How Do Digital Images Work?

A technical description for beginners

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Audience and Scope

This document aims to provide the reader with a basic understanding of how digital images are created and used in our everyday life. After reading this document, the audience will be able to identify the different characteristics of a digital image and how they relate to each other, the underlying process to create them, and what decisions must be made in order to find a balance between accuracy in the image representation and practicality. Additionally, readers will get a taste of further developments beyond basic 2D digital images.

The intended audience for this document is any person with a curiosity for learning about how digital images are created. In particular, this document could be used as an introductory reading for people starting to work with image processing tools such as Photoshop, Paint, or GIMP and who want to take full advantage of the functionality those tools offer. Readers of this document can also find it helpful to solidify basic imaging concepts before embarking on a more in-depth study of the digitalization process, its applications, and future areas of development.

Introduction

The advances in technology have made the use of digital images prevalent everywhere in our everyday lives. Whether we are taking a picture with our smartphone, scanning a printed document, or using software to do some drawing, we are creating a digital image. An image that later, we might want to manipulate to enlarge, enhance or combine with others using some image processing software so we can then use it in a web page, display in a monitor, or print in a flyer.

As common as digital images are, there are many times that we hear terms like image resolution, file compression, or RGB model, and we might not totally understand what they mean. This document presents an overview of concepts related to digital images to promote a better understanding of them.

What is a digital image?

A digital image is an electronic representation of a real image that is stored and handled by a computer[1]. The most important thing to understand about a digital image is that we cannot see it, and it does not have any physical size until it is displayed on a screen or printed on paper. Until that point, it is just a set of numbers describing the individual elements of the image. These elements are called **pixels** (short for picture elements). Each pixel contains a specific value that tells the computer what color or how bright it should be. Pixels are organized in an array of rows and columns corresponding to their vertical and horizontal positions in the image. This way of arranging digital image information using pixels produces a **bitmap**, i.e., a “map” of where the “bits” of information are stored.

