**Hardware component**

**Raspberry Pi**

The Raspberry Pi is a low cost, **credit-card sized microcontroller. This microcontroller can connect a computer monitor or TV, standard keyboard and mouse.** It’s capable of doing everything you would expect a personal computer to do, from browsing the internet and playing high-definition video, to making spreadsheets, word-processing, and playing games. Moreover, it is a capable of performing computing in high level programming languages like Scratch and Python. Raspberry Pi SBCs feature a [Broadcom](https://en.wikipedia.org/wiki/Broadcom) system on chip with an integrated ARM-compatible CPU and on-chip GPU.

Developed in the [United Kingdom](https://en.wikipedia.org/wiki/United_Kingdom) by the [Raspberry Pi Foundation](https://en.wikipedia.org/wiki/Raspberry_Pi_Foundation), in association with [Broadcom](https://en.wikipedia.org/wiki/Broadcom_Inc.), the Raspberry Pi has evolved over different generation.

[1] The *Raspberry Pi Model B* was released in February 2012, followed by the simpler and cheaper *Model**A* in 2014. These first-generation boards feature ARM11 processors, are approximately credit-card sized and represent the standard mainline form-factor. Improved A+ and B+ models were released a year later. A "Compute Module” was released in April 2014 for embedded applications.

The *Raspberry Pi 2* was released in February 2015 and initially featured a 900 MHz 32-bit quad-core ARM Cortex-A7 processor with 1 GB RAM. Revision 1.2 featured a 900 MHz 64-bit quad-core ARM Cortex-A53 processor. This processor model is also used by *Raspberry Pi 3 Model B* but has an improved clock speed of 1.2 GHz.

A *Raspberry Pi Zero* with smaller size and reduced I/O and GPIO capabilities was released in November 2015. On 28 February 2017, the *Raspberry Pi Zero**W* was launched, a version of the Zero with Wi-Fi and Bluetooth capabilities. On 12 January 2018, the *Raspberry Pi Zero WH* was launched, a version of the Zero W with pre-soldered GPIO headers.

*Raspberry Pi 3 Model B* was released in February 2016 with a 1.2 GHz 64-bit quad core ARM Cortex-A53 processor, on-board 802.11n Wi-Fi, Bluetooth, and USB boot capabilities. In 2018, the *Raspberry Pi 3 Model B****+*** was launched, on Pi Day. It has a faster 1.4 GHz processor, a three-times faster gigabit Ethernet (throughput limited to ca. 300 Mbps by the internal USB 2.0 connection), and 2.4 / 5 GHz dual-band 802.11ac Wi-Fi (100 Mbps). Other features are POE, USB boot and network boot.

*Raspberry Pi 4 Model B* was released in June 2019 with a 1.5 GHz 64-bit quad core ARM Cortex A-72 processor, on-board 802.11ac Wi-Fi, Bluetooth 5, full gigabit Ethernet, two USB 2.0 ports, two USB 3.0 ports, and dual-monitor support via a pair of micro HDMI Type D ports for up to 4K resolution. The Pi 4 is also powered via a USB-C port, enabling additional power to be provided to downstream peripherals, when used with an appropriate PSU. The initial Raspberry Pi 4 board has a design flaw where third-party e-marked USB cables, such as those used on Apple MacBooks, incorrectly identify it and refuse to provide power.

*Raspberry Pi 400* was released in November 2020. It features a custom board that is derived from the existing Raspberry Pi 4, specifically remodeled with a keyboard attached. The case was derived from that of the Raspberry Pi Keyboard. A robust cooling solution like the one found in Commodore 64 allows the Raspberry Pi 400's Broadcom BCM2711C0 processor to be clocked at 1.8 GHz, which is slightly higher than the Raspberry Pi 4 it's based on. The keyboard-computer features 4 GB of LPDDR4 RAM.

*Raspberry Pi Pico* was released in January 2021. It was Raspberry Pi's first board based upon a single microcontroller chip; the RP2040, which was designed by Raspberry Pi in the UK. The Pico has 264 KB of RAM and 2 MB of flash memory. It is programmable in MicroPython, CircuitPython and C. It has partnered with Vilros, Adafruit,Pimoroni,Arduino and SparkFun to build Accessories for Raspberry Pi Pico and variety of other boards using RP2040 Silicon Platform. Rather than perform the role of general-purpose computer like the others in the range it is designed for physical computing, similar in concept to an Arduino. [1]

This project utilizes the Raspberry Pi 2 Model B. The detail of this model of Raspberry Pi is given below.

**Raspberry Pi 2 Model B**

The Raspberry Pi 2 Model B is the second-generation Raspberry Pi. It is based on the BCM2836 system-on-chip (SoC), which includes a quad-core ARM Cortex-A7 processor and a powerful GPU. It weights 42g and has a dimension of 5 x 4 x 3 inches. The raspberry pi 2 model B is illustrated in the figure below.

