Introduction to Computer Graphics (CS360A)

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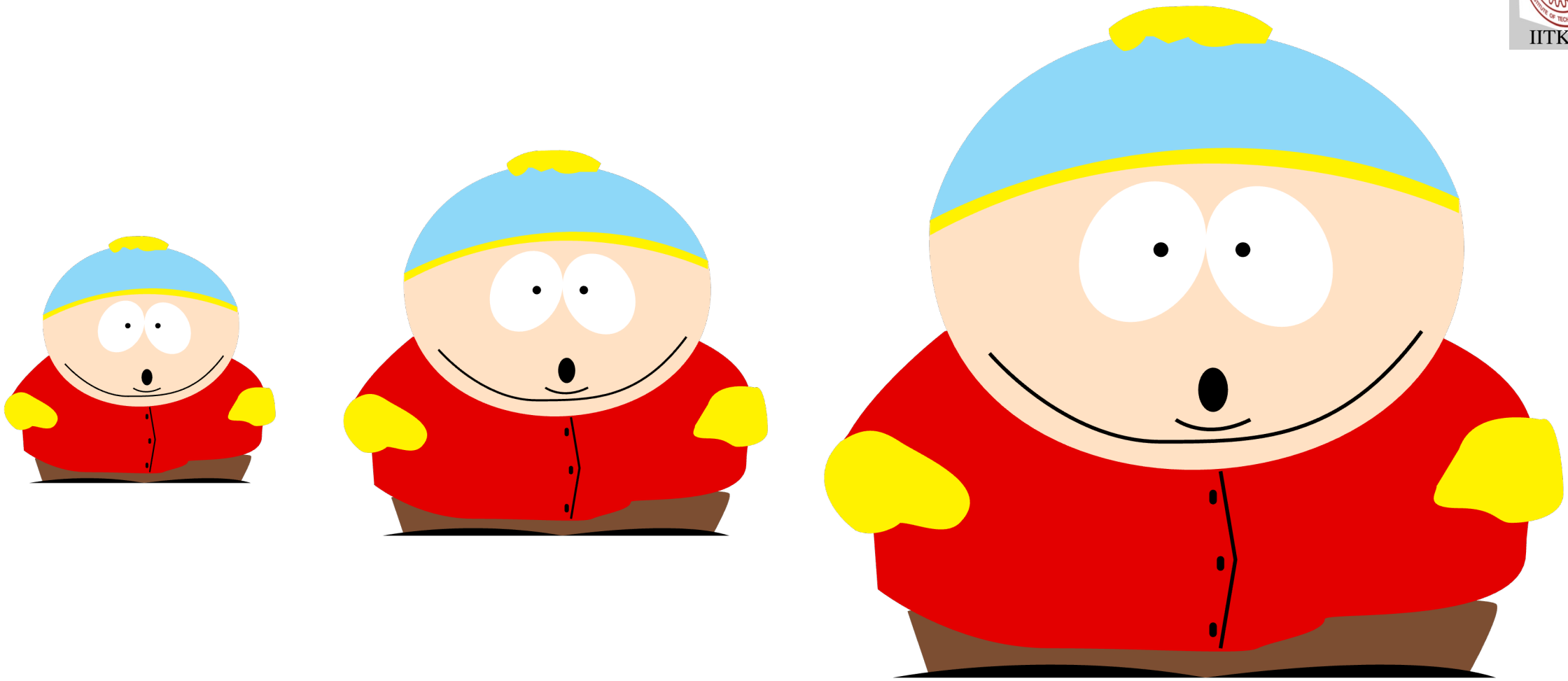
Acknowledgements

- A subset of the slides that I will present throughout the course are adapted/inspired by excellent courses on Computer Graphics offered by Prof. Han-Wei Shen, Prof. Wojciech Matusik, Prof. Frédo Durand, Prof. Abe Davis, and Prof. Cem Yuksel



The quality of the image remains intact, even if we zoom it significantly!!

What is this image made of?

SVG, vector Image, made of some scalable vector graphical primitives

Scalable Vector Graphics (SVG)

```
<svg viewBox='0 0 104 97' xmlns='http://www.w3.org/2000/svg'>
  <path d='M14,85l3,9h72c0,0,5-9,4-10c-2-2-79,0-79,1' fill='
  #7C4E32'/>
  <path d='M19,47c0,0-9,7-13,14c-5,6,3,7,3,7l1,14c0,0,10,8,23
  ,8c14,0,26,1,28,0c2-1,9-2,9-4c1-1,27,1,27-9c0-10,7-20-11-29
  c-17-9-67-1-67-1' fill='#E30000'/>
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  #8ED8F8"/>
  <path d='M54,35a10 8 60 1 1 0,0.1zM37,38a10 8 -60 1 1
  0,0.1z' fill='#FFF'/>
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  5,0c-2-1-1-1-1-1l-3,1l-2-1h-1c0,0-1,2-3,2c0,0-2-1-2-3M17,34
  l0-2c0,0,35-20,71-3v2c0,0-35-17-71,3M5,62c3-2,5-2,8,0c3,2,1
  3,6,8,11c-2,2-6,0-8,0c-1,1-4,2-6,1c-4-3-6-8-2-12M99,59c0,0-
  9-2-11,4l-3,5c0,1-2,3,3,3c5,
  0,5,2,7,2c3,0,7-1,7-4c0-4-1-11-3-10' fill='#FFF200'/>
  <path d='M56,78v1M55,69v1M55,87v1' stroke='#000'
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  <path d='M60,36a1 1 0 1 1 0-0.1M49,36a1 1 0 1 1
  0-0.1M57,55a2 3 0 1 1
  0-0.1M12,94c0,0,20-4,42,0c0,0,27-4,39,0z'/>
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  stroke-width='0.5'/>
</svg>
```

Made of some scalable graphical vector primitives

Scalable Vector Graphics (SVG)

What is this image made of?

Raster Image, made of **Pixels**

Raster vs Vector Graphics (Images)

Vector Graphics

Raster vs Vector Graphics (Images)

Vector Graphics

Raster Graphics

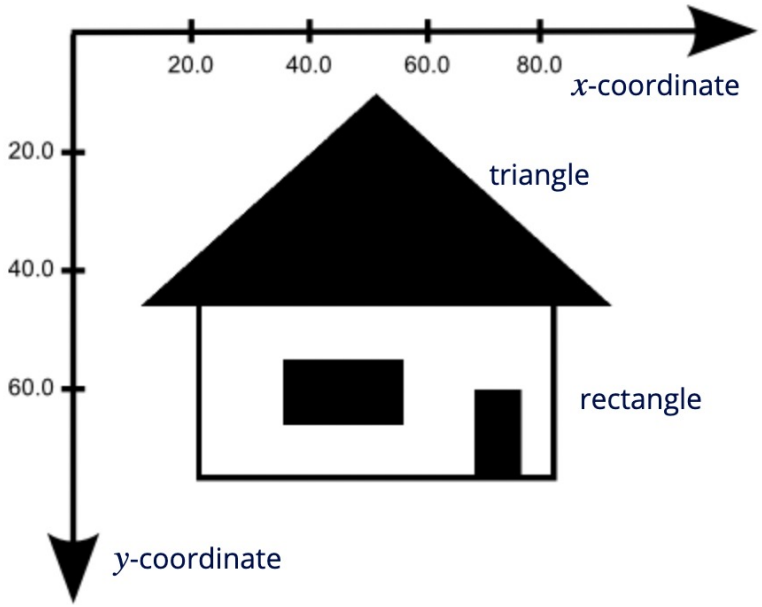
Raster vs Vector Graphics (Images)

Raster (PNG)

Vector (SVG)

Raster vs Vector Graphics (Images)

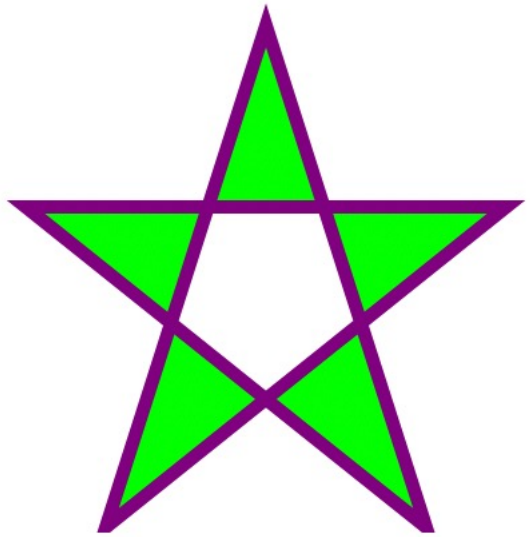
- Vector Graphics:
  - Use mathematical equations, lines and curves with fixed points on a grid to produce an image
  - There are no concept of ‘pixel’ in vector graphics
  - Objects are described by combining basic objects (such as line, rectangle, circle, triangle, polygon)
  - Because the mathematical formula recalibrates to any size, you can scale a vector image up or down without affecting its quality.