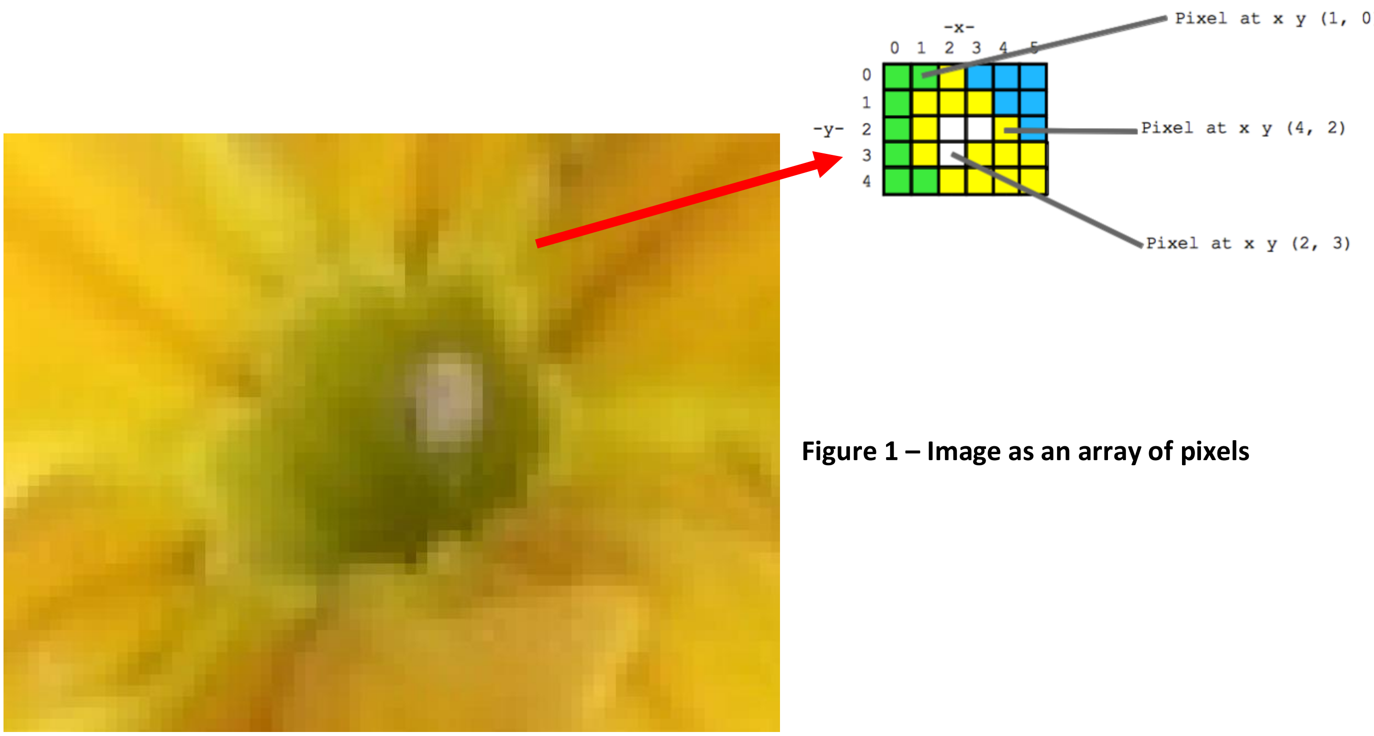

Figure 1 – Image as an array of pixels

There are a few ways to produce a digital image. We could create one using some design software (like Paint, Photoshop, or GIMP), take one on a digital camera, or scan one using a scanner. Regardless of the method used, the actual creation of the digital image is done by the process of **digitalization** that occurs inside our device (computer, camera, scanner). We will explore this process in more depth later in this document.

Characteristics of a Digital Image

A digital image has several basic characteristics[2] which relate to:

- What information is stored in the pixels (color/brightness)
- How the image is stored in a computer file (format)
- How the image is displayed (resolution)

Color representation

An image could be bitonal, grayscale, or color

- **Bitonal** images have only black or white values with no shades of gray.
- **Grayscale** images have a range of neutral tonal values from black to white. To represent them is only necessary to know each pixel's level of intensity or brightness.
- **Color** images can be represented with three colors, normally **RGB** (Red, Green, Blue) or four colors **CMYK** (Cyan, Magenta, Yellow, blacK)

Color Depth

Also known as "bits per pixel," is the number of **bits** used to store the values that describe the brightness or color in a pixel. More bits make it possible to record more shades of gray or more colors. For example, an RGB image with 8 bits of color has a total of 24 bits per pixel. Each bit can represent two possible colors, so we get a total of 16'777,216 possible colors.

Format

It gives more details about the image file, such as what compression was used to save it. Among the most popular of formats available are GIF, JPEG, PNG, and TIFF.

Resolution

Image resolution refers to the density at which pixels are displayed, i.e., how many pixels are displayed per inch of screen or paper. This is usually expressed as dots per inch (**dpi**) or pixels per inch (**ppi**). A higher resolution gives a more detailed image.

- RGB

A color model in which red, green and blue are added together in various ways to produce a broad array of colors. RGB is typically associated with electronic displays, such as LCD monitors, digital cameras, and scanners

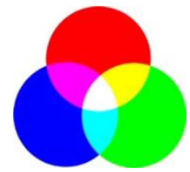

Figure 8: RGB

- CMYK

A subtractive color model in which four colors are used to filter out other colors. Cyan absorbs red, Magenta absorbs green, and Yellow absorbs blue. Black is used to cover unwanted tints in dark areas of the image. CMYK is typically used for printing.

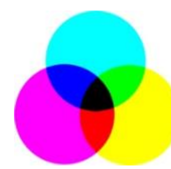

Figure 9: CMYK

- Bit

The most basic unit of information in computing. It represents a logical state with one of two possible values: 0 or 1.

- Byte

A unit of digital information that most commonly consists of eight bits.

Digitalization Process

The process of **digitalization** takes an image and turns it into an array of pixels. The dimension of this array is defined by the number of pixels along the width of the image (columns) and the number of pixels along its height (rows). Thus, the more pixels are used to represent an image, the closer it would resemble the original once the digitalized version is displayed.

Figure 2 depicts the steps from the moment an image is captured, then digitalized, and finally rendered on a screen or printed. Notice that the digitalization process occurs inside the device doing the capturing.

