Introduction to Digital Image Processing

There are multiple application areas where digital image processing is required which can be categorized under two broad categories.

1. Improving and enhancing the quality of images for visual perception and interpretation
2. Processing of image data for storage, transmission and information extraction

Vision is one of our advanced senses that allow us to understand the environment around us. This vision enables us to perceive the image visually using images. However, our vision is very limited and we can see through a narrow band in electromagnetic spectrum. Hence, we need other devices that can better visualize, can see beyond the human eye capability and can dive deeper in information obtained. The area of digital image processing lies under the larger domain of computer science known as $Artificial\ Intelligence$ that tries to emulate human like intelligence.

1.1. The digital image processing

An image is a 2D function $f(x, y)$ that maps light intensity values to pixel locations. We start our discussion with gray scale images where the different shades of gray are used to represent the image. Figure-1 shows a gray scale image.

Figure 1-1: A) Gray Scale B) Gray Scale Image

In function $f(x, y), x, y$ represent the spatial plane (representation in 2D space) and value of $f(x, y)$ represents the intensity of light or value of gray scale at that point. A digital image is one that has discrete values for x, y, and f. It means that each next pixel is located at the difference of one and number of values of f are discrete. The values of f are also called as gray levels where each level is at discrete distance from other. And digital image processing refers to processing a digital image using digital machine i.e. computer. A digital image is composed of number of discrete values where each value is located at particular position in the image. Each value in an image is called $image\ element\ or\ picture\ element\ or\ pixel$ or simply pel.

There are multiple fields that involve image processing like $Digital\ Image\ Processing$, $Computer\ Vision$, $and\ Medical\ Image\ Analysis$. There are no clear boundaries among these fields however we can categorize image processing based on granularity of different features.

1.2. Electromagnetic Spectrum

It is the distribution of electromagnetic radiation according to their frequencies. All electromagnetic waves travel at the speed of light however their frequencies, wavelengths and photon energies vary. The waves with different range of frequencies are grouped in the form of bands based on their features like emission, transmission and absorption. A group of specific frequencies is called a band and there are multiple bands in the electromagnetic spectrum. Bands are also defined based on their type of applications and there are no specific boundaries between the bands.