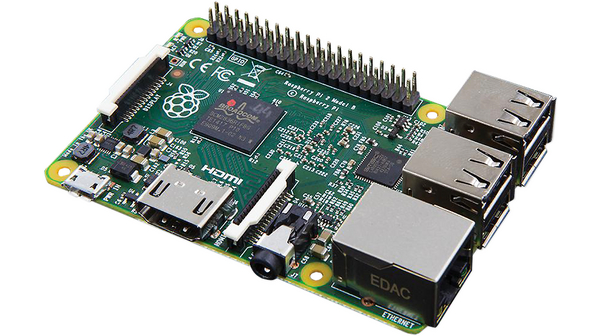


Figure - Raspberry Pi 2 Model B

The specifications of this model are:

* 900 MHz quad-core ARM Cortex-A7 CPU
* 1 GB of RAM
* Video Core IV 3D graphics core
* Ethernet port
* HDMI output
* Audio output
* RCA composite video output
* Four USB ports
* MicroSD card reader
* 40 pins

Raspberry Pi needs an Operating System to operate. Raspberry pi OS, previously known as Raspbian, is the officially supported operating system. To add this operating system, a microSD card is required, hence the microSD card reader on the list of specifications stated above. Earlier models Raspberry Pi used a full-sized SD card.

Because of a hardware limitation in the Raspberry Pi Zero, 1 and 2, the boot partition on the SD card must be 256GB or smaller otherwise the device will not boot up. Later models of Raspberry Pi 2 with a BCM2837 SoC, Raspberry Pi 3, 4 and 400 do not have this limitation. This does not affect Raspberry Pi OS, which always uses a small boot partition.

An SD card of 8GB or greater capacity is recommended to use for the Raspberry Pi OS. However, the lite version of Raspberry Pi OS requires lesser memory size of 4GB. Other operating systems have different requirements: for example, LibreELEC can run from a smaller card.

An imager provided by Raspberry Pi official website called Raspberry Pi Imager can be used to easily install the Raspberry Pi OS on the microSD card. This software is available for different platforms including windows, macOS and Linux. After downloading the software compatible for the platform at hand, we can run it and the following window will appear.



Figure - Raspberry Pi OS Imager

It is possible to select from the different OS variations available on the “CHOOSE OS” dropdown. It is also possible to download the file directly from the website and select it here from our local machine. After connecting the microSD card on our personal computer, we can select it on the “CHOOSE STORAGE” dropdown and press the “WRITE” button, which will be active after selecting the appropriate OS and storage device. Once complete, we can plug the microSD card on the microSD card reader located at the back of the Raspberry Pi board.

We can use two different ways to control the Raspberry Pi. One is by using the different ports provided by the Raspberry Pi board to connect IO devices. That is, connecting a conventional keyboard and mouse to the USB ports and a desktop monitor, TV, or any display with HDMI input to the HDMI output of the Raspberry Pi. This way we can use the Raspberry Pi as a personal computer.

Another option is to perform a Raspberry Pi headless setup and use a personal computer to control the Raspberry Pi. To do this, we must follow the following steps.

* After installing the OS on the microSD using the imager shown above, we must first open the boot partition of the microSD and add an extension less file called “**ssh**”. The Raspberry Pi OS will automatically enable SSH (Secure Socket Shell) on first boot-up. This will allow us to remotely access the Pi command line or Desktop from a PC.
* Next, we use an ethernet cable to connect the Pi to our personal computer. Then we use Putty, the leading SSH client for Windows, to access the CLI of the Raspberry Pi. On Putty we enter raspberrypi or raspberrypi.local **as the host name of the connection we want to create.**
* **The above step will open a window prompting us to login. By default, the username is Pi and the password is raspberry, which can later be changed. This will give us access to the Raspberry pi CLI. It is possible to stop here and use just the CLI or continue to access the Pi desktop.**
* **On the CLI, enter the command *sudo raspi-config*. This opens a configuration window.**
* **To enable VNC, navigate to Interfacing Options > VNC select it and select Yes.**
* **After this we run VNC Viewer software.**
* **Select New Connection from the File menu.**
* **Enter** raspberrypi**.local or** raspberrypi **in the "VNC Server" field.**
* **Double click the connection icon.**
* **Enter Pi’s username and password. Use either the default or the one you entered if it was changed previously.**
* **The Raspberry pi desktop will then appear, it looks like the following.**