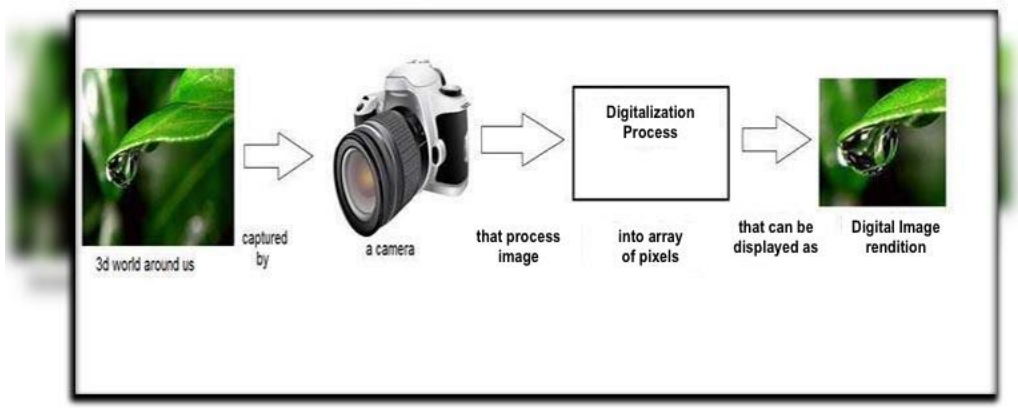

Figure 2: Digitalization process takes place inside the digital device

To better illustrate how the digitalization process works, we use an example to walk through the steps that need to happen inside a digital device to produce a digital image finally.

In this case, we pretend to take a picture of the scene shown in Figure 3 using a digital camera. For simplicity, we are using a grayscale scene so not many calculations are needed. However, the process is the same as with a full-color scene.

Figure 3: Scene to photograph

Inside the digital device, the digitalization process[3] takes place.

1. The original image is divided into little squares. Figure 4 shows the general idea: many small squares, all the same size. Each square represents a "pixel."

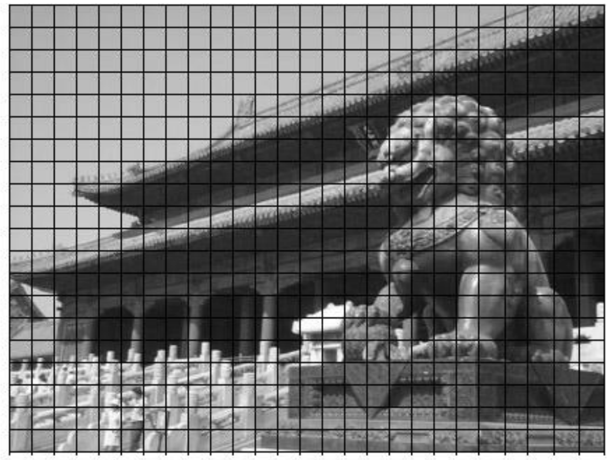

Figure 4: Starting digitalization

2. The "numbers" that describe this image are calculated. For our grayscale image, our device just needs to calculate levels of brightness using the following method:
   - Find the darkest part of the image. Call that level of brightness zero.
   - Find the lightest part of the image. Assign a positive integer – 1000, for example - to that level of brightness.
   - Finally, for every pixel, find the average level of brightness in the part of the scene covered by that pixel. Assign a number between 0 and 1000 to this average level.

Now the picture of the scene we wanted to photograph has been replaced by the numbers associated with every pixel. These numbers represent the average brightness within each pixel. Therefore, to get a better representation of the original image, the pixels should be very small, and there should be many of them.

Figure 5 shows an enlargement of one part of the picture (the head of the person wearing a light-colored hat in the lower left corner) with more practical pixel sizes. These pixels are almost small enough to faithfully represent the detail of the picture.

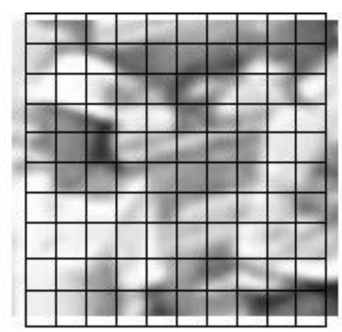

Figure 5: Image section enlargement

There are many variations of this digitalization process. Often the range of 0 to 255 is used for the calculations because one **byte** of memory can store 256 different values. There are cases in which the pixel is shaped like a rectangle rather than a square. Regardless, none of these variations change the basic idea of this process.