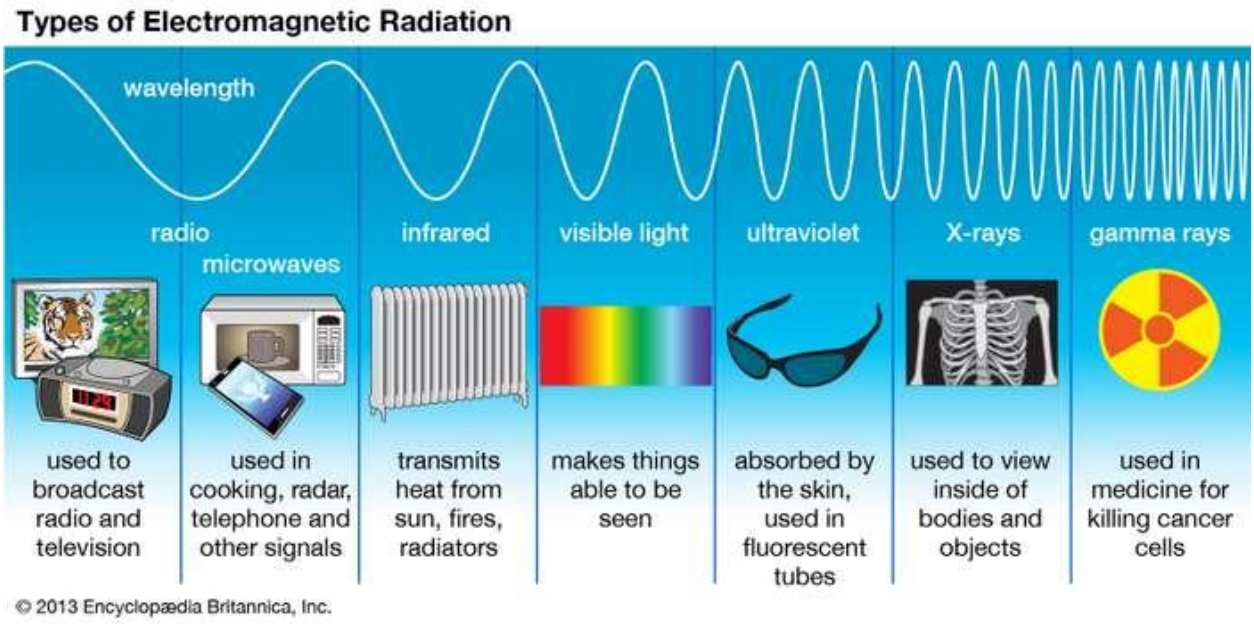


Figure 1-2: Electromagnetic Spectrum

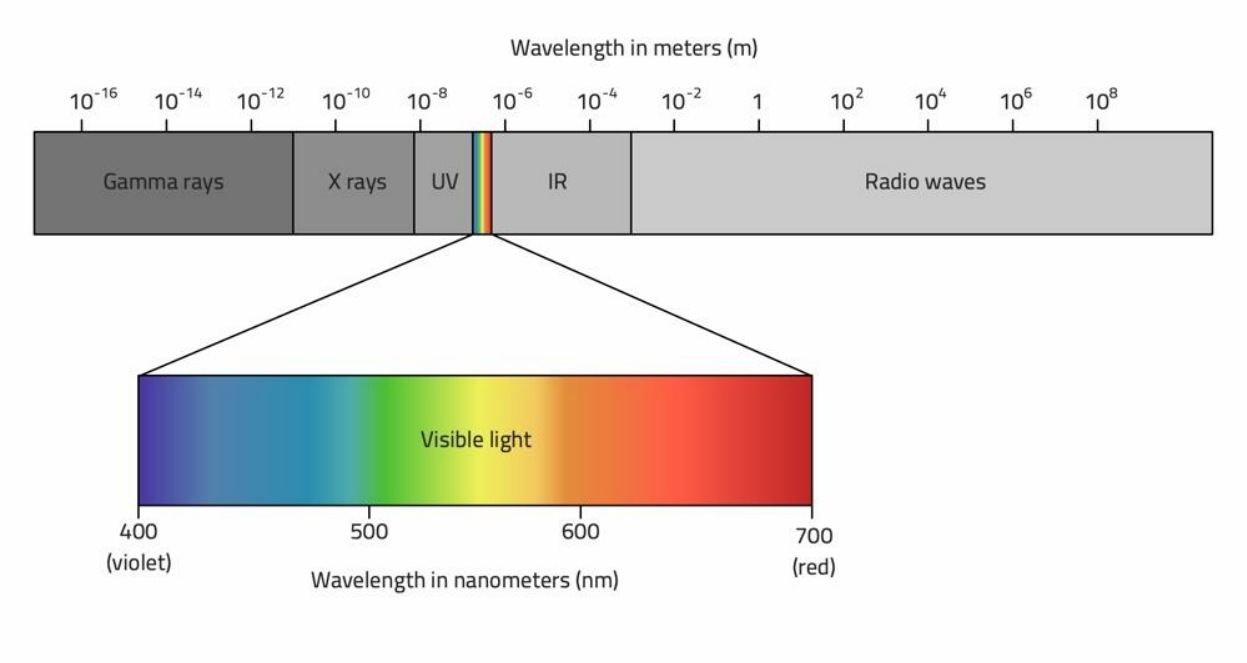


Figure 1-3: EM spectrum and band frequencies

1.3. Applications of Digital Image Processing

There is large variety of digital image processing applications. It is difficult to provide a comprehensive list. However according to different bands of EM spectrum, few of them are listed below:

- **GAMMA-RAY IMAGING**
  Nuclear medicine and astronomical applications are prominent in this area. positron emission tomography (PET), Single positron Emission tomography (SPECT). 2D and 3D images can be produced using these imaging methods or modalities.