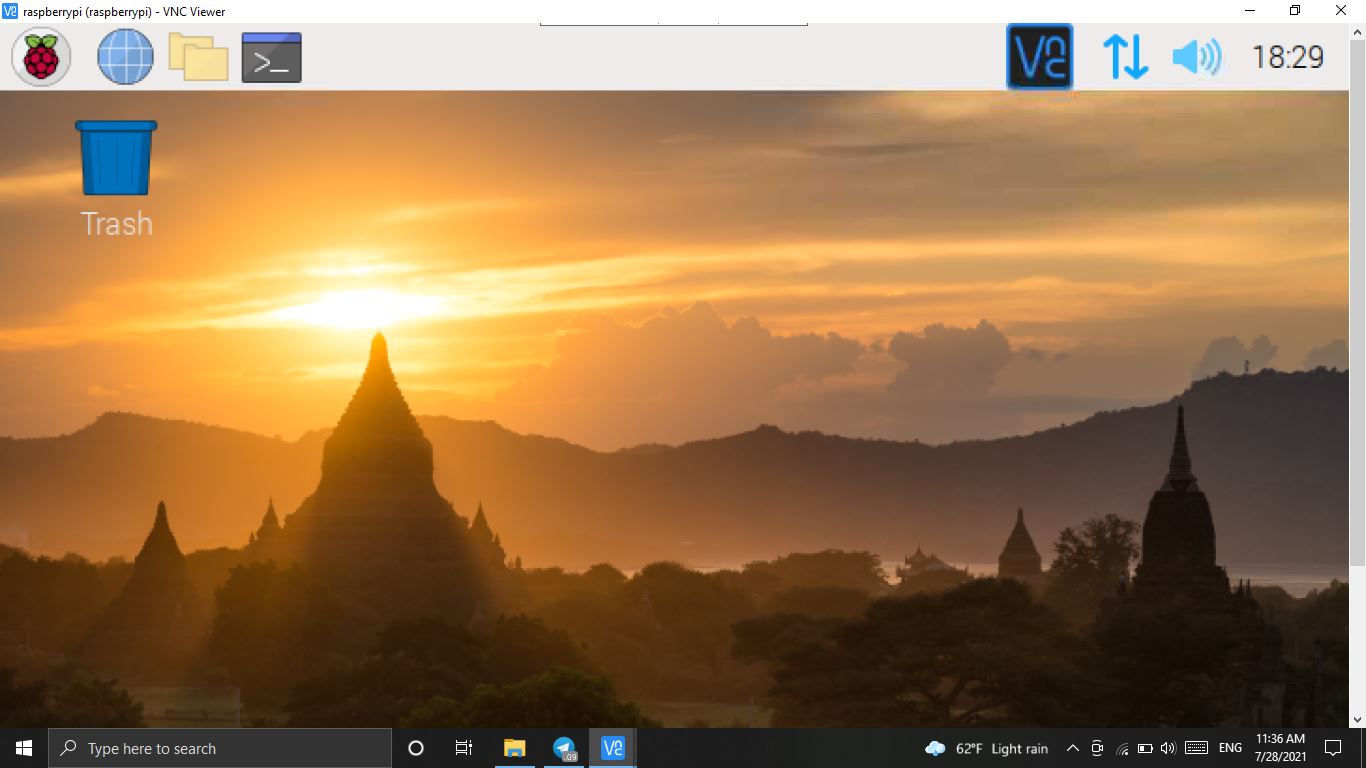
****

Figure - Raspberry Pi Desktop

Note that we can also use Wi-Fi and direct USB connection to do this, which has its own steps to follow.

[2] A powerful feature of the Raspberry Pi is the row of GPIO (general-purpose input/output) pins along the top edge of the board. A 40-pin GPIO header is found on all current Raspberry Pi boards (unpopulated on Pi Zero and Pi Zero W). Prior to the Pi 1 Model B+ (2014), boards comprised a shorter 26-pin header. The picture below illustrates the details of the pins.

We can do programming by either opening the CLI or an IDE under the PI icon on top left. To do this, it is essential to know the pin configuration. The figure below illustrates this.

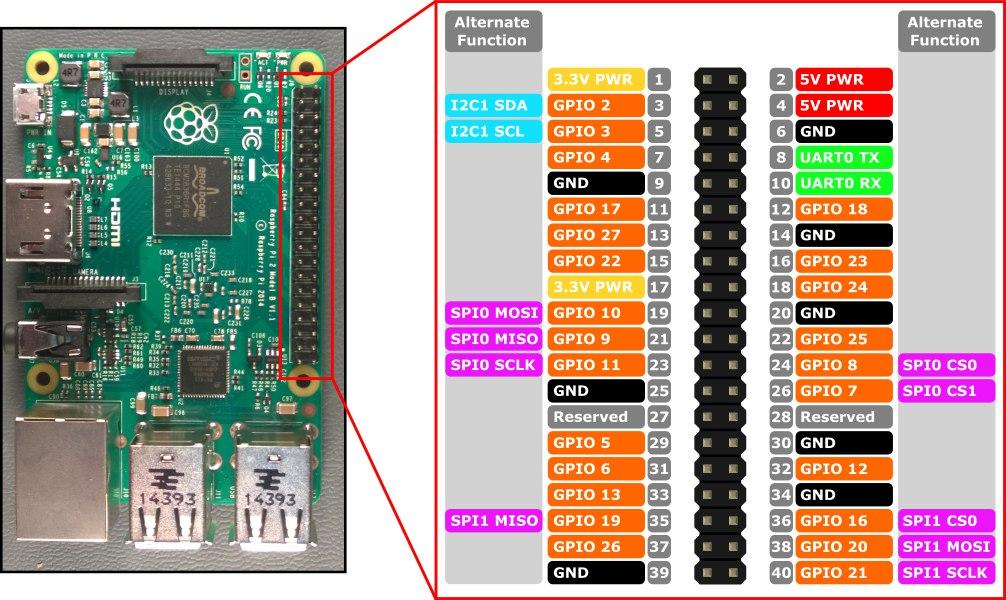


Figure - Raspberry Pi 2 Pin Configuration

**Voltages**

Two 5V pins and two 3V3 pins are present on the board, as well as a number of ground pins (0V), which are unconfigurable. The remaining pins are all general purpose 3V3 pins, meaning outputs are set to 3V3 and inputs are 3V3-tolerant.

**Outputs**

A GPIO pin designated as an output pin can be set to high (3V3) or low (0V).

**Inputs**

A GPIO pin designated as an input pin can be read as high (3V3) or low (0V). This is made easier with the use of internal pull-up or pull-down resistors. Pins GPIO2 and GPIO3 have fixed pull-up resistors, but for other pins this can be configured in software.

**More**

As well as simple input and output devices, the GPIO pins can be used with a variety of alternative functions, some are available on all pins, others on specific pins.

