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Deep Learning-Based Web Application for the Detection of COVID-19 from Chest CT-Scan Images

Soutenu le …… 2020 devant le Jury

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Dedication

I dedicate my thesis to my favourite human, sitting in the heaven above, to the person that I love the most,

My shelter,
Riyadh, May God bless him with his mercy in his vast Paradise.

Abstract

Coronavirus Disease 2019 caused by the severe acute respiratory syndrome coronavirus 2 (SARS-CoV-2) first appearing in China has spread to more than 200 countries, and more than 1,700,000 confirmed cases and 111,600 deaths have been recorded, with massive global increases in the number of cases daily. Lung infection or pneumonia is the common complication of COVID-19, and imaging techniques, especially computed tomography (CT), have played an important role in diagnoses and treatment assessment of the disease while Deep Learning models are largely used in the automatic analysis of radiological images has open the door into using classification techniques to help the early detection of the infection.

The purpose of this work is addressing this problem by building a web application that categorise images into covid-19 and non covid-19 cases. The first part of the work is preparing the Dataset using image preprocessing and data augmentation for the training phase. The evaluation of the dataset went through two training models: VGG16, InceptionV3 and ResNet. At the end, Grad-Cam visualisation techniques was used to highlight infected regions in the image. The second part, is the presentation of the web application which is a system of decision support just by uploading an CT-scan image and waiting it to be classified few seconds after.

VGG16 has shown a high accuracy allowing the application to give a better decision when classifying infected cases while adding visualisation explains the model prediction.

Keywords : COVID-19, Deep Learning, Classification, Web Application, Infection, CNN, Visualisation, Dataset,

Résumé

La maladie à coronavirus 2019 causée par le coronavirus 2 du syndrome respiratoire aigu sévère (SRAS-CoV-2) apparu pour la première fois en Chine s'est propagée à plus de 200 pays, et plus de 1 700 000 cas confirmés et 111 600 décès ont été enregistrés, avec une augmentation mondiale massive du nombre des cas chaque jour. L'infection pulmonaire ou pneumonie est la complication commune du COVID-19 alors que les techniques d'imagerie, en particulier la tomographie assistée par ordinateur (CT), ont joué un rôle important dans le diagnostic et l'évaluation du traitement de la maladie.

Les modèles d'apprentissage profond sont largement utilisés dans l'analyse automatique des images radiologiques, ce qui ouvre la voie à l'utilisation de techniques de classification pour aider à la détection précoce de l'infection.

L'objectif de ce travail est de répondre à ce problème en construisant une application web qui catégorise les images de covid-19 et de non covid-19. La première partie du travail consiste à préparer les données en utilisant le prétraitement des images et l'augmentation des données. L'évaluation des données est ensuite passée par deux modèles d'entraînement : VGG16 et ResNet. A la fin, les techniques de visualisation Grad-Cam ont été utilisées pour mettre en évidence les régions infectées dans l'image.
La deuxième partie est la présentation de l'application web qui est un système d'aide à la décision qui consiste à télécharger une image CT-scan et à attendre qu'elle soit classée quelques secondes plus tard.

Le VGG16 a montré une grande précision permettant à l'application de donner une meilleure décision lors de la classification des cas infectés tout en ajoutant la visualisation qui explique la prédiction du modèle.

Mot clés : Classification, Coronavirus, Pneumonie, Apprentissage Profond, Visualisation, Application, Base de données.

Glossary

- CT: Computed Tomography
- COVID-19: Coronavirus disease of 2019
- SARS Cov-2: Severe Acute Respiratory Syndrome Coronavirus 2
- AI: Artificial Intelligence
- ML: Machine Learning
- CNN: Convolutional Neural Network
- ReLU: Rectified Linear Unit
- ResNet : Residual Network
- VGG : Visual Geometry Group
- TP: True positives
- TN: True negatives
- FP: False positives
- FN: False negatives
- UML: Unified Modeling Language

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General Introduction

Pandemics aren't something the humanity encounter every year and COVID-19 has infected millions of people worldwide and took so many lives. One of the most important hurdles in controlling the spread of this disease is the inefficiency and lack of medical tests while limited resources and many reported cases were a real daily struggle.