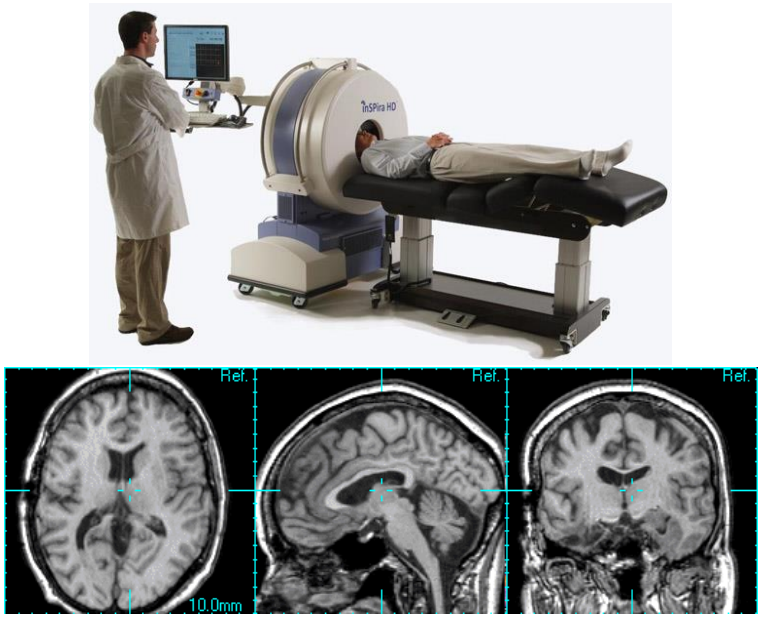


Figure 1-4: A) MRI imaging machine B) Brain MRI

There are various applications of Gamma ray imaging. Few of them are listed below:

- $Disease\ Diagnosis$: Positron emission tomography (PET) scans
- $Detection\ of\ precious\ stones$ i.e. conversion of white topaz to blue topaz
- $Industrial\ uses$ in refining, mining, chemicals, food, soaps and detergents, pulp, paper, water and oil industries, for the measurement of levels, density, and thicknesses
- $Trade\ vehicle\ analysis$: it is the application in which containers are checked using gamma rays to visualize their inner contents

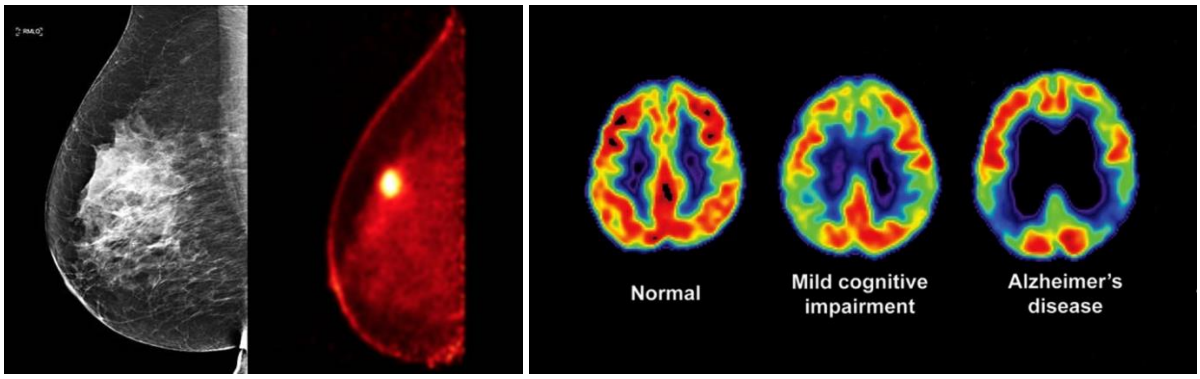


Figure 1-5: A) Breast Cancer Detection B) Brain Disease Detection

- **X-RAY IMAGING**
  X-ray imaging is a well-known application. Such images are used in medical as well as industry and astronomy.