* PWM (pulse-width modulation)
  + Software PWM available on all pins
  + Hardware PWM available on GPIO12, GPIO13, GPIO18, GPIO19
* SPI
  + SPI0: MOSI (GPIO10); MISO (GPIO9); SCLK (GPIO11); CE0 (GPIO8), CE1 (GPIO7)
  + SPI1: MOSI (GPIO20); MISO (GPIO19); SCLK (GPIO21); CE0 (GPIO18); CE1 (GPIO17); CE2 (GPIO16)
* I2C
  + Data: (GPIO2); Clock (GPIO3)
  + EEPROM Data: (GPIO0); EEPROM Clock (GPIO1)
* Serial
  + TX (GPIO14); RX (GPIO15)

**Warning: while connecting simple components to the GPIO pins is perfectly safe, it's important to be careful how you wire things up. LEDs should have resistors to limit the current passing through them. Do not use 5V for 3.3V components. Do not connect motors directly to the GPIO pins, instead use an H-bridge circuit or a motor controller board.** [2]

**LED**

An LED is an electronic component which emits light when it receives electricity. Compared to incandescent bulbs, LEDs are more efficient as most of the electricity is converted into light not heat. Different LEDs can give off different color of light. It merely depends on the chemical composition of the semiconducting material.

LEDs emit more lumens per watt than incandescent light bulbs. The efficiency of LED lighting fixtures is not affected by shape and size, unlike fluorescent light bulbs or tubes. LEDs can have a relatively long useful life.

 Diagram

Description automatically generated

Figure - LEDs Figure 6 - LED Circuit

The conventional current enters the LED, a polarized electrical device through its anode and leaves through the cathode.

The current in an LED or other diodes rises exponentially with the applied voltage so a small change in voltage can cause a large change in current. Current through the LED must be regulated by an external circuit such as a constant current source to prevent damage.

Since most common power supplies are nearly constant-voltage sources, LED fixtures must include a power converter, or at least a current-limiting resistor.

Other than power considerations, one needs to take electrical polarity into consideration as well. Unlike a traditional incandescent lamp, an LED will light only when voltage is applied in the forward direction of the diode. No current flows and no light is emitted if voltage is applied in the reverse direction. If the reverse voltage exceeds the breakdown voltage, a large amount of current flows and the LED will be damaged. If the reverse current is sufficiently limited to avoid damage, the reverse-conducting LED is a useful noise diode.

**GSM Module**

A GSM modem or GSM module is a hardware device that uses GSM mobile telephone technology to provide a data link to a remote network. From the view of the mobile phone network, they are essentially identical to an ordinary mobile phone, including the need for a SIM to identify themselves to the network. GSM modems typically provide TTL-level serial interfaces to their host. They are usually used as part of an embedded system.

**Software**

**Computer Vision**

**Introduction**

[3] Computer vision is a field of artificial intelligence that enables computers and systems to derive meaningful information from digital images, videos and other visual inputs and take actions or make recommendations based on that information. If AI enables computers to think, computer vision enables them to see, observe and understand.

Computer vision works much the same as human vision, except humans have a head start. Human sight has the advantage of lifetimes of context to train how to tell objects apart, how far away they are, whether they are moving and whether there is something wrong in an image.

Computer vision trains machines to perform these functions, but it has to do it in much less time with cameras, data and algorithms rather than retinas, optic nerves and a visual cortex. Because a system trained to inspect products or watch a production asset can analyze thousands of products or processes a minute, noticing imperceptible defects or issues, it can quickly surpass human capabilities.

Computer vision is used in industries ranging from energy and utilities to manufacturing and automotive – and the market is continuing to grow. It is expected to reach USD 48.6 billion by 2022

**How it works**

Computer vision needs lots of data. It runs analyses of data over and over until it discerns distinctions and ultimately recognize images. For example, to train a computer to recognize automobile tires, it needs to be fed vast quantities of tire images and tire-related items to learn the differences and recognize a tire, especially one with no defects.

Two essential technologies are used to accomplish this:

1. Deep learning

[4] A subset of machine learning in artificial intelligence that has networks capable of learning unsupervised from data that is unstructured or unlabeled. It imitates the workings of the human brain in processing data and creating patterns for use in decision making. Also known as deep neural learning or deep neural network.[4]

1. Convolutional neural network

[5] A Deep Learning algorithm which can take in an input image, assign importance to various aspects/objects in the image and be able to differentiate one from the other. The pre-processing required in a Convolutional neural network is much lower as compared to other classification algorithms. [5]

Machine learning uses algorithmic models that enable a computer to teach itself about the context of visual data. If enough data is fed through the model, the computer will “look” at the data and teach itself to tell one image from another. Algorithms enable the machine to learn by itself, rather than someone programming it to recognize an image.

A CNN helps a machine learning or deep learning model “look” by breaking images down into pixels that are given tags or labels. It uses the labels to perform convolutions (a mathematical operation on two functions to produce a third function) and makes predictions about what it is “seeing”. The neural network runs convolutions and checks the accuracy of its predictions in a series of iterations until the predictions start to come true. It then starts recognizing or seeing images in a way like humans.

Much like a human making out an image at a distance, a CNN first discerns hard edges and simple shapes, then fills in information as it runs iterations of its predictions. A CNN is used to understand single images. A recurrent neural network (RNN) is used in a similar way for video applications to help computers understand how pictures in a series of frames are related to one another.

**Common Application Areas**

The following are some of the classes of application areas where computer vision is used.