Raster vs Vector Graphics (Images)

- Vector Graphics:
- SVG: Scalable Vector Graphics (SVG) is an XML-based vector image format

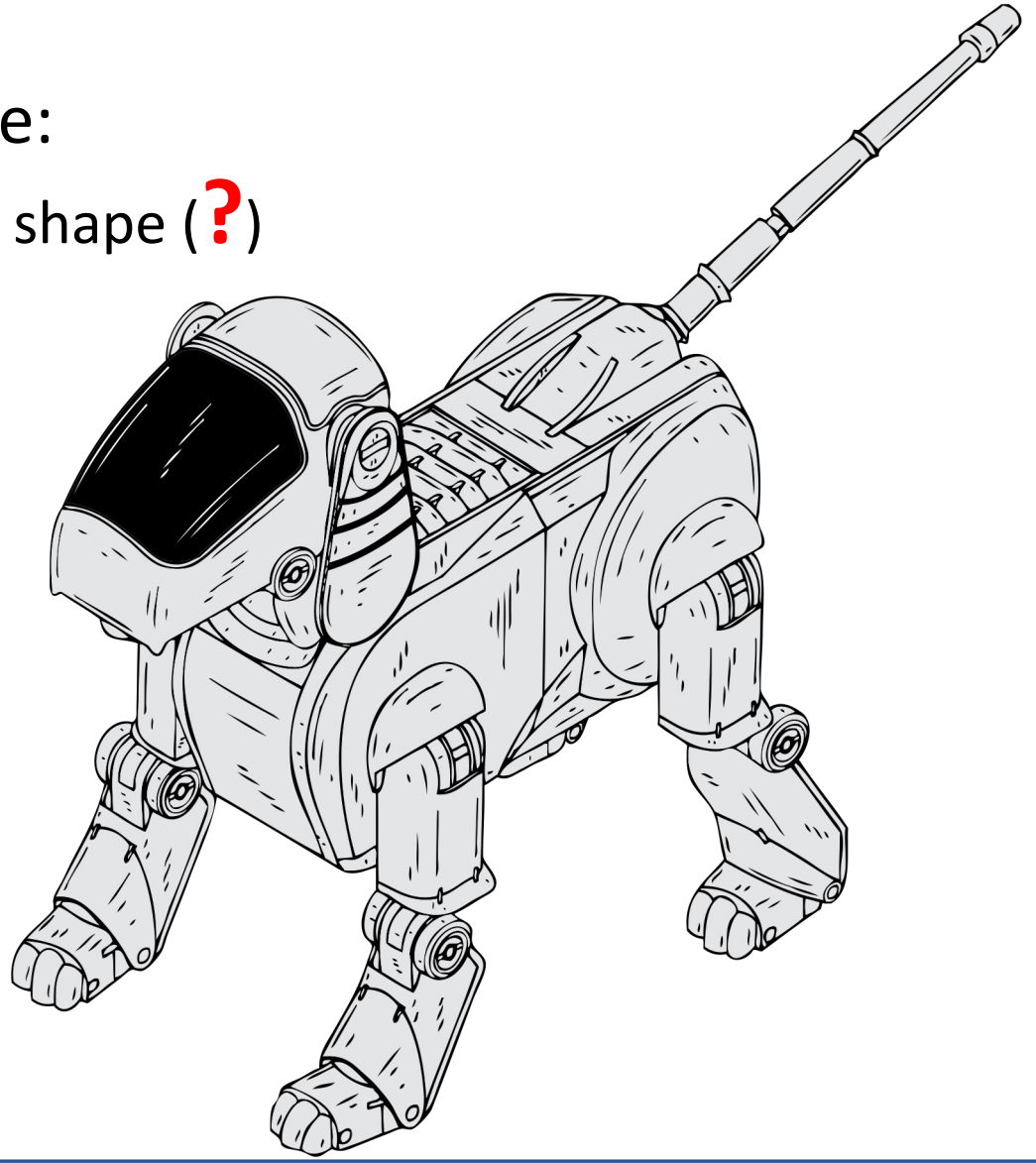
```
<!DOCTYPE html>
<html>
<body>

<svg width="300" height="200">
  <polygon points="100,10 40,198 190,78 10,78 160,198"
  style="fill:lime;stroke:purple;stroke-width:5;fill-rule:evenodd;" />
Sorry, your browser does not support inline SVG.
</svg>

</body>
</html>
```



More about SVG: https://www.w3schools.com/graphics/svg_intro.asp

Raster vs Vector Graphics (Images)

- Another SVG Example:
  - It can make complex shape (?)



https://openclipart.org/detail/1667/robot-dog

Raster vs Vector Graphics (Images)

- Vector Graphics:
  - Commonly used for logos, illustrations, technical drawings, engravings, etchings, product artwork
  - Also used in CAD, engineering drawing, etc.
  - Common vector creation and editing programs include Adobe Illustrator, CorelDraw, and InkScape
  - File formats used to store vector graphics:
    - SVG
    - PDF
    - PS

Raster vs Vector Graphics (Images)

How about we try to generate this image using vector images?

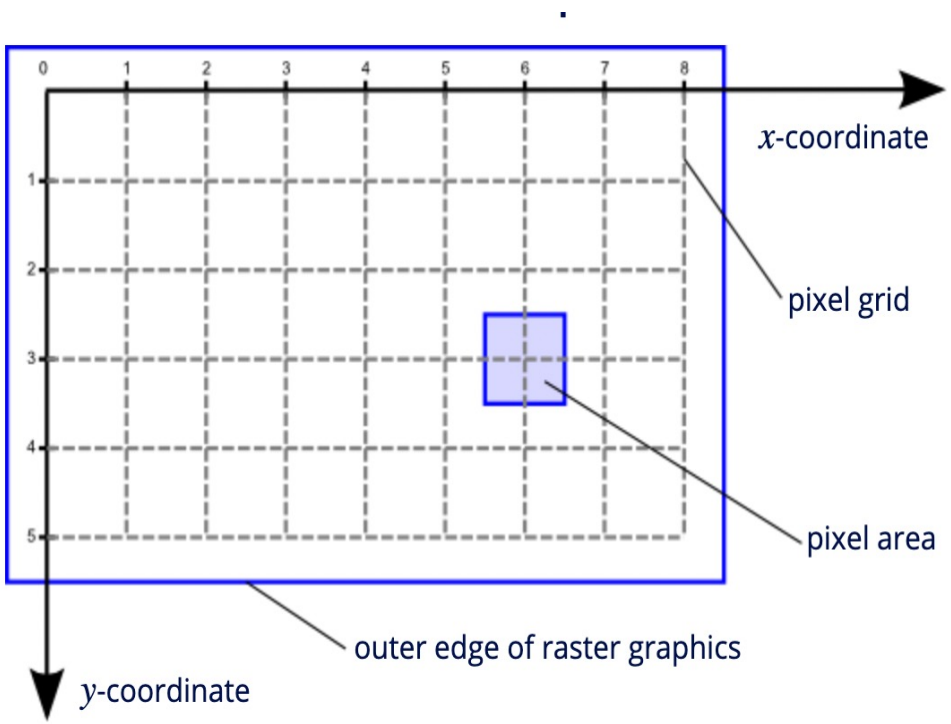
Source: Google

Raster vs Vector Graphics (Images)

- It is going to be an extremely hard process, and may not even be possible
- The minute details of blended colors, shading, shadows, and gradient make it impossible to get a true-to-life representation of a photograph with vector images
- The process could be excruciatingly tedious, as every color change would require a new shape

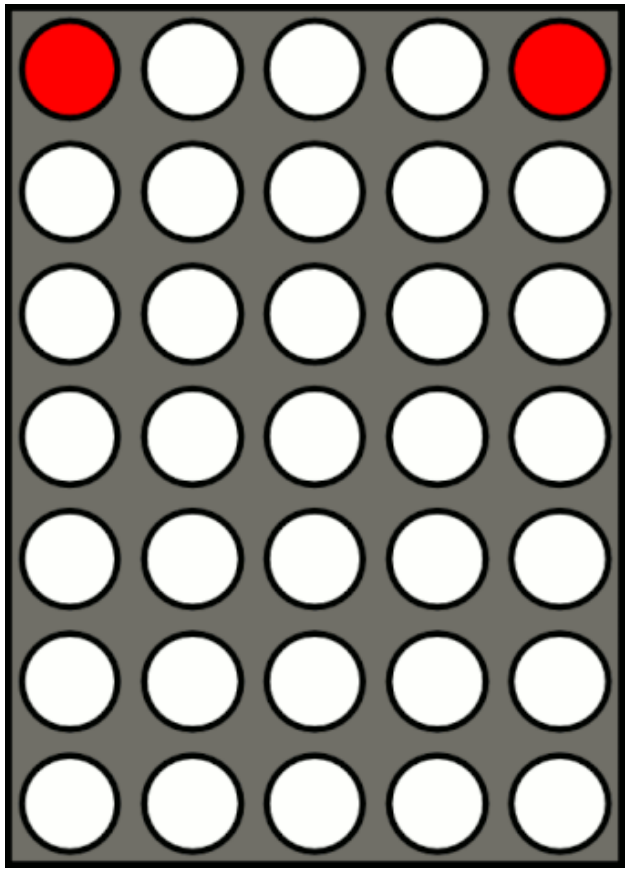
Raster Graphics (Images)