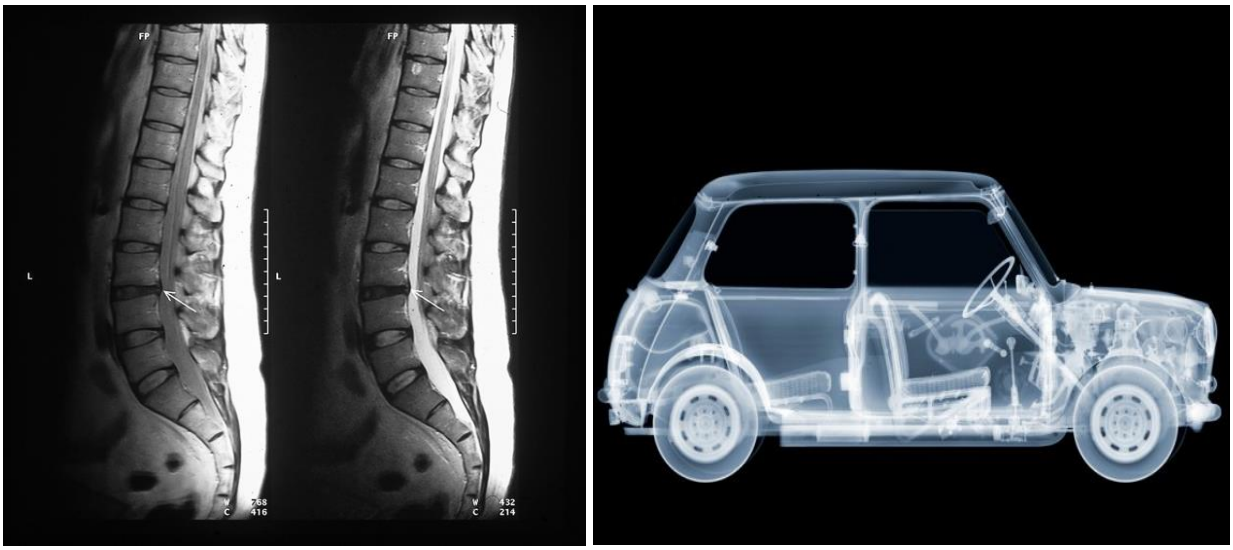


Figure 1-6: X-Ray imaging A) Spine X-ray B) Car X-ray D) Space X-rays

Few of the uses are listed here:

- $Projectional\ radiography$: It is the process of producing two-dimensional images using x-ray radiation
- $Computed\ Tomograph$: Slices of specific areas of the body are obtained from a series of two-dimensional X-ray images taken in different directions. These cross-sectional images can be combined into a three-dimensional image of the inside of the body and used for diagnostic and therapeutic purposes in various medical disciplines.
- $Fluoroscopy:$ It is the process to get the moving images of internal body organs using fluoroscope. In this method, an X-ray imaging intensifier is used along with CCD video camera that captures the moving pictures of human body and plays them on monitor.

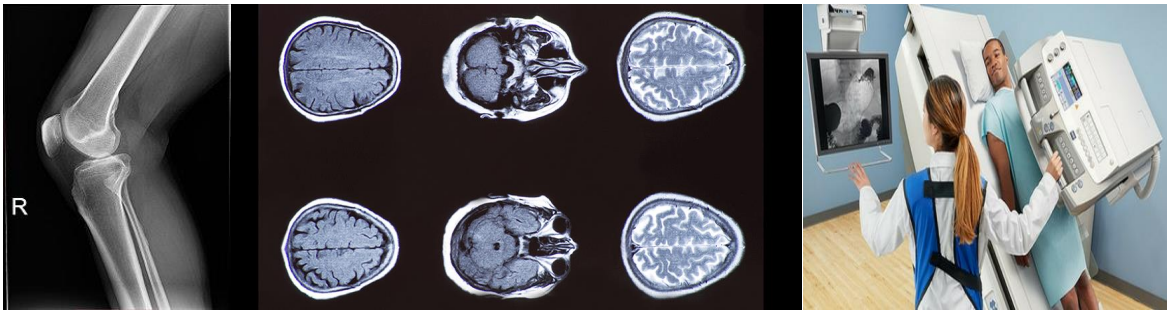


Figure 1-7: A) Plain x-ray of human knee B)Human head CT Scan C) Fluoroscopy

- **IMAGING IN THE ULTRAVIOLET BAND:** These applications include lithography, industrial inspection, microscopy, lasers, biological imaging, legal uses and forensic applications, and astronomical observations. There are two main categories of UV imaging: UV light and UV-fluorescence imaging. True ultraviolet (UV) imaging inspection isn't used often in machine vision. However, as UV-sensitive cameras and UV-emitting light sources, particularly LED lighting, have become widely available and less costly, new applications are emerging.