* ***Image classification*** sees an image and can accurately predict that a given image belongs to a certain class. For example, a social media company might want to use it to automatically identify and take the appropriate action if a user uploads objectionable images.
* ***Object detection*** can use image classification to identify a certain class of image and then detect and tabulate their appearance in an image or video. Examples include detecting damages on an assembly line or identifying machinery that requires maintenance. This projects vehicle detection algorithm belongs to this class.
* ***Object tracking*** follows or tracks an object once it is detected. This task is often executed with images captured in sequence or real-time video feeds. Autonomous vehicles, for example, need to not only classify and detect objects such as pedestrians, cars and road infrastructure, they need to track them in motion to avoid collisions and obey traffic laws.
* ***Content-based image retrieval*** uses computer vision to browse, search and retrieve images from large data stores, based on the content of the images rather than metadata tags associated with them. This task can incorporate automatic image annotation that replaces manual image tagging. These tasks can be used for digital asset management systems and can increase the accuracy of search and retrieval. [3]

**OpenCV**

[6] OpenCV is an open source computer vision and machine learning software library. OpenCV was built to provide a common infrastructure for computer vision applications and to accelerate the use of machine perception in the commercial products. Being a BSD-licensed product, OpenCV makes it easy for businesses to utilize and modify the code.

The library has more than 2500 optimized algorithms, which includes a comprehensive set of both classic and state-of-the-art computer vision and machine learning algorithms. These algorithms can be used to detect and recognize faces, identify objects, classify human actions in videos, track camera movements, track moving objects, extract 3D models of objects, produce 3D point clouds from stereo cameras, stitch images together to produce a high resolution image of an entire scene, find similar images from an image database, remove red eyes from images taken using flash, follow eye movements, recognize scenery and establish markers to overlay it with augmented reality, etc.

OpenCV has more than 47 thousand people of user community and estimated number of downloads exceeding 18 million. The library is used extensively in companies, research groups and by governmental bodies.

Along with well-established companies like Google, Yahoo, Microsoft, Intel, IBM, Sony, Honda, Toyota that employ the library, there are many startups such as Applied Minds, VideoSurf, and Zeitera, that make extensive use of OpenCV. OpenCV’s deployed uses span the range from stitching streetview images together, detecting intrusions in surveillance video in Israel, monitoring mine equipment in China, helping robots navigate and pick up objects at Willow Garage, detection of swimming pool drowning accidents in Europe, running interactive art in Spain and New York, checking runways for debris in Turkey, inspecting labels on products in factories around the world on to rapid face detection in Japan.

It has C++, Python, Java and MATLAB interfaces and supports Windows, Linux, Android and Mac OS. OpenCV leans mostly towards real-time vision applications and takes advantage of MMX and SSE instructions when available. A full-featured CUDA and OpenCL interfaces are being actively developed right now. There are over 500 algorithms and about 10 times as many functions that compose or support those algorithms. OpenCV is written natively in C++ and has a templated interface that works seamlessly with STL containers. [6]

OpenCV uses an algorithm called Haar cascade classifier to perform detection of different objects. A classifier, in machine learning, is the algorithm used by the machine to categorize data into one or more of set of classes. For example, an email classifier is used to scan emails to filter the spams from the useful emails. Haar cascade classifier is then a classifier that is used to detect object from an image or video. A short abstraction of how this algorithm works is presented in the section to follow.

**Haar cascade classifier**

A Haar cascade classifier, or a Haar classifier, is a machine learning object detection program that identifies objects in an image or video. This is algorithm is described in detail in a paper prepared by Paul Viola and Michael Jones, titled “Rapid Object Detection using a Boosted Cascade of Simple Features”. This article goes into the details of Haar Cascade classifier using mathematics to elaborate the technical details of how it works. Here we have presented a highlight instead.

The algorithm can be explained in four stages. We explain each one in detail. The following are the four stages:

* Calculating Haar Features
* Creating Integral Images
* Using Adaboost
* Implementing Cascading Classifiers

1. **Calculating Haar Features**

Owing their name to their intuitive similarity with the mathematical Haar wavelets, Haar features were used in the first real-time face detector. Essentially, a Haar feature is a series of calculations that are performed on adjacent rectangular regions at a specific location in a detection window. The calculation involves summing of the intensities of the pixels in each region and looking for the difference between the sums.

There are several types of Haar features. Three of these are the basic ones and are listed below:

1. Edge Features
2. Line Features
3. Four-rectangle Features

The picture below shows these three basics Haar Features in the order they are presented above.

A picture containing diagram

Description automatically generated

Figure - Basic Haar Features

The first two are edge features. As their name indicates, they are used to detect edges in an image. The third one is a line feature used to detect a vertical line. The last one is a four-rectangle feature most likely used to detect a slanted line.

In each of these features, the white bars represent pixels that contain parts of an image that are closer to the light source and would therefore be whiter on a grayscale image (A grayscale image is an image where all the pixels carry only light intensity information). The black bars are the opposite, they are pixels whose image features are farther away from the light source or are obstructed by another object. An example of this could be eyebrows casting slight shadows over the eyes below. Similarly, these features would appear blacker on a grayscale image. The most important reason behind transforming the image to grayscale is this comparison between white and black pixels.

Note that Haar like features are scalable but they cannot be a one-by-one pixel. This is because each cell of the frame represents a single pixel, which can only contain the value for a single color. Since the entire function of these frames is to compare the “white-ness” and “black-ness” of neighboring pixels it cannot be scaled down to a single pixel. The smallest scale for the basic features is:

* Edge Features: 1x2 or 2x1.
* Line Features: 1x3 or 3x1.
* Four-Rectangle Features: 2x2

To explain these basic features. Consider a face detection algorithm.