The tests provided for Covid-19 cannot be sufficient facing the massive amount of daily suspect cases leaving the healthcare systems and staff exhausted and always exposed to the risk of contamination, The current tests for diagnosis of this disease are principally based on reverse transcription-polymerase chain reaction (RT-PCR). However, RT-PCR test kits are in a huge shortage and slow compared to the needed time of detection.

Computed tomography (CT) scans are promising in providing valid and rapid detection of COVID-19 which has led us to the idea of building a deep learning based web application to help with a swift disease detection.

The use of medical and healthcare web applications have become very popular and getting improved day by day in order to reduc the effort and the time for the users and make the whole process easy in one click. Thus, to overcome the mentioned obstacles, an automatic, well grounded and reliable approach using advanced machine learning offers a good solution. This system can overcome these limitations and can be utilized everywhere with no need for a highly trained radiologist. Deep learning is among the best used methods for helping the healthcare in taking decisions and minimizing the struggles doctors and patients face on daily basis.

Our work consists mainly of building a web application that can classify CT scan images of lungs into positive or negative cases, in order to judge our classification performance on the three used pre-trained models we employed the three metrics : Accuracy, Specificity and Sensitivity in which we have got promising results.
The thesis is divided in three chapters, the first one is an overview about coronavirus disease and the ways provided to detect it all along 2020. The second chapter is about deep learning and related works previously made in

the interest of Covid-19 detection using CT scan images. At the end, the chapter three concerns our proposed application of the classification and the methodology followed to achieve it.

Chapter 1

Medical Context

1.1 Introduction

The 2020 famous virus SARS Cov-2 has changed the world, from locking down people inside their homes affecting their lives and productivity, to closing whole international airports and causing many countries huge economic losses. The disease origins was firstly spotted in China, expeditiously running all over the globe with its surprising capacity of spreading between individuals. Health care system stood incapable of truly understanding it the first time, detecting it and then controlling it and many innocent people have died in the process.

In this chapter, we will be introducing the Coronavirus, its properties , ways of transmission, common symptoms how imaging techniques were really efficient for detecting it.

1.2 Anatomy of human lung

1.2.1 Human Lung

The human gas-exchanging organ, the lung, is located in the thorax, where its delicate tissues are protected by the bony and muscular thoracic cage. The lung provides the tissues of the human body with a continuous flow of oxygen and clears the blood of the gaseous waste product, carbon dioxide. to accomplish their major functions of movement of air, delivery of oxygen to organs and removal of carbon dioxide. The pulmonary anatomic compartment are tightly integrated for this purpose [1]

1.2.2 Components and Functions

Our lungs are uniquely designed, a pair of spongy, air-filled organs located on each sides of the chest (thorax). The Trachea or also called the windpipe conducts the inhaled air into the lungs into its tubular branches (bronchioles), they end eventually in clusters of microscopic air sacs called Alveoli. In the Alveoli, oxygen from the air is absorbed into the blood while carbon dioxide which is a waste of metabolism, travels from the blood to the alveoli and then exhaled outside the body. To help support this alveoli there is a thin layer containing vessels and cells called the interstitium. The pleura is a thin tissue layer that covers the lungs and the inside the chest cavity, this layer of fluids lubricates the area to allow the lungs a smooth movement when expanding and contracting as we breath [7]. The nexit figure explains the anatomy of human lungs.

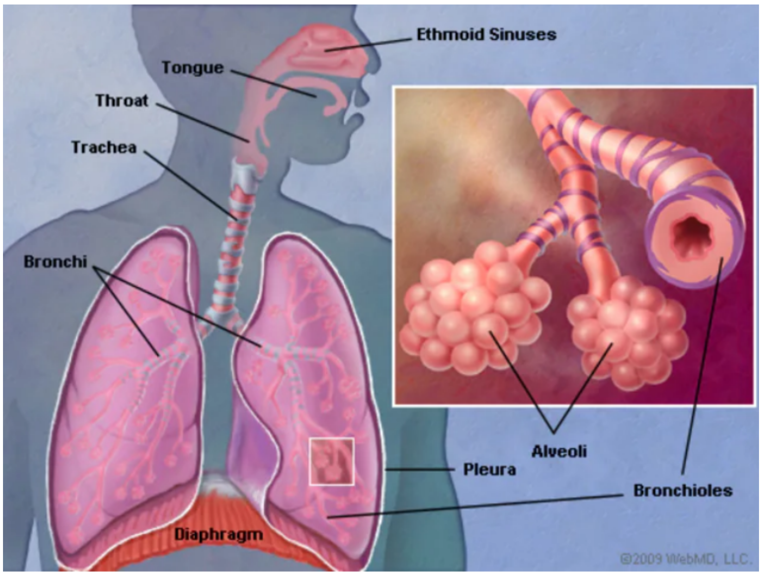


Figure 1.1: Human Lung Anatomy [1]

