nvidia.com (b)

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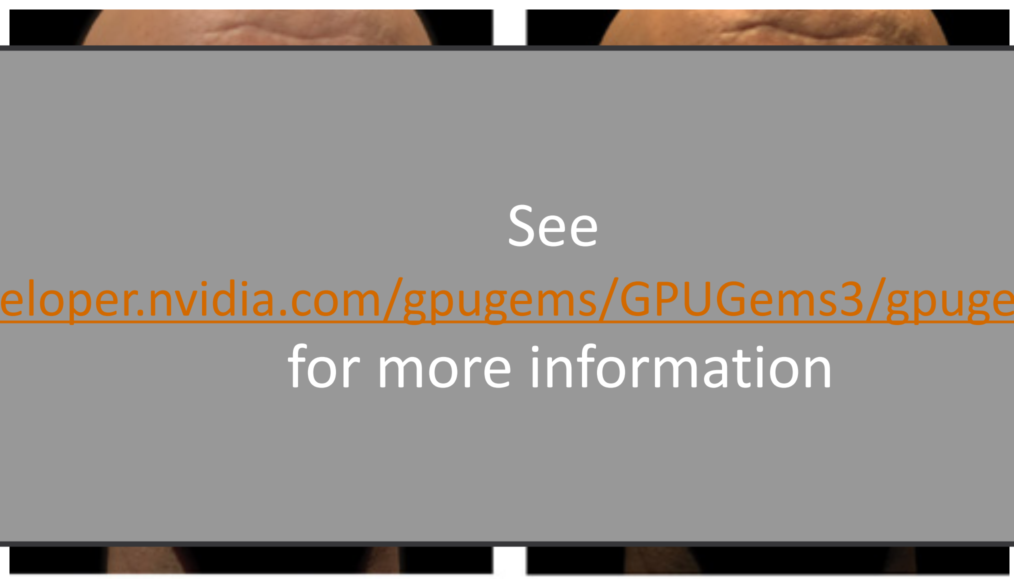

See
https://developer.nvidia.com/gpugems/GPUGems3/gpugems3_ch24.html
for more information

(a) nvidia.com (b)