**a) [7] Edge features**: Think of the forehead and the eyebrows or eyes. The forehead is an exposed, flat surface of the face. This allows it to reflect more light, so it is often “lighter”. Eyebrows and the eye area are generally darker. The algorithm would read the lighter shade of the forehead and the transition to the darker eyebrows as an “edge” boundary. Which means it would place the inverted version of the second feature from the image above.

**b) Line features**: In a line feature, the pattern can go white-black-white just like the third feature in the image above or black-white-black. Think about a nose. The top edge of your nose that stretches from the bridge to the nose tip, while not as flat as the forehead, is still reflective and the closest point on the face to a light source that might be in front of the subject, so it will naturally be brighter and stand out. The area around the nostrils typically bends away from the light making them darker. This pattern would be picked up as a line feature, opposite of the one given in the picture above. Another interesting way that line features are being utilized is in eye-tracking technology. A **darker** iris sandwiched between the **white** space of your eye on either side of it.

**c) Four-Rectangle Features**: This is good for finding diagonal lines and highlights in an image. This is used best on a micro scale. Depending on the lighting, it can pick out the edges of the jaw, chin, wrinkles, etc… These typically are features that aren’t as important in general face-detection as there are so many of them, as well as so many variations in every individual’s face, that it would lead to an algorithm that was too slow and might only detect the faces of certain people. In other words, too specialized.[7]

The following image shows an image transformed to greyscale with few Haar features placed. Note that, the contrast of the images to the right have been turned up to make the difference clear.

![A picture containing text

Description automatically generated](data:image/jpeg;base64,/9j/4AAQSkZJRgABAQEAYABgAAD/4RD6RXhpZgAATU0AKgAAAAgABAE7AAIAAAAQAAAISodpAAQAAAABAAAIWpydAAEAAAAgAAAQ0uocAAcAAAgMAAAAPgAAAAAc6gAAAAgAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAE1pa2l5YXMgVGVzZmF5ZQAABZADAAIAAAAUAAAQqJAEAAIAAAAUAAAQvJKRAAIAAAADMTQAAJKSAAIAAAADMTQAAOocAAcAAAgMAAAInAAAAAAc6gAAAAgAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAA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Figure - Haar Features on a Face

In the above right most picture, we can see that the algorithm uses edge and line features to classify different transitions on a person’s face. The transition from forehead to the eyebrow, eyes to chicks, upper lip to mouth and the jaw to the chin are classified using edge features. The nose on the other hand is classified using a line feature that uses black-white-black pattern.

As stated above, a picture transformed to gray scale would not look like the picture in figure 8. This is not a transformation that happens in the process. Instead, it would look for features on an image like this figure 9 below.

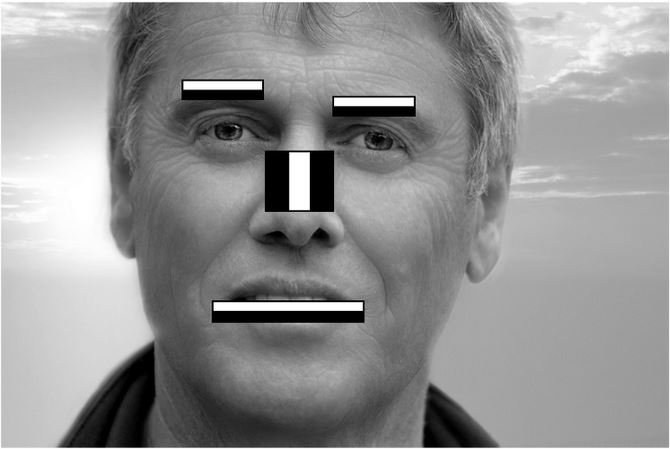
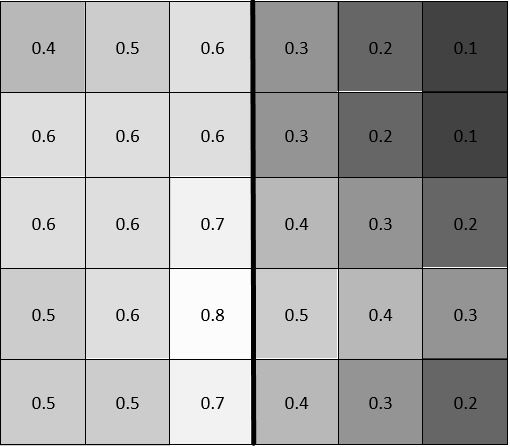


Figure - Grayscale Image vs Haar Features

To classify part of an image as black and white and assign the appropriate feature, the algorithm does the evaluation as follows. Consider an image with intensity values ranging from 0 to 1. The algorithm is taught that, in a Haar-like feature, if the difference between the means of the light and dark areas is above some threshold value, treat them as black and white. Let’s look at an example using a 6x5 pixels dimension segment of an image.



Let’s assume the threshold to be 0.25. We can see that the pixels to the left of the dark line are lighter while the ones to the right darker. The mean of the lighter side is 0.58667 and the mean of the darker side is 0.28. The difference between these values is 0.30667, which is greater than the threshold value. Therefore, the algorithm treats this segment as a feature that looks like the first Haar feature in figure 7.

The need for the second stage arises from the problem explained next. [8] Since these frames are scalable, there are thousands of combinations and places where features fit within even a tiny image. A 24x24 pixel image contains over 180,000 possible features. The frames within that image can be between 1x2 (or 2x1) pixels and 24x24 pixels.