After reviewing the digitalization process, we can see there are two critical decisions buried in it:

- How many pixels are needed? In other words, what resolution the digital image should have.
- How many different values are needed to cover the range of brightness in the pixels? That is, what would be the color depth of the digital image.

These are important decisions because they determine how much digital space (memory in the device) is needed to hold the image and how much time is needed to handle it.

Image Compression

Digital images tend to produce big files and are often compressed to make the files smaller. Compression takes advantage of the fact that many nearby pixels in the image have similar colors or brightness. Instead of recording each pixel separately, it is possible to record that, for example, “the 100 pixels around certain position are all white.”

There are two types of compression, lossy and lossless, which vary in their efficiency and speed.

- **Lossless** compression works by rewriting the data, so it is stored more efficiently. The quality of the file remains the same.
- **Lossy** compression works by removing some of the data, thus reducing the quality of the file.

Depending on how we will use the digital image, we might find appropriate one type of compression rather than the other. Therefore, knowing about image formats comes in handy, since they vary mainly based on the type of compression they use. The following table summarizes the characteristics of the four most used formats.

Format	Compression	Good for	Disadvantage
TIFF **Tagged Image File Format**	Lossless	Master copies of images	Files are too big (not suitable for web delivery)
JPEG **Joint Photographic Experts Group**	Lossy	Web delivery of photographic images	Loss of quality causes blurring effect
GIF **Graphical Interchange Format**	Lossless	Web delivery of icons and graphics	Limited color capabilities (not suitable for photographs)
PNG **Portable Network Graphics**	Lossless	Web delivery (with support for “true color” images)	Not as good for photographic images

Different type of images

Usually, the term "digital image" refers to bitmapped images (i.e., images described by an array of bits). Bitmapped images are also known as **Raster images** or Pixel images.

There is another type of image commonly used for digital work. It is called **Vector Graphics.** A vector graphic is described by lines, curves, and shapes in a format that incorporates geometric formulas for rendering the image elements.

The following example illustrates the difference between these two types of images.

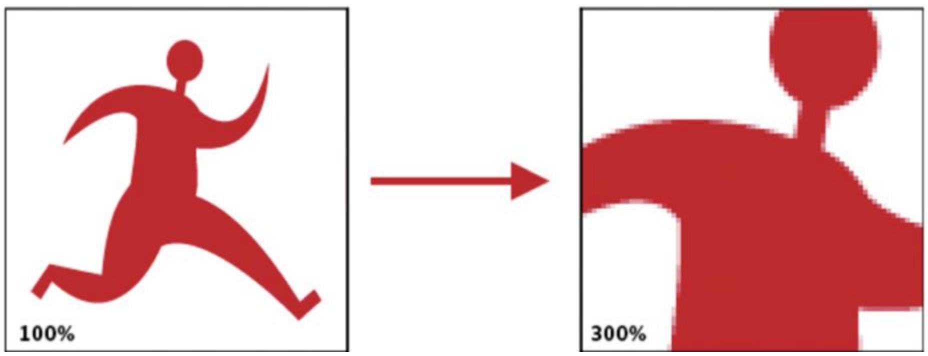

Figure 6: Raster Image

At 100%, the raster image shown in Figure 6 looks almost the same as the vector version (Figure 7 below). However, as soon as the image is scaled (enlarged), the pixels on the edges begin to show, and the edges no longer look smooth.

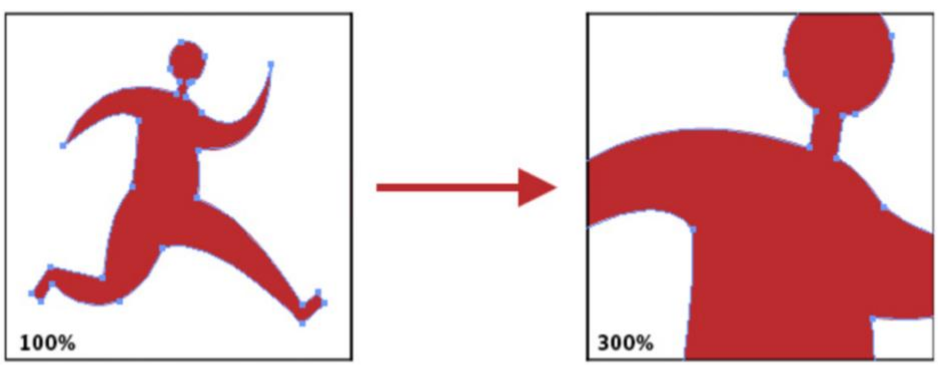

Figure 7: Vector Graphic

A vector graphic is created by defining points and joining them with straight or curved lines called vectors. When vector graphics are scaled, the edges remain crisp and sharp no matter the size.