Figure 1-8: A) Visible band Image B) Ultraviolet band image C) Room floor and dirt spots on it

- **IMAGING IN VISIBLE AND INFRARED BAND**

Compared to all other bands, visible band has lot more imaging applications. In most of the cases, imaging in these two bands is used combinedly. Few of such applications are listed below:

- $Entertainment$: This is the biggest application domain of visible band imaging. We capture our own images, pictures of our loved ones and natural scenes. Moving pictures is another big application domain.
- $Microscopy$: A processing of visualizing very small objects that are difficult to be viewed with naked using specialized instruments like microscopes is called the microscopy. Microscopy has three branches: optical, electron and scanning probe microscopy.
- Astronomy:
- Remote sensing:
- Industry
- Law enforcement

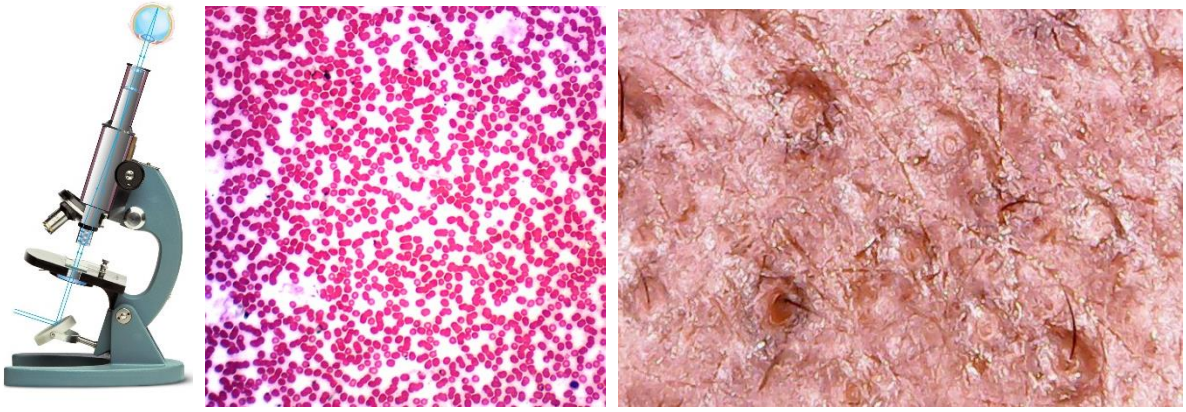


Figure 1-9: A) Microscope B) Blood microscopy image C) Face skin microscopy

Infrared radiation extends from the nominal red edge of the visible spectrum at 700 nanometers (nm) to 1 millimeter (mm). There are multiple uses of infrared that may include:

- Night Vision:
- Thermography
- Hyperspectral imaging
- Spectroscopy
- Meterology
- Astronomy
- Climatology

1.4. Fundamental Steps in Digital Image Processing

There are multiple steps involved in digital image processing. We list these steps in sequence here however it is not necessary that an application follows these steps in same order or follow all steps.

