Images

**Computer Graphics
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Today

- **Images and Digital Images**
- **Raster Graphics**
- **Vector Graphics**

Images

- **Image:**
  - **Continuous** 2D distribution of intensity or color, defined as a 2-D function $f(x, y)$ at spatial coordinate (x, y)
  - $f(x, y)$ is the intensity (or gray level) or the amplitude of light.

Lena: the most famous test image in image processing community

Digital Images

- **Digital image: a *finite*, *discrete* quantities of image**
  - finite range: e.g., 0-255
  - discrete quantities: e.g., 0, 1, 2, ..., 255 (integer only here)
  - usually has 3 channels: RGB (red, green, and blue)
    - motivated by 3 types of cone cells (L, M, S) in the retina

- **Pixel (picture element):**
  - A single element of a digital image
    - For multi-channel images, three channel elements form a pixel.
  - c.f., voxel (volume element), texel (texture element)

Digital Images: Example

- **3-channel RGB format**
  - Intensity of the red channel is stronger than the other two in the example.

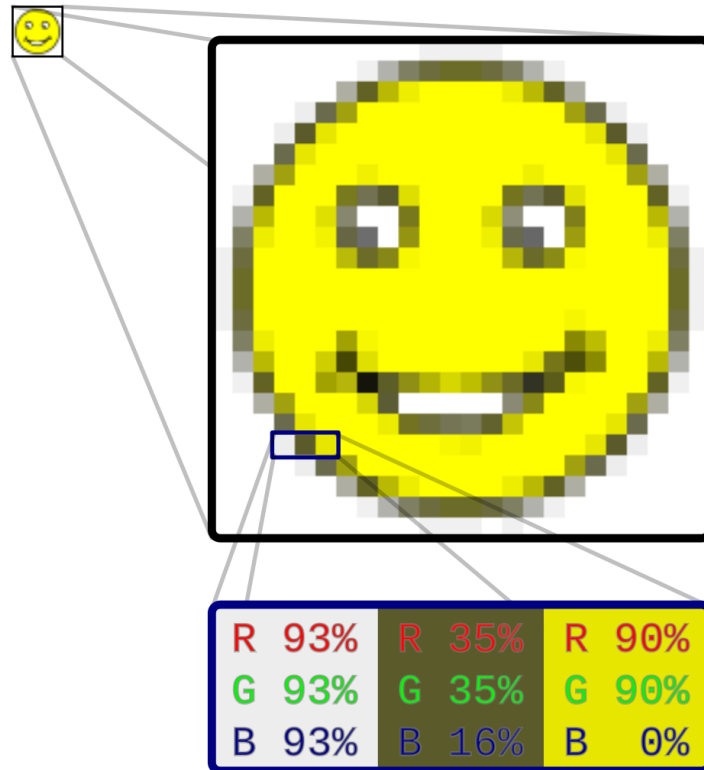red   +   green   +   blue   =   RGB

Raster Graphics

Raster Graphics

- **A raster graphics representation (also called the bitmap)**
  - *2D array* structure that represents a rectangular grid of pixels.
  - When enlarged, a blocky structure is visible