To better illustrate this problem, consider this example. Let’s say that the amount of time it takes for a computer to calculate the mean of a single feature is 1 millisecond (this would be incredibly slow, but let’s run with it). Since there are over 180,000 features in a 24x24 pixel image, it would take 180,000ms, 3 minutes, to calculate all the features in it. That’s not including processing power and memory used up to complete it.

The amount of time explodes even more when you consider that, these days, you’re most likely going to be using an image with a resolution of 1920x1080 pixels. To reduce the amount of time and resources used up, we need to find a way to reduce the complexity of the task. How did Viola and Jones, authors of the paper “Rapid Object Detection using a Boosted Cascade of Simple Features”, accomplish this to such a degree that their algorithm could detect faces in real-time on a digital camera? [8] Enter the integral images.

1. **Creating Integral Images**

An integral image is an image that takes the value of a pixel as the sum of pixel values from the original image. The value of a pixel is equal to the sum of all the pixels located to the top and left of that pixel, including that pixel itself. To understand this, lets consider an image of 10x8 pixels dimension.

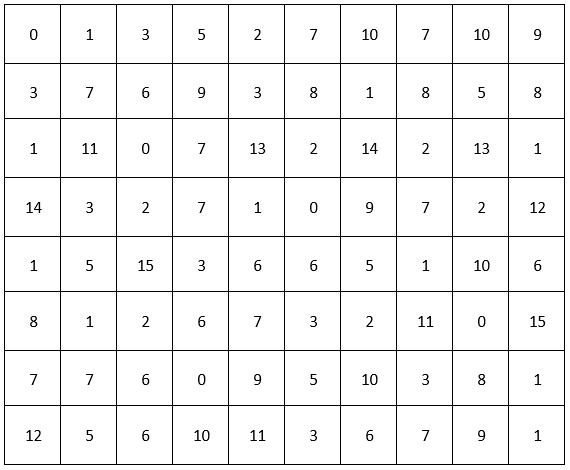


Figure - Original Image

This image uses values from 0 to 255 to represent the intensity values of its pixels.

To get the integral image, the algorithm moves through all the pixels and assign a new value for that pixel. This value is the sum of pixel values that are in a rectangular, where the pixel we are evaluating for is located at the bottom right of this rectangle. The rectangle extends to the images left and top side, bounded by a horizontal and vertical line starting from the pixel on evaluation. The image below illustrates this.

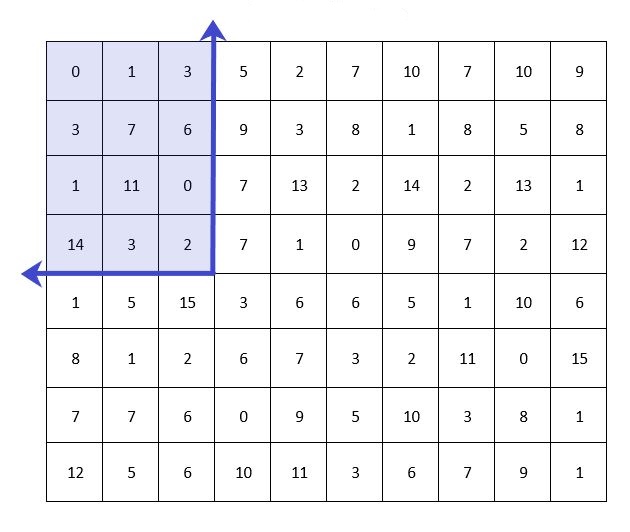


Figure - Evaluating Pixel Integral Value

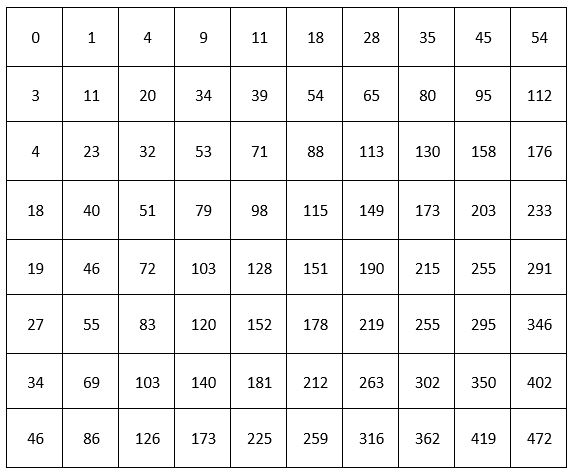


Figure - Integral Image

On figure 11, the sum of pixel values in the shaded region will be the corresponding value of that pixel, pixel with value 2, in the integral image. The corresponding value would then be 51. The algorithm goes through all the pixels and performs the same operation. The integral image looks like the one given on figure 12.

Previously we have stated that, for a 24x24 pixel image. There are 180,000 features. Which means that, the algorithm must perform addition for different sized frames again and again to find the means of each side of a feature. This takes a lot of processing time. Here is where the integral image comes in. The integral image reduces the number of additions that needs to be performed to a maximum of four. Whether the dimension of the selected area is 24x24 pixels or 1000x1000 pixels, only four numbers are required to find the area’s sum. To make this clear, let’s use the 10x10 image example used before.