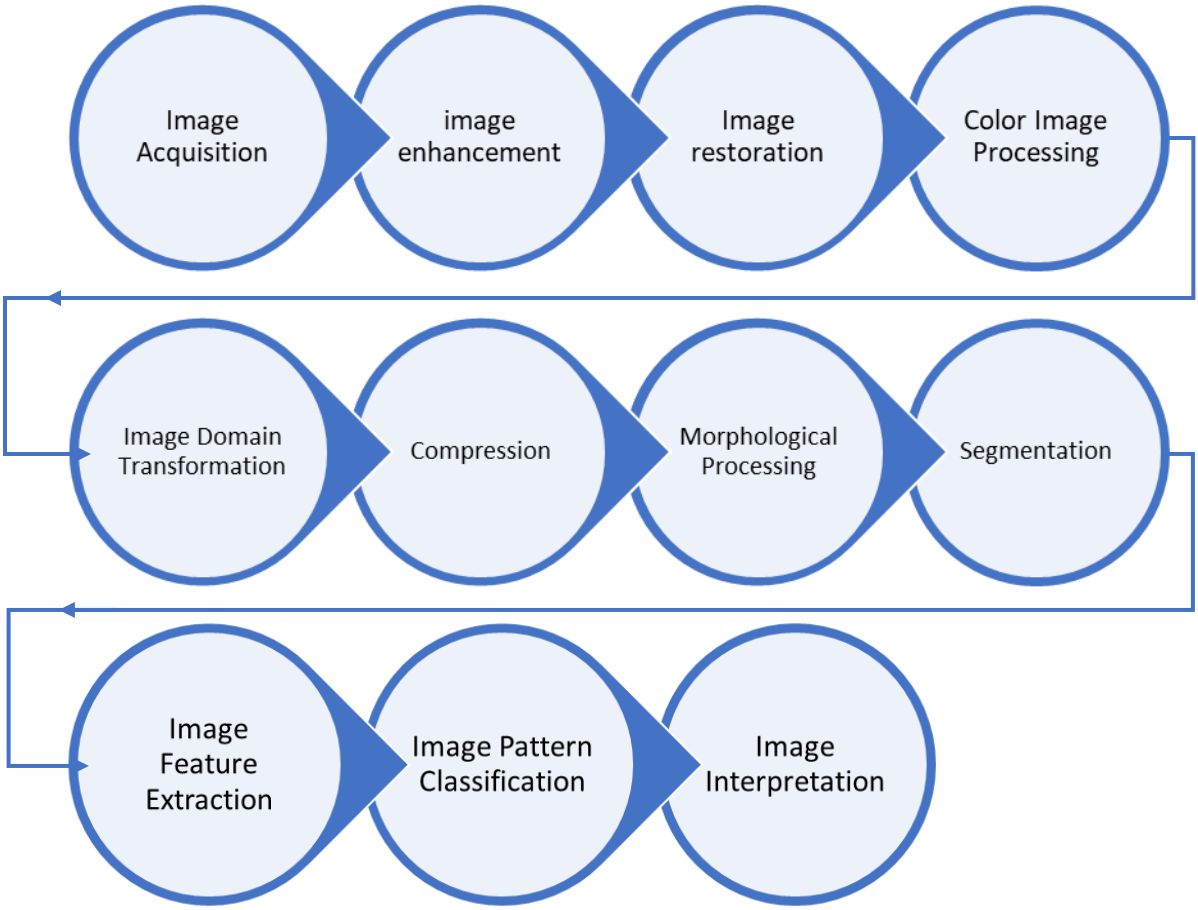


Figure 1-10: Image Processing pipeline

1.5. Components of Image Processing System

A computer system that can process the images consists of various components and these may vary from application to application.

- **A computer system**: Normal or specialized computer. For this course, your laptop may work
- **Image display devices**: Specialized screens are required for professional work however your current system will be good for current requirement.
- **Mass storage devices**: Normally image processing professional require lot of mass storage and if your system has at least 10 GB space, it will be ok.
- **Image processing specialized software**: We may need some specialized software like python, PyCharm and other relevant libraries.
- **Image processing specialized hardware:** Normally your current VGA card and processor are ok to work with this manual. However, GPUs are now common in image processing applications.
- **Hardcopy:** you may need a printer to get the print of your work.