- Raster (bitmap) Graphics:
  - Raster images are defined by pixels (picture elements), which are arranged on a fixed grid
  - Raster images have a color value for each pixel of their grid
  - They are fully defined by:
    - Image width: Number of pixels in the x direction
    - Image Height: number of pixels in the y-direction
    - A data field with (width x height) color values
- In this example it is assumed that the pixel grid intersects with the center of the pixel area



Raster Graphics (Images)

- Raster (bitmap) Graphics:
- **Pixel**: In digital imaging, a pixel, pel, or picture element is the smallest addressable element in a raster image, or the smallest addressable element in a dot matrix display device
- By arranging pixels and slowly incrementing or changing the color or shade of pixels adjacent to them, raster images produce smooth gradation between colors



LED Display Dot-Matrix

Raster Graphics (Images)

- Raster (bitmap) Graphics:
- The resolution of a raster image is referred to in DPI (dots per inch) or PPI (pixels per inch)
  - If you zoom in or expand the size of a raster image, you start to see the individual pixels
- File formats used to store vector graphics:
  - bmp, jpg, png, gif, tiff, psd, etc.

Raster vs Vector Graphics (Images)

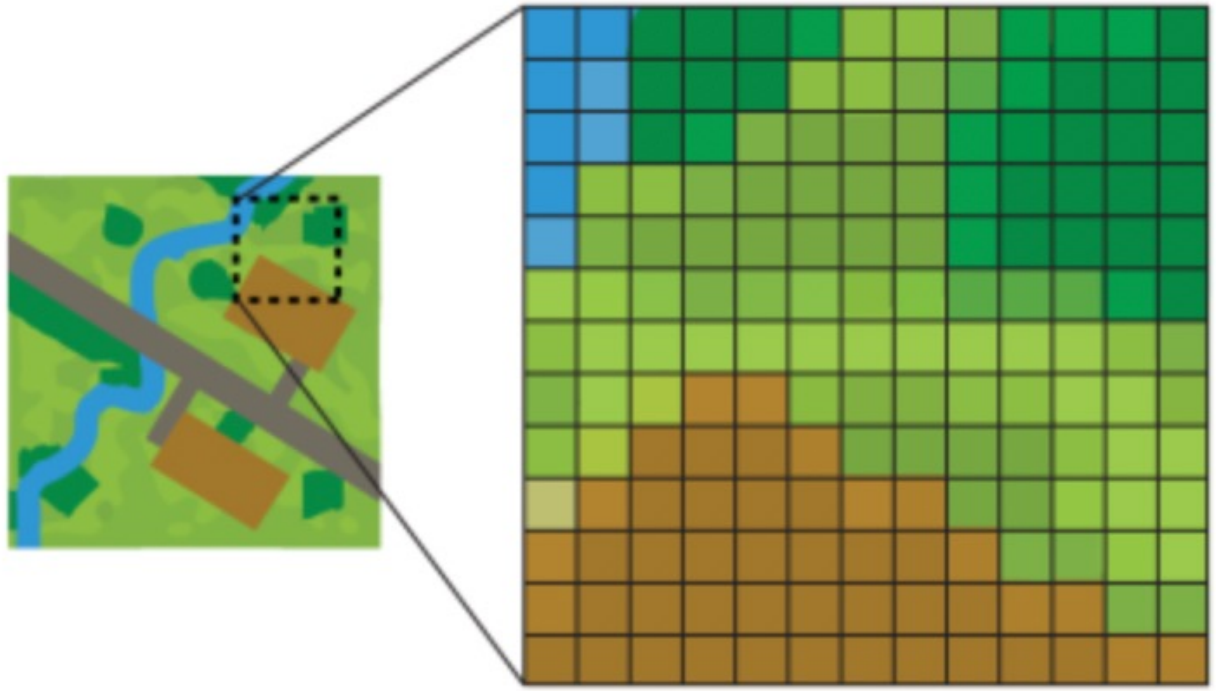
- Raster (bitmap) Graphics:
- File formats used to store raster graphics:
  - PPM (Portable Pix Map), lossless, human readable, simplest raster image format
  - BMP (Bitmap), lossless compression
  - PNG (Portable Network Graphics), lossless compression
  - JPEG, smaller files because of lossy compression
  - TIFF (Tagged Image File Format), typically lossless compression, high color depth (up to 32 bit)
  - TGA (Targa Image File), uncompressed or lossless compression
  - GIF (Graphics Interchange Format), lossless compression, allows animation sequences
- Common raster creation and editing programs include Gimp, Microsoft Paint, Adobe Photoshop, Corel Photo-Paint, etc.

Raster vs Vector Graphics (Images)

Raster Image	Vector Image
Comprised of pixels, arranged to form an image	Comprised of paths, dictated by mathematical formulas
Constrained by resolution and dimensions	Infinitely scalable
Capable of rich, complex color blends	Difficult to blend colors without rasterizing
Large file sizes (but can be compressed)	Small file sizes
Capable of detailed editing	Less detailed, but offers precise paths

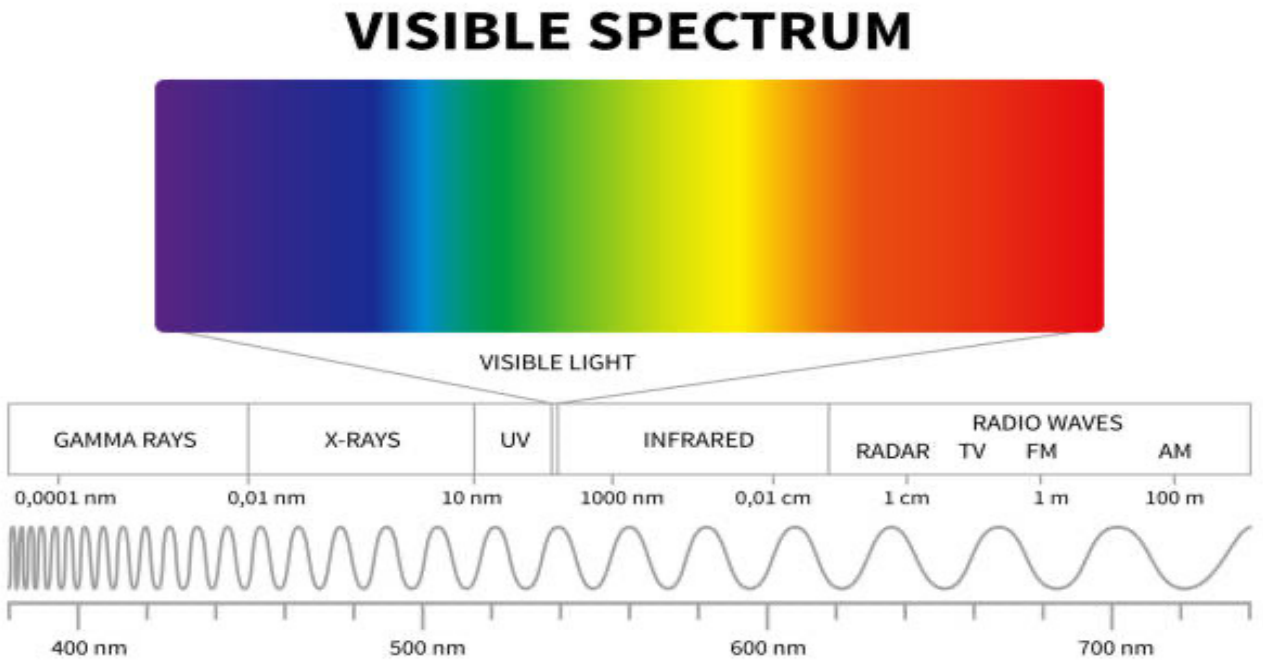
Raster Graphics: This Course

- Raster graphics (images) are primarily used in computer graphics, digital photography, computer games, animations, etc.
- We will discuss about raster image generation/rendering techniques in this course
- Each pixel in raster image has a color, so let's talk about color!