Most modern computer graphics software allows drawing an image using a mixture of raster or vector graphics because sometimes one approach works better than the other. Using software like GIMP, we can draw curves on the screen before converting them into pixels to incorporate them into a raster image.

What is next?

So far, the type of images we have discussed in this document are based on two-dimensional (2D) graphic models where depth is approximated using color and brightness. Real life, though, is not made of pixels or vectors. When we look around us, our brains gather much more information than what can be included in even the more realistic computer images. Thus, there is a need to work with 3D models that allow us to incorporate more information into the images. Consequently, we now see more widespread use of 3D graphics in computer games, **Virtual Reality** simulations, **CGI** animation, and the arts in general. Moreover, 3D graphics are also making their mark in the scientific world with applications such as medical scanning, astronomical image processing, 3D mapping, and many others.

- Virtual Reality

An interactive 3D computer-created world that a person can explore giving the feeling that they are there, mentally, and physically.

- CGI

Computer-generated imagery (CGI) is the application of computer graphics to create or contribute to images in art and media.

Conclusion

Digital images are extremely valuable for conveying visual information to general audiences. With more and more of people's lives shifting to the computer, digital images become more present in our lives. Whether it is for entertainment or work-related reasons, understanding the basics of how digital images work is the first step to enter the world of 3D graphics and more complex applications that are part of our current digital world.

Works Cited

1. Weiss, Isaac. "Digital Images." *Encyclopedia.com* Web. June 6, 2021. <https://www.encyclopedia.com/computing/news-wires-white-papers-and-books/digital-images>
2. Peterson, A. "Introduction to Basic Measures of a Digital Image for Pictorial Collections Kit." June 2005. Prints & Photographs Division, Library of Congress. Web. June 6, 2021. <https://www.loc.gov/rr/print/tp/IntroDgtlImage.pdf>
3. Milch, James. "How a picture can be represented as a collection of numbers." *Society for Imaging Science and Technology*. Web. June 6, 2021 <https://www.imaging.org/site/IST/Resources/Imaging_Tutorials/How_a_Picture_can_be_Represented_as_a_Collection_of_Numbers/IST/Resources/Tutorials/Digital_Image.aspx?hkey=53cc8b2f-3ca0-4ace-93d2-459645ed8554>

Figure 1 (Manually composed using images from the following source)
Taylor, Ashley. "Introduction to Digital Images." *Stanford University*. CS101 class website. June 13, 2021
<https://web.stanford.edu/class/cs101/image-1-introduction.html>

Figure 2 (Modified image: labels of process step were changed to describe the digitalization process).
"Digital Image processing: What is Image Enhancement and Image Restauration." *IIEC Business School*. Web. June 9, 2021.
<https://artificialneuralnetworks.org/digital-image-processing-what-is-image-enhancement-and-image-restoration>

Figure 3 (Resized)
Figure 4 (Resized)
Figure 5 (Resized)
Milch, James. "How a picture can be represented as a collection of numbers." *Society for Imaging Science and Technology*. Web. June 6, 2021
<https://www.imaging.org/site/IST/Resources/Imaging_Tutorials/How_a_Picture_can_be_Represented_as_a_Collection_of_Numbers/IST/Resources/Tutorials/Digital_Image.aspx?hkey=53cc8b2f-3ca0-4ace-93d2-459645ed8554>

Figure 6 (Resized)
Figure 7 (Resized)
"Raster and Vector." *Adobe.com*. Web. June 6, 2021
<https://helpx.adobe.com/photoshop/key-concepts/raster-vector.html>

Figure 8 (Resized)
Figure 9 (Resized)
"What is the difference between CMYK and RGB colors?" *Ashworth Creative Blog*. June 10, 2014. Web. June 10, 2021
<https://www.ashworthcreative.com/blog/2014/06/difference-cmyk-rgb-colors/>