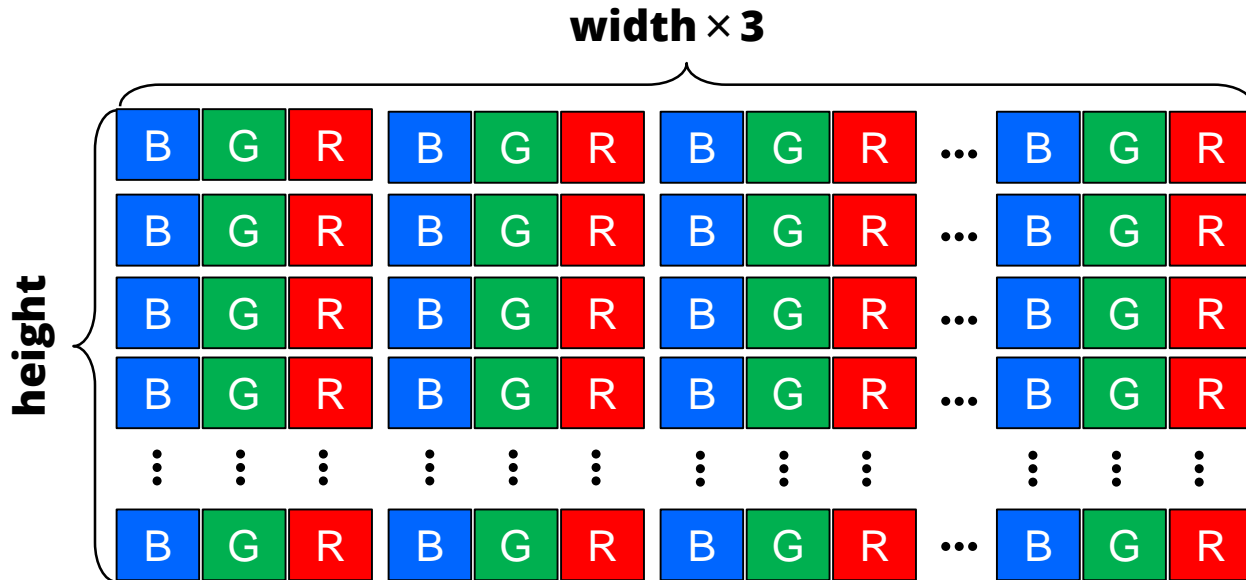| R 93% | R 35% | R 90% |
| G 93% | G 35% | G 90% |
| B 93% | B 16% | B 0% |

Raster Graphics

- **Memory structure**

```
unsigned char image[height*width*3];   // as a 1D array
```

 - e.g., BGR format in Windows BMP

  - Note: OpenGL uses 4-byte alignment for texture/images and framebuffer, which may pad additional bytes for each row.

Raster Graphics

- **Implication of a raster image**
  - ***approximation*** (sampled representation) of a real intensity distribution
    - c.f., a floating-point number in computers is always an approximation.
  - A single pixel represents the color of the pixel center location, not on its whole pixel area.
  - Example:
    - the yellow color of the center approximates the whole pixel area.
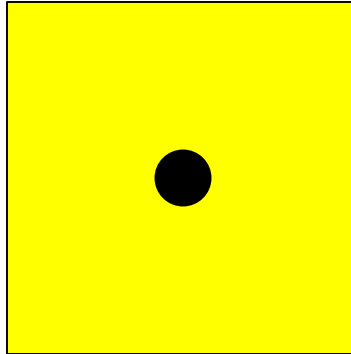
Raster Graphics: Advantages

- **Representation of arbitrary images**
  - Brute-force sampling can represent arbitrary images without the function of a continuous image.
  - This works, because memory is cheap.

- **Quality control**
  - Quality can be higher with denser sampling (higher resolution).

- **Mapping to displays**
  - Shapes of most display devices are rectangular.
  - The 2D array can easily be mapped to display devices.

Raster Graphics: Data Types

- **Bitmaps:**
  - boolean per pixel (black or white); e.g., fax, (old) newspaper
- **Grayscale:**
  - integer per pixel (gray levels)
  - Precision: usually 8-*bits per pixel* (bpp), but often 10, 12, 16 bpp
- **Color:**
  - 3 or 4 integers per pixel (RGBA for 4 integers; "A" means alpha/opacity
  - Precision: usually 24 bpp (RGB) or 32 bpp (RGBA)
- **Floating-point**
  - Floating-point format is often used for high-dynamic range (48 or 96 bpp)
  - Exposure effects can be captured with HDR formats

Raster Graphics: Storage Requirements

- **1024 × 1024 image (1 Megapixel) example**
  - bitmap: 128 KB
  - grayscale 8bpp: 1MB
  - grayscale 16bpp: 2MB
  - color 24bpp: 3MB
  - floating-point HDR color: 12MB

- **Think about:**
  - how much memory is required for an arbitrary resolution and bpp.