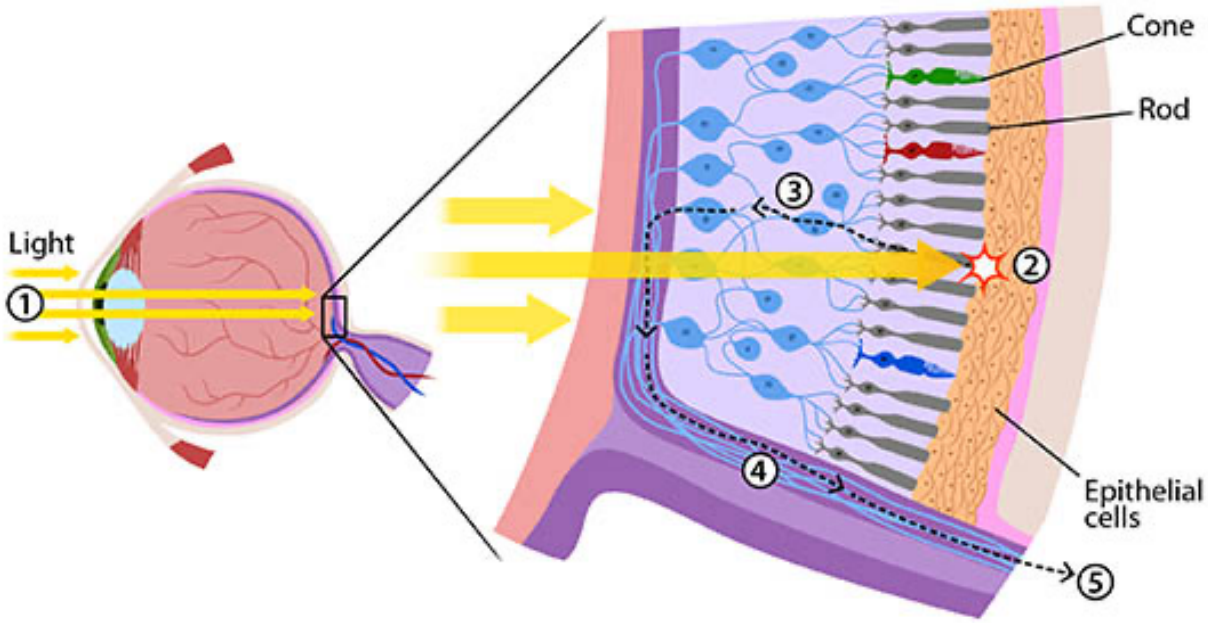


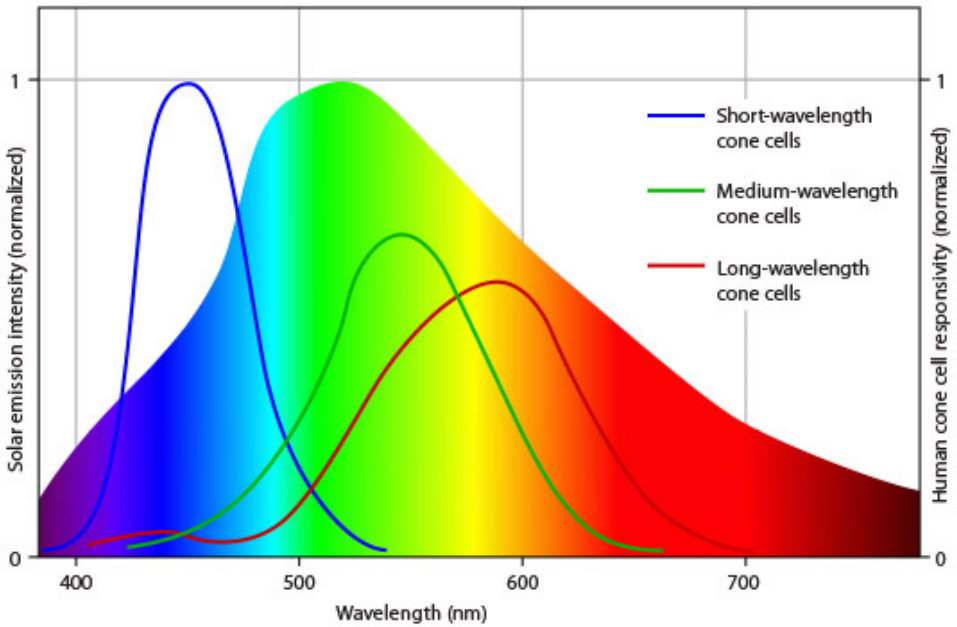
Color

- Color is all about How we perceive light!
- When we see some light, we typically see a combination of wavelengths with different amplitudes



Color

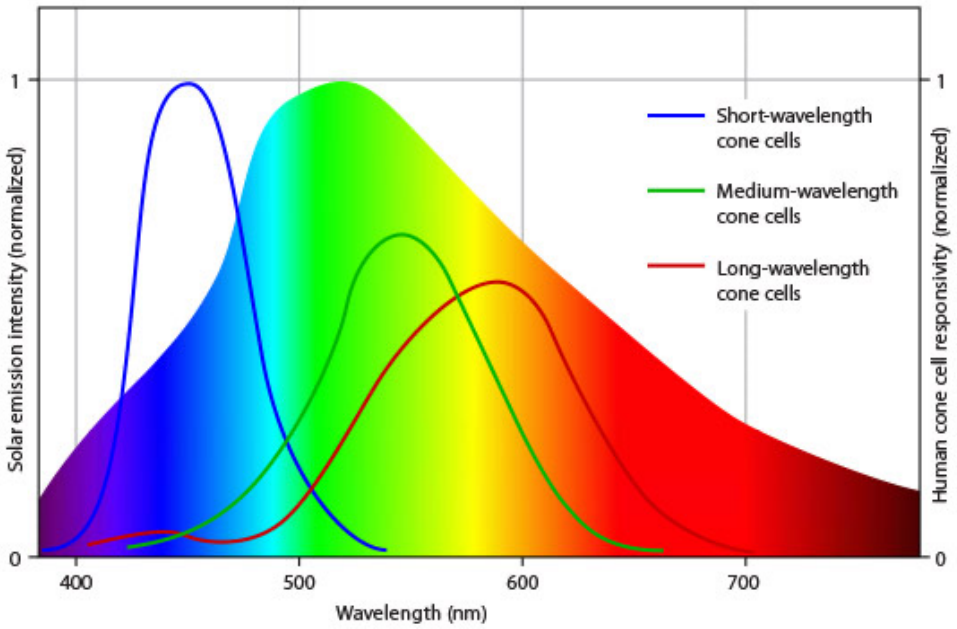




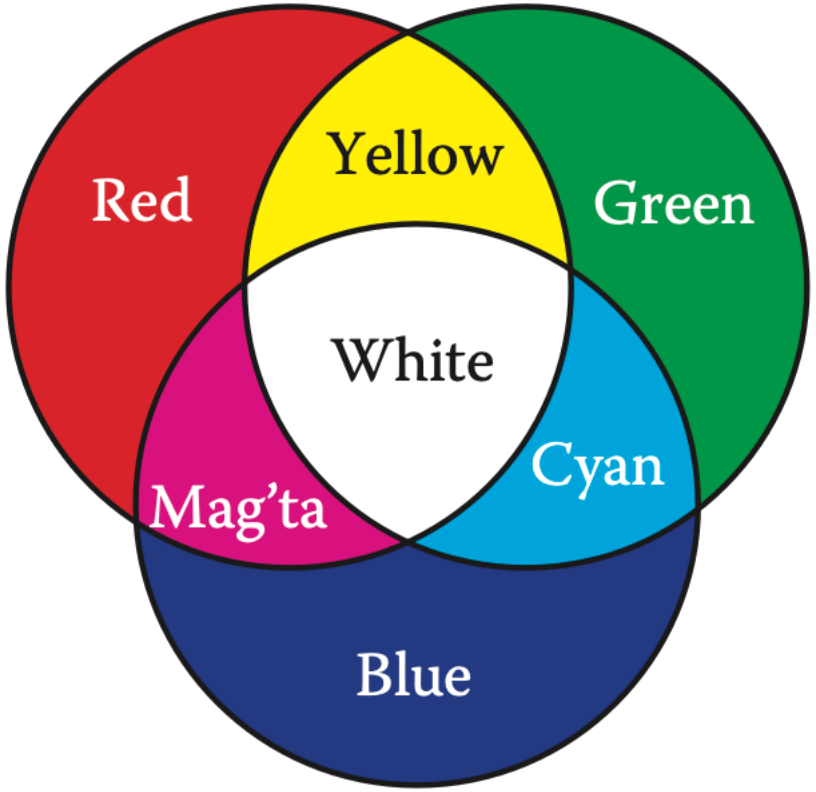
- Humans have 3 different types of cone cells
- Cones send a nervous signal when they detect light, and the strength of that signal is determined by the wavelength
- It is a shared experience for all humans to see color
- Other animals perceive light differently since their visual system is different than ours