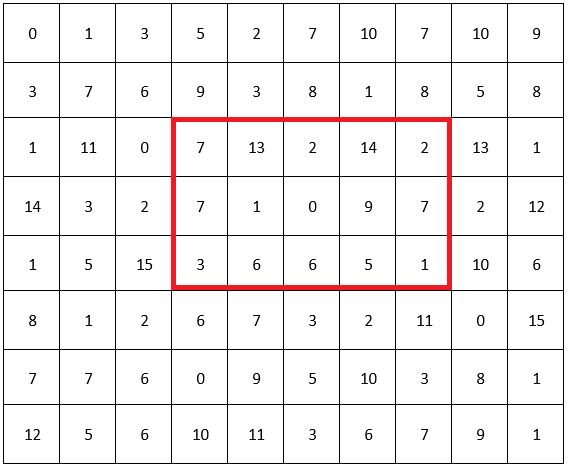


Figure - Selected area

Consider the 3x5 pixels region in the red rectangle. We can see that the sum of the pixel values in this region is 83. Finding this value required 14 addition operations. Let’s see how many addition operations it takes using the integral image.

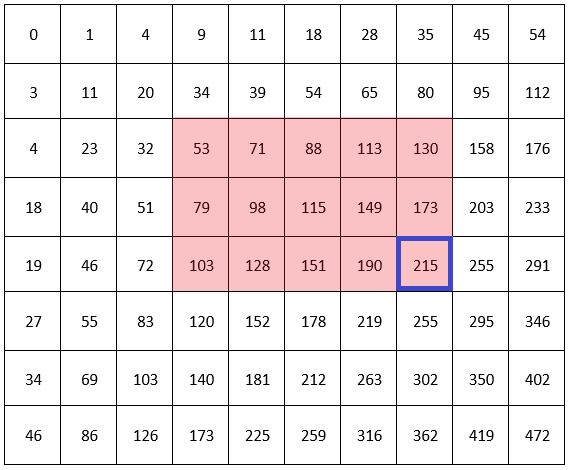


Figure – Selected Region Shaded

Clearly the value inside the blue square is not the right answer. This is because, it is the sum of all the pixels the left and top of it. That means it contains pixel values to the left and top of the shaded region. To get the right value, we need to subtract the sum of the regions outside of the shaded one.

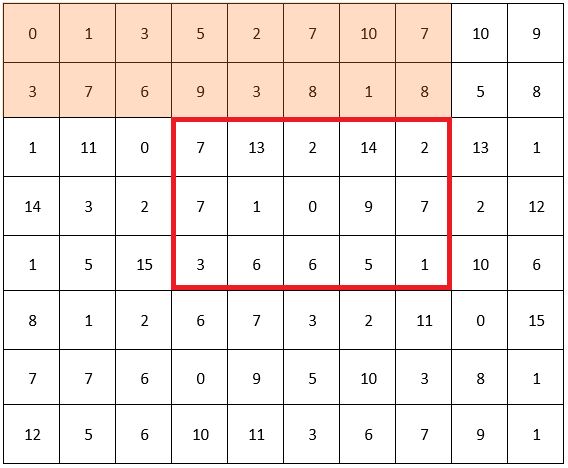


Figure - Region 1

![Table

Description automatically generated](data:image/jpeg;base64,/9j/4AAQSkZJRgABAQEAYABgAAD/4RD6RXhpZgAATU0AKgAAAAgABAE7AAIAAAAQAAAISodpAAQAAAABAAAIWpydAAEAAAAgAAAQ0uocAAcAAAgMAAAAPgAAAAAc6gAAAAgAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAE1pa2l5YXMgVGVzZmF5ZQAABZADAAIAAAAUAAAQqJAEAAIAAAAUAAAQvJKRAAIAAAADMjkAAJKSAAIAAAADMjkAAOocAAcAAAgMAAAInAAAAAAc6gAAAAgAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAA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Figure - Region 2

To get the sum of the pixels inside the red rectangle, all we need is to do is subtract the sum of the pixel values in these two regions from the integral value of the pixel inside the blue square in figure 14. One other thing to consider is that these two regions have overlapping area. To account for double subtraction of this region, we need to add this region’s sum value once. Therefore, the pixels to consider are as given in the figure below.

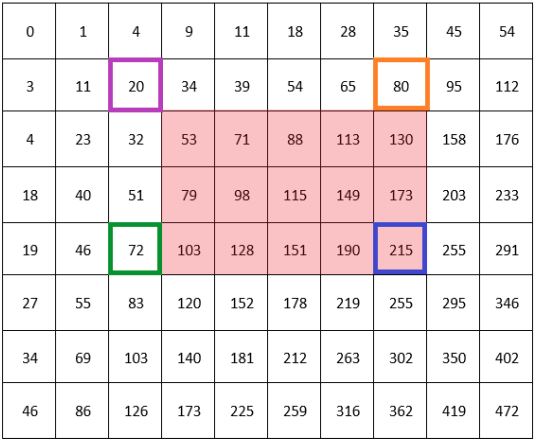


Figure - 4 points of consideration

So, instead of performing 14 addition operations, the algorithm now will perform only 4. That is 215-72-80+20 = 83. Note that we add the region with sum 20, because the region with sum value 72 and 80 both contain this region.

Reducing from 14 addition operation to 4 might not seem like much improvement, but what you must consider is larger frames. For example, consider a 24x24 dimension frame. It contains a total of 576 pixels, which would mean 575 addition operations. In this case, it saves time required to perform 571 to 574 addition operations. Additionally, such kind of operation is performed for so many features within a single image. This process drastically reduces the complexity of the task, which reduces the amount of time and resources needed to compute.

1. **Using Adaboost**
2. **Implementing Cascading Classifiers**