1.6. OpenCV and Image Processing

A software $toolkit$ is collection of libraries that help you to learn, experiment and develop software for a particular domain. For example, in image processing, there are many algorithms that we apply on images to perform different tasks on images like quality enhancement, sharpening, information extraction and

segmentation. All these algorithms are programmed by experts of that domain and are made available for others to use. Although there are lot many image processing toolkits are available in market however two most popular applications are

- OpenCV
- MATLAB

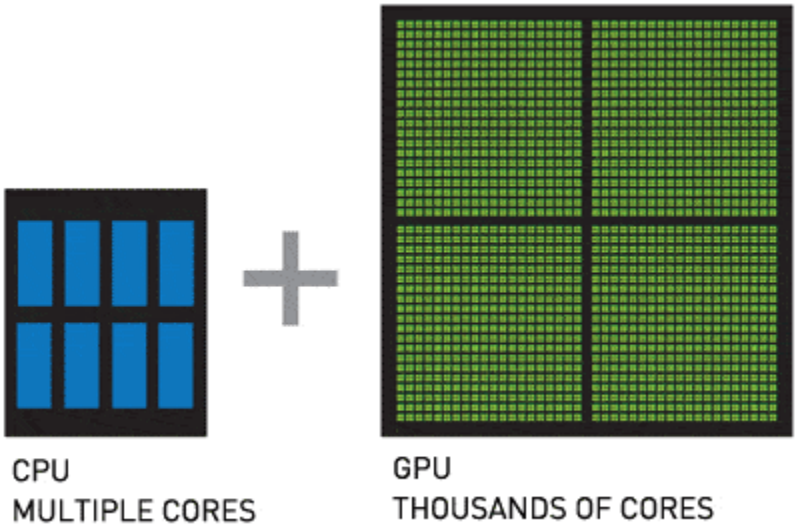
a. OpenCV

OpenCV stands for Open Computer Vision or most precisely Open Source Computer Vision Library. There are two main objectives behind the development of OpenCV:

- To provide common infrastructure for computer vision applications
- To accelerate the use of machine vision in commercial software products

At present, the library contains 2500 image processing and computer vision algorithms coded. According to opencv.org there are more than 47,000 registered users. This library is being used by researchers, academia, govt. bodies and commercial companies like Google, Yahoo, Microsoft, Intel, IBM, Sony, Honda and Toyota. The library has support for C++, Java, Python and MATLAB. It can be run on Windows, Linux and Android OS. According to opencv.org:

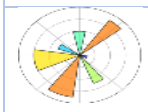
> "*Modern Graphical Processing Unit (GPU) accelerators has become powerful and featured enough to be capable to perform general purpose computations (GPGPU). It is a very fast-growing area that generates a lot of interest from scientists, researchers and engineers that develop computationally intensive applications. Despite of difficulties reimplementing algorithms on GPU, many people are doing it to check on how fast they could be. To support such efforts, a lot of advanced languages and tool have been available such as CUDA, OpenCL, C++ AMP, debuggers, profilers and so on.*
>
> *Significant part of Computer Vision is image processing, the area that graphics accelerators were originally designed for. Other parts also suppose massive parallel computations and often naturally map to GPU architectures. So, it's challenging but very rewarding to implement all these advantages and accelerate OpenCV on graphics processors*"
>
> Following figure gives a high-level view of CPU and GPU.



And when working with such high number of processing cores, massively parallel processing is required that being built in OpenCV. OpenCV is being mainly developed in C++.

b. Software Required for this book

We will be using open source software that are freely available. Here is the list:

 **Python 3.6**	 **PyCharm Community Edition**
 **Numpy**	 **OpenCV**
 **Matplotlib**	

Appendix-A shows you the process of installing software and running your first python program.

c. Support and Debugging

If you write an OpenCV program and need to debug it do the followings:

- At first try to troubleshoot the problem using OpenCV documentation and tutorials. The documentation is provided at https://docs.opencv.org/. There are many versions of OpenCV so when you are going to find something, search in the documentation of OpenCV version that you have installed. In this book we are using OpenCV version 4.1.1. You can also download the documentation and make available offline. To be a good user, make yourself familiar with library documentation.
- If it doesn't help, search for an answer or ask a question at OpenCV Answers https://answers.opencv.org/questions/ or on Internet.
- Keep on visiting OpenCV Answers and as you learn the library, do answer at the forum.