Color

- The three types of cone cells are sensitive to three different types of lights, Red, Green, and Blue
- So, by combinations of these three different colors, we can form other colors and our visual system can perceive it
- Red, Green, and Blue are fundamental colors



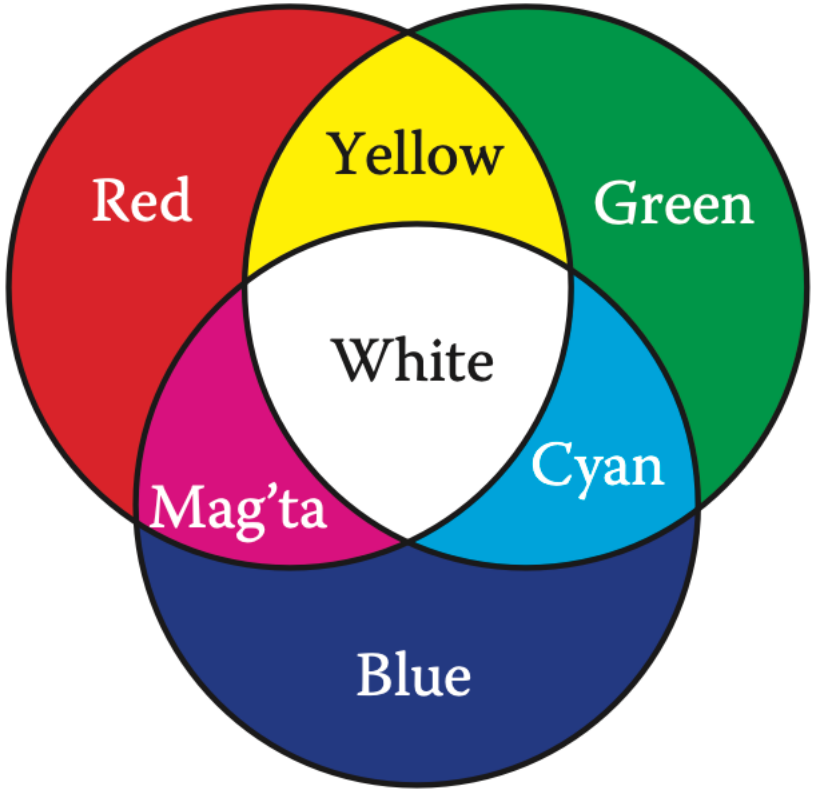
Color



The additive mixing rules for colors red/green/blue

RGB Color Circle

Color



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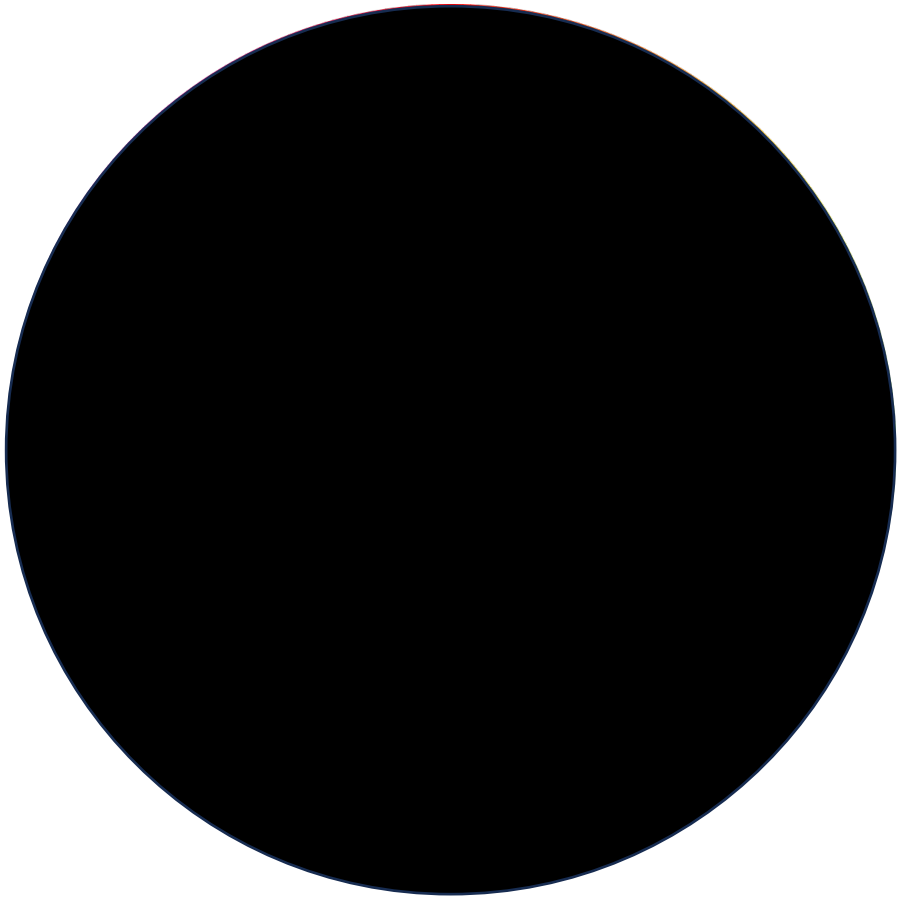
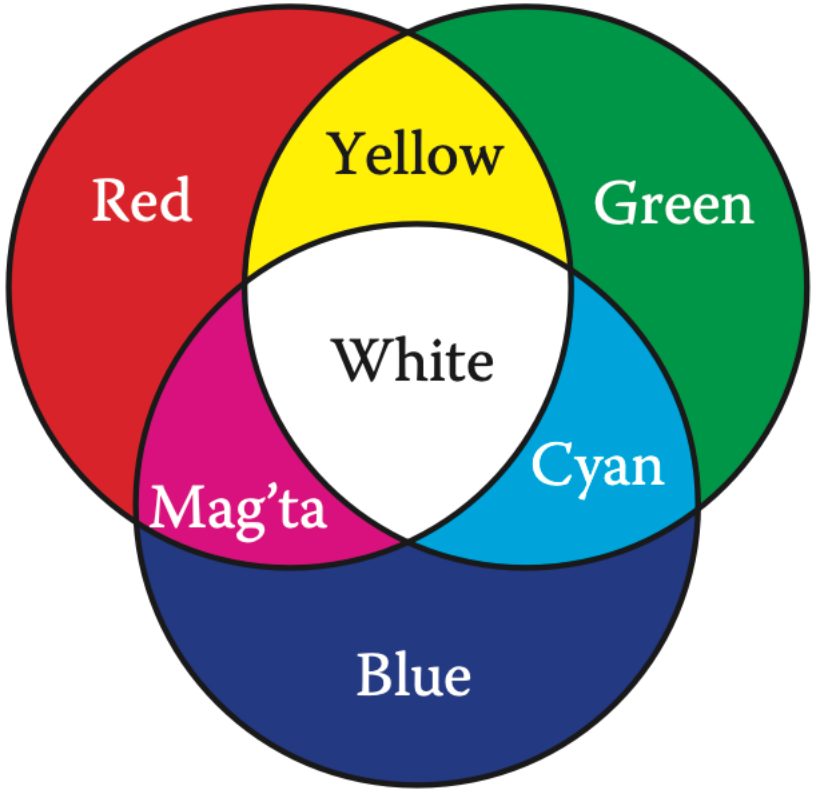
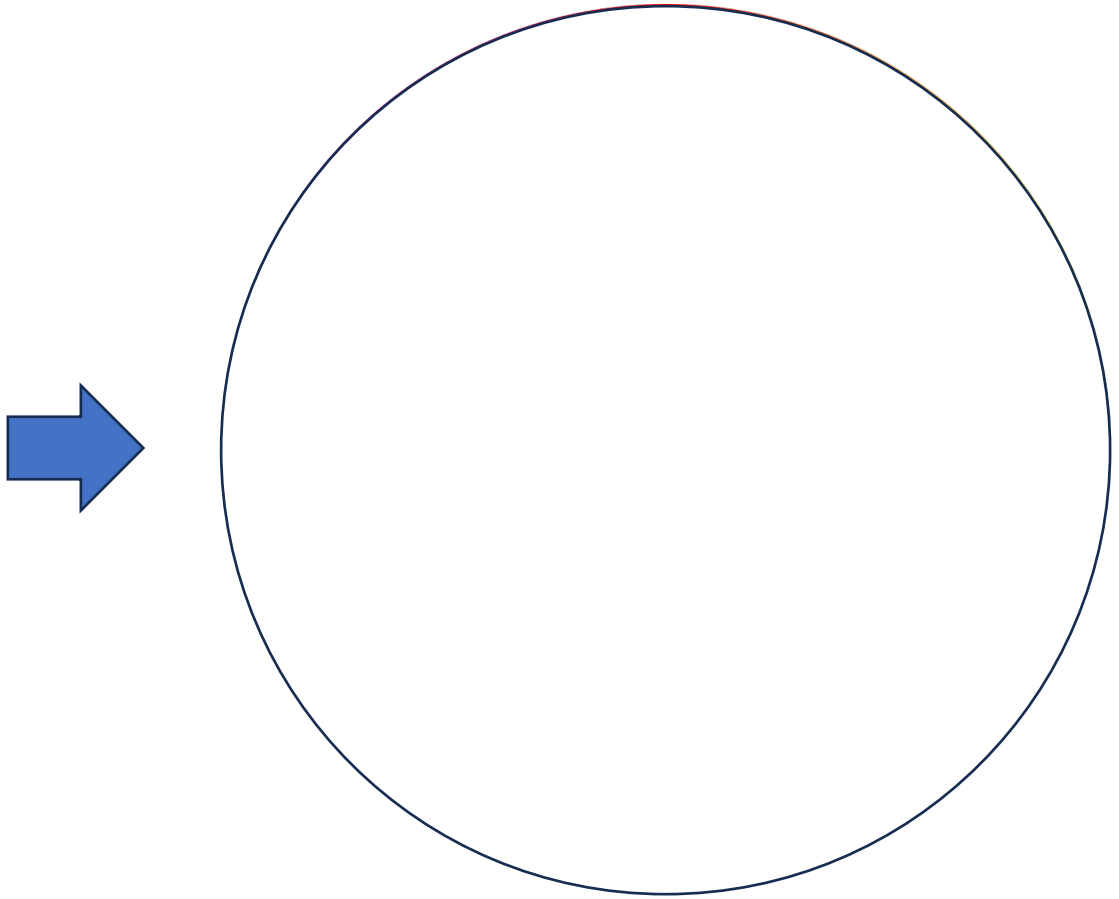