Raster Graphics: File Containers

- **Compression of image files**
  - When images are stored into disks with particular formats, they are usually compressed. So, you see much smaller file sizes for them.

- **Typical containers**
  - BMP: Lossless raw format
  - JPEG: Lossy compression (pronounced as "Jay-Peg")
    - Using DCT (discrete cosine transform for compression)
  - PNG: Lossless compression (pronounced as "Ping")
    - Using ZLIB for compression
  - TIFF, GIF, ... (obsolete)
 - WebP (recent container/compression by Google)

Vector Graphics

Vector Graphics

- **Unlike the raster graphics, vector graphics uses geometrical primitives such as points, lines, triangles, curves, etc.**
  - The primitives are represented as a mathematical expressions.
  - "Vector", in this context, is more than a straight line.

- **Common tools/formats to manipulate 2D vector graphics**
  - Adobe illustrator
  - Adobe Acrobat
  - SVG (Scalable Vector Graphics; recently available on the web)
  - Postscripts (for printers or printer file)

Vector Graphics

- **Vector graphics representations are usually independent of the output resolution.**
  - Because they are rasterized on the fly at the output stage to be displayed.
  - Still, most of display devices use raster display.

7x Magnification

Vector

Bitmap

Ice Cream
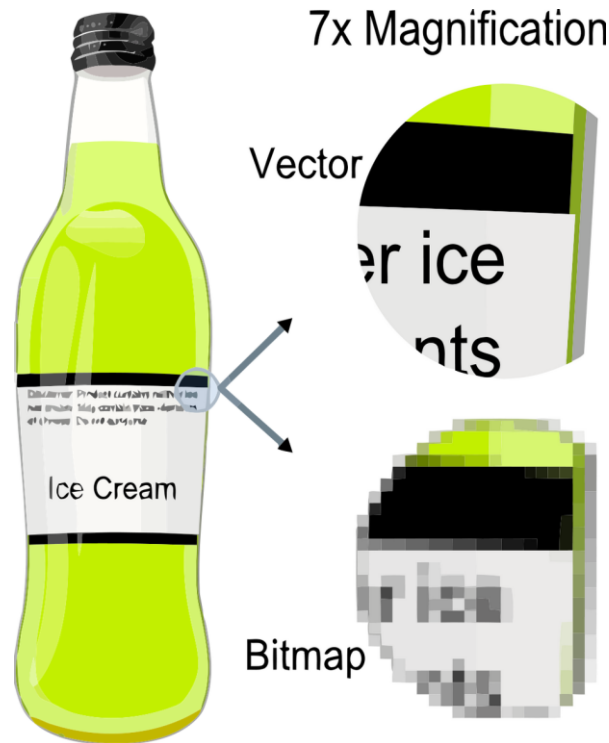
3D Graphics: 3D Vector to 2D Raster

- **Input: 3D vector representation**
  - Graphics uses vector graphic formats as an input
  - Points, lines, triangles, quads, polygons, curves, …

- **Output: 2D raster representation**
  - Raster images whose dimension is identical to the window resolution

Graphics Terms

- **"*capture images*" means:**
  - record the light distribution on the sensor (using cameras)

- **"*represent images*" means:**
  - encode images numerically (normally binary)

- **"*display images*" means:**
  - realize the encoded images as actual intensity distribution on the display devices (e.g., monitors)

Raster Display System

- **Screen image is defined by a 2D array in RAM**
  - The memory area is called the *frame buffer*.
  - Most modern systems have it in Graphics Processor Unit (**GPU**) memory.
  - GPU memory is often shared with main memory.

- **Common architecture of a raster display system**