RGB Color Circle

Color

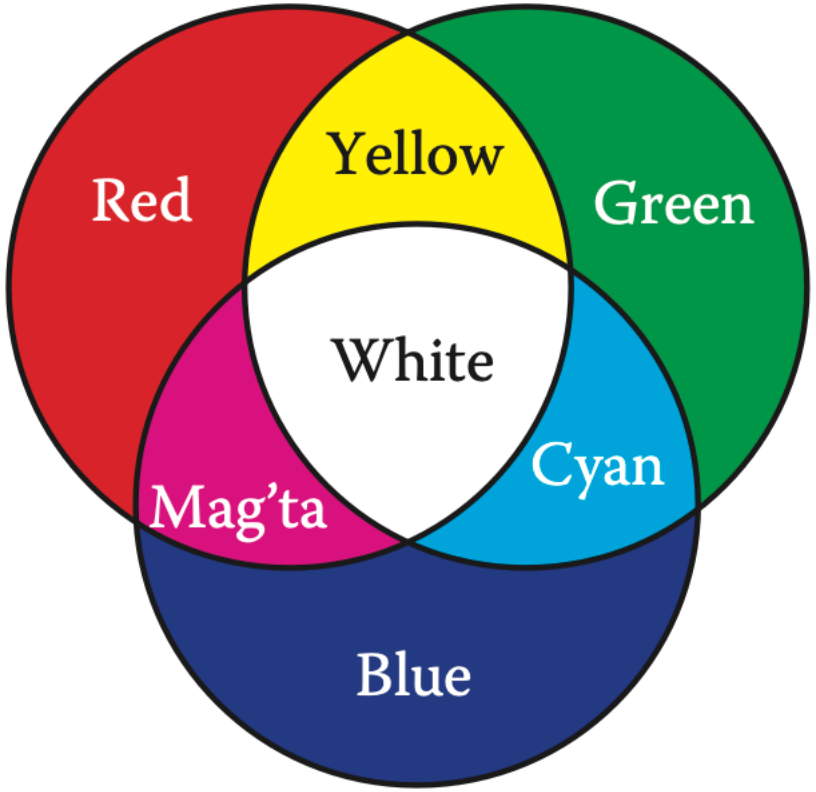


The additive mixing rules for colors red/green/blue



RGB Color Circle

Color



The additive mixing rules for colors red/green/blue

RGB Color Circle

Color

- RGB values in [0,1]
  - Black = [0,0,0]
  - White = [1,1,1]
  - Red = [1,0,0]
  - Green = [0,1,0]
  - Blue = [0,0,1]
  - Yellow = [1,1,0]
  - Magenta = [1,0,1]
  - Cyan = [0,1,1]

Color

- RGB values in [0,1]
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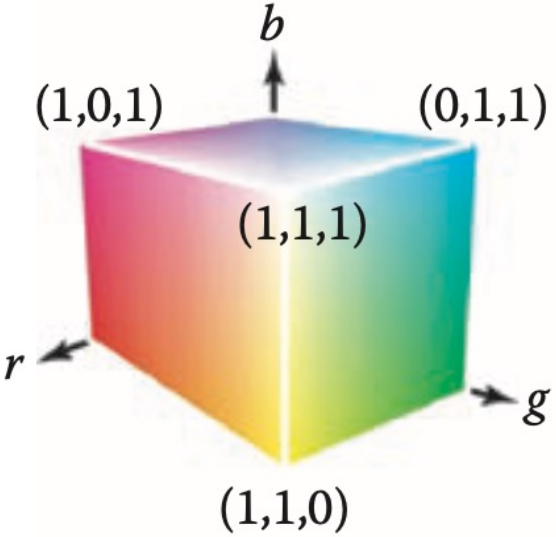

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  - Blue = [0,0,1]
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  - Magenta = [1,0,1]
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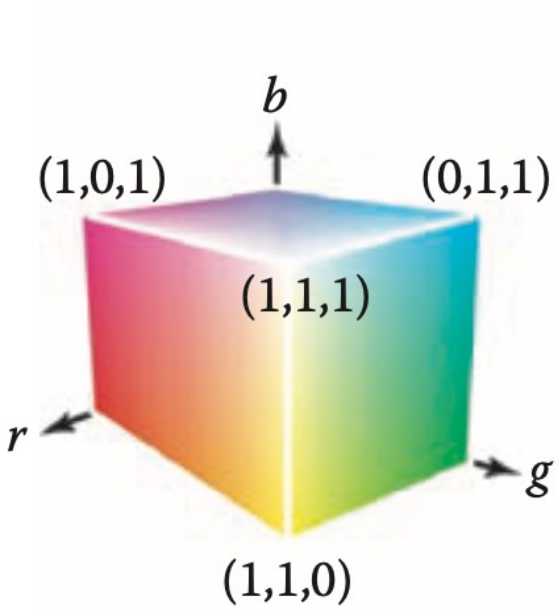
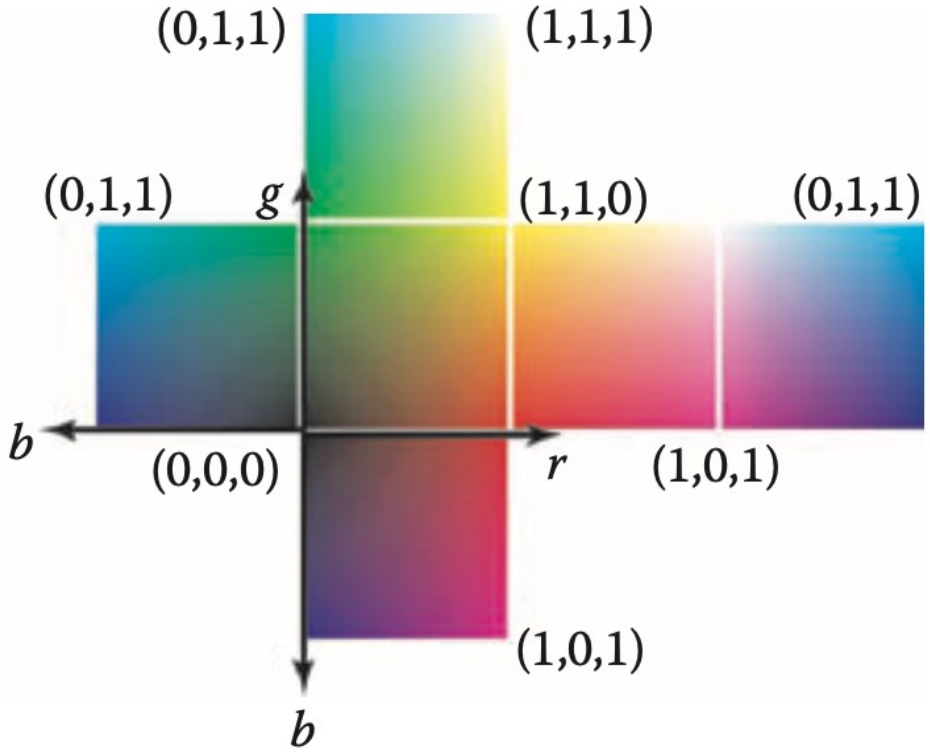




Color: LDR and HDR

- RGB Values in [0,1]

Color: LDR and HDR

- Dynamic range is defined as the ratio of the largest value of a signal to the lowest measurable value
- Dynamic range of luminance in real-world scenes can be **100,000 : 1**
- With HDR rendering, luminance and radiance (pixel intensity) are allowed to extend beyond [0..1] range
  - Nature isn't clamped to [0..1], neither should CG
- Computations done in floating point where possible
- In lay terms:
  - Bright things can be really bright
  - Dark things can be really dark
  - And the details can be seen in both

Color: LDR and HDR

- Low Dynamic Range Representation
  - 8 bits/color channel (0-255)
  - 16 bits/color channel (0-65536)
- High Dynamic Range Representation
  - 16 bit float
  - 32 bit float
- If you do it write and with some tricks, 8bits/channel is often sufficient
- Hence compute everything in 32bit precession and then finally convert to 8bit color for display

Modern HDR Displays

- HDR display produces greater luminance and color depth than screens built to meet older standards
- The increased light produced by an HDR display makes its brightest pixels far brighter than before, further differentiating them from the darkest one
- This increased contrast ratio enables more subtle pixel-to-pixel changes and better image reproduction
- New HDR formats can process 10-bit (or even 12-bit) color, increasing the potential on-screen color variations exponentially

Comparisons LDR vs HDR

HDR File Formats

- EXR: OpenEXR (created in 1999)
  - A high-dynamic range, multi-channel raster file format
  - 16/32 bit per channel
  - Storage increases and compression does work as well
  - Academy Award for Technical Achievement (2007)
- Widely used in film production, motion pictures, television industry

Raster Image in Memory

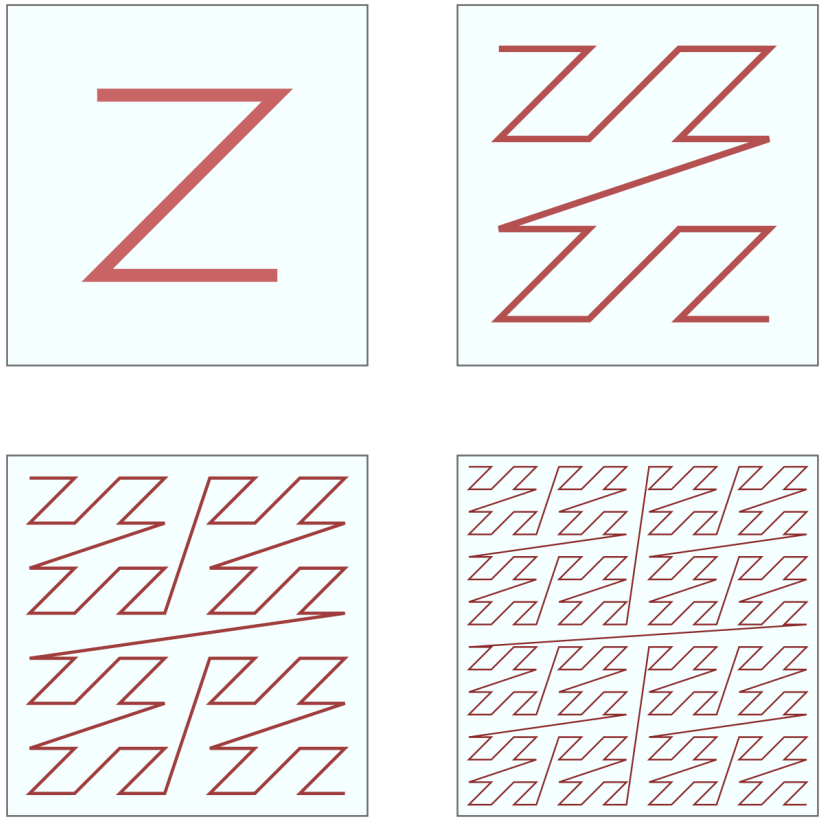
- Interleaved

  RGB RGB RGB RGB RGB RGB RGB RGB

  RGB RGB RGB RGB RGB RGB RGB RGB

  RGB RGB RGB RGB RGB RGB RGB RGB

- Scanline Order
- *Swizzled or Z-order*



Alpha Blending

Alpha Blending

- Alpha (α):
- It is used to represent the opacity value
  - α=0, transparent
  - α=1, fully opaque
  - α=[0,1], semi transparent

Alpha Blending

- For every pixel, we have α values
- Color and alpha (α) values stored
  - **RGBA**
- 8 bit per channel
  - Total 32 bit for RGBA
- Storage format of such information

RGBA RGBA RGBA RGBA RGBA RGBA RGBA RGBA
RGBA RGBA RGBA RGBA RGBA RGBA RGBA RGBA
RGBA RGBA RGBA RGBA RGBA RGBA RGBA RGBA

Alpha Blending

Foreground image

Alpha channel

Background image

Blended Image

Alpha Blending

- No alpha channel for background image
- Foreground has alpha channel

$$c_{final} = \alpha_{fg} c_{fg} + (1 - \alpha_{fg}) c_{bg}$$

- When both foreground and background has alpha channel

$$\alpha = \alpha_{fg} + (1 - \alpha_{fg}) \alpha_{bg}$$

When $\alpha_{bg} = 1$, we get, α=1

When $\alpha_{bg} = 0$, we get, $\alpha = \alpha_{fg}$

$$c_{final} = \frac{\alpha_{fg} c_{fg} + (1 - \alpha_{fg}) \alpha_{bg} c_{bg}}{\alpha}$$

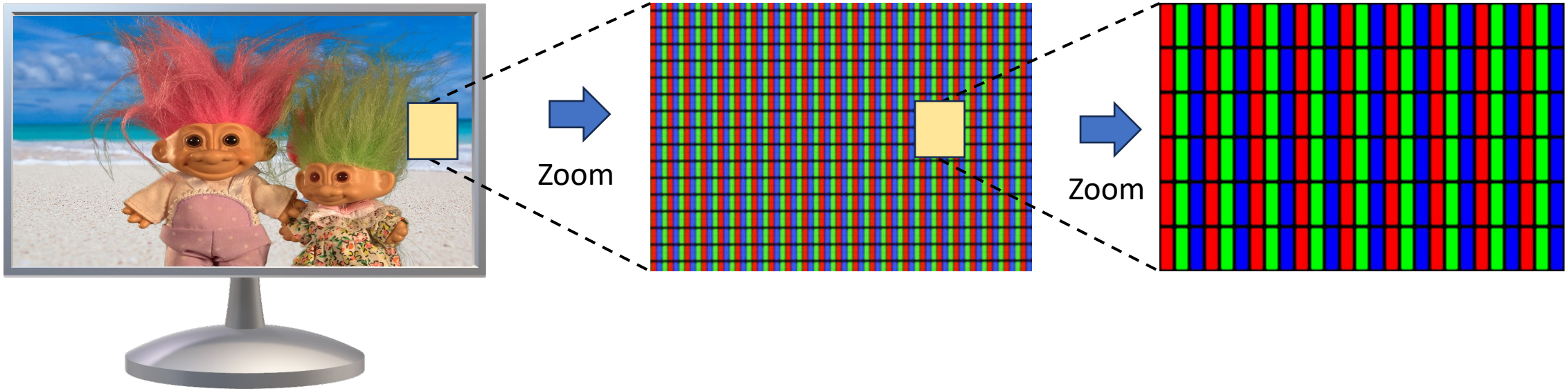
Alpha Blending

- Pre-multiplied alpha $(\alpha R, \alpha G, \alpha B, \alpha)$
  - Seems like make sense as we have to multiply eventually
  - But if we need manipulation, this strategy loses information
  - When alpha value is small, there could be precession issues as color values multiplied by alpha will be very small

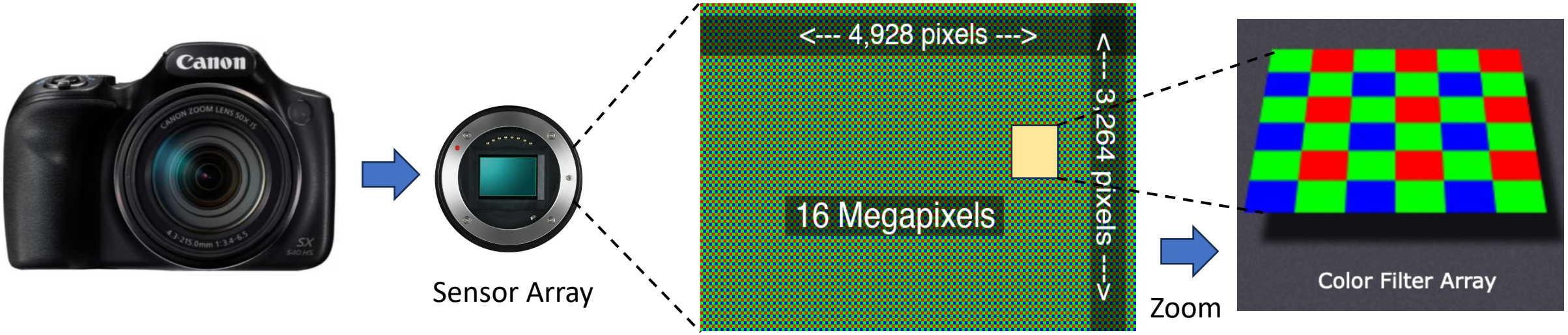
- Straight alpha (R, G, B, α)
  - Used in practice
  - No loss of information
  - Color vales can be manipulated easily

$(\alpha R, \alpha G, \alpha B)$

Displays: Monitors

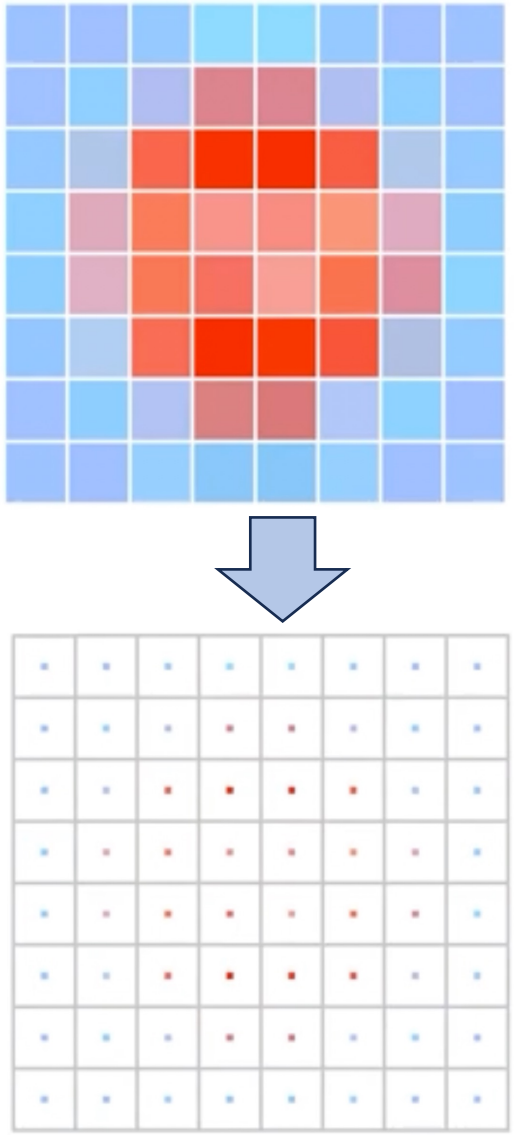


Displays: Digital Camera

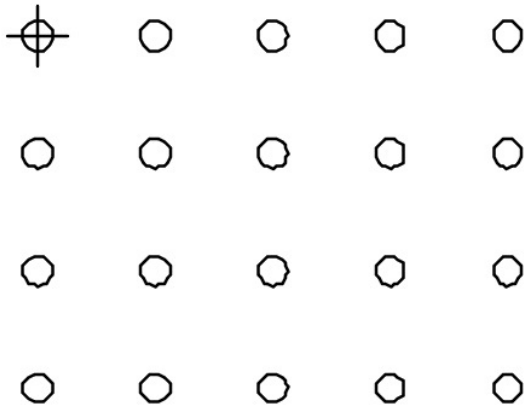


A Pixel Is Not A Little Square

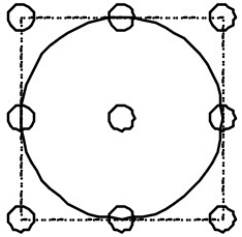
- http://alvyray.com/Memos/CG/Microsoft/6_pixel.pdf
- A pixel is a point sample
  - It exists only at a point
- An image is a rectilinear array of point samples (pixels)
- We can reconstruct a continuous entity from such a discrete entity using an appropriate *reconstruction filter*
  - A truncated Gaussian filter



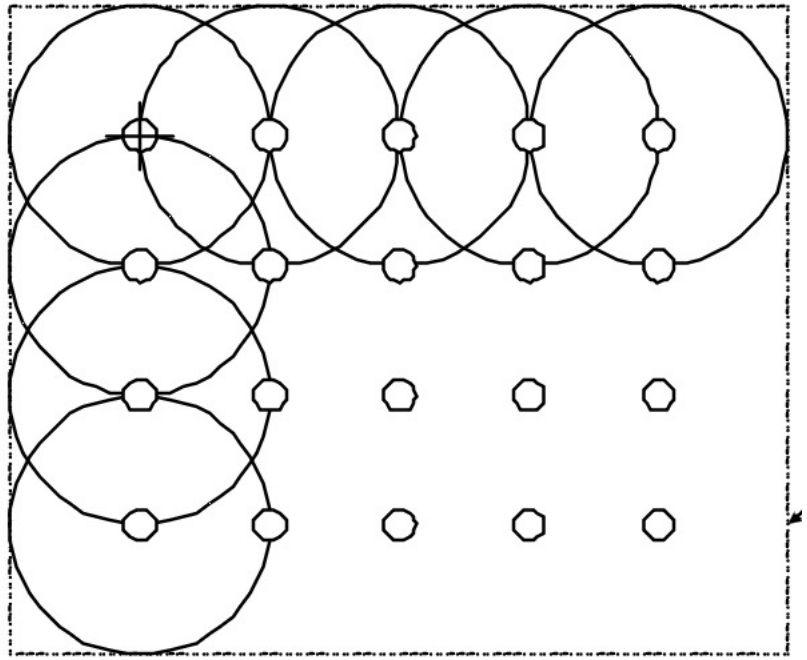
A Pixel Is Not A Little Square



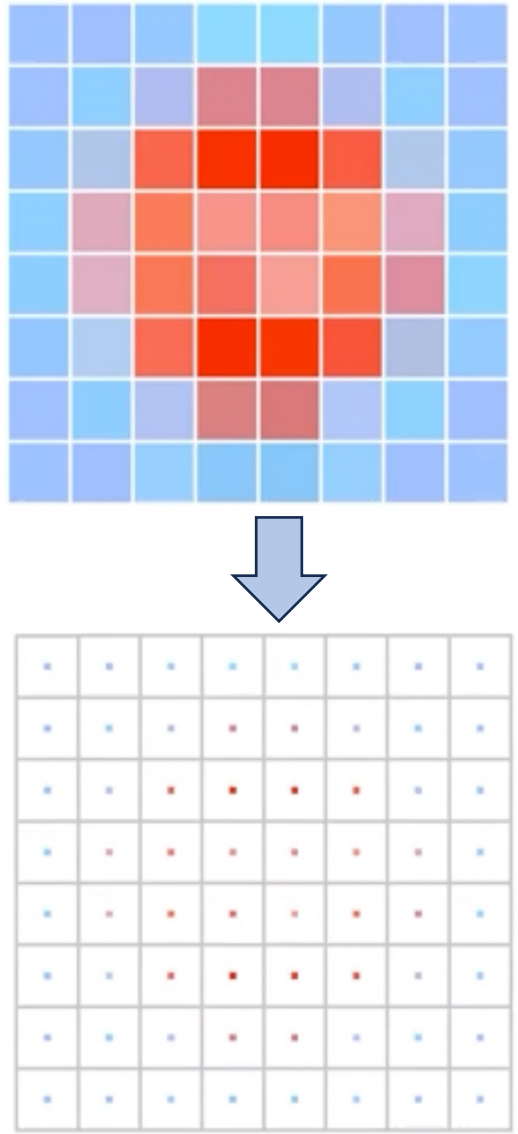
(a) A 5x4 image.



(b) The footprint of a reconstruction filter.
A truncated Gaussian, for example.



(c) Footprint of image under reconstruction



- https://pages.graphics.cs.wisc.edu/559-f14/2014/08/29/what-is-a-pixel-and-what-is-a-point-sample/