1.3 Covid-19 disease

Covid-19 is an infectious disease caused the most recent discovered coronavirus caused by SARS-CoV-2, emerged in December 2019. COVID-19 can be severe, and has caused millions of deaths around the world as well as lasting health problems in some who have survived the illness. [8].

1.3.1 Classification and Taxonomy

Coronaviruses are spherical enveloped viruses, measuring approximately 80-220 nm in diameter. It is positive single-stranded large RNA viruses that infect humans, but also a wide range of animals. Coronaviruses are one of the largest groups belonging to the nidoviral order, suborder of Cornidovirineae and family of Coronaviridae. Firstly described in 1966 by Tyrell and Bynoe as a solar corona from which comes the name Corona-virus bases on their morphology that has a spherical virions with a core shell. This virus has four families: alpha, beta, gamma delta. Figure 1.2 Shows the difference corona families and the phylogenetic relationships in them. alphacoronaviruses and betacoronaviruses can affect mammals,while gamma coronaviruses and delta-coronaviruses mainly affect birds. The first coronavirus responsible for infection in humans body (HCoV) was isolated in 1960 and named B814. Until 2019, six coronaviruses have been identified as responsible for human infection, of which infection in humans, of them belonging to the alpha coronavirus genus (HCoV -NL63,HCoV-229) and four belong to the beta coronavirus genus (HCoV-OC43, HCoV-HKUI, SARS-CoV-1, MERS-CoV). In january 2020, a new coronavirus made its way into the the human body in the seafood market of Wuhan in China, SARS Cov-2 (Severe acute respiratory syndrome coronavirus 2) belonging to the Beta family ; They made their way into the human body in the seafood market of Wuhan in China. [8, 9] .

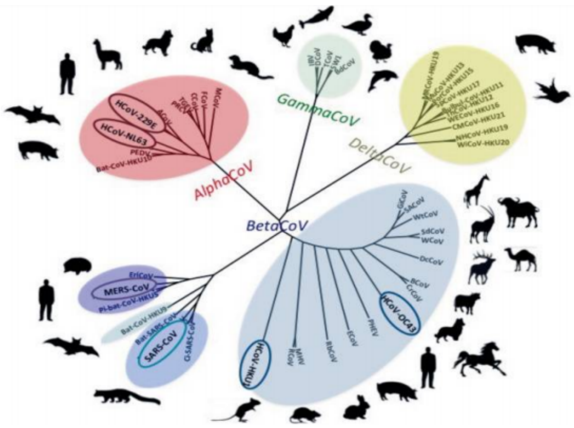


Figure 1.2: Phylogenetic relationships in the Coronavirinae subfamily based on 51 complete genomes of coronavirus using Neighbour-joining method [2]

1.3.2 Physiocochemical properties of the virus

Sensitivity to sanitizers

Coronaviruses are sensitive to common virucidal sanitizers such as 0.5% sodium hypochlorite, peracetic acid/hydrogen peroxide acid/hydrogen peroxide, ethanol or 70% isopropanol, glutaraldehyde according to the manufacturer's recommendations (respect of concentration and contact time). [10]

Physical inactivation

UV inactivation can be achieved by exposure to 1200 μJ/cm2 for 30 minutes, SARS is also sensitive to a temperature of 60°C for 30 minutes.[10].

Survival outside of the host

Coronaviruses can survive up to 6 days in aqueous media and up to 3 hours on dry inert surfaces. Depending on its location. It has been reported that SARS CoV-2 is more stable on plastic and stainless steel than on copper and cardboard, and viable virus was detected up to 72 h on these surfaces. On cardboard the half-life of SARS CoV-2 was longer than that of SARS CoV, while the longer viability of both viruses was on stainless steel and plastic [11].

1.3.3 Transmission

Covid-19 spreads from an infected person to an uninfected person, either by direct or indirect transmission.

Airborne transmission

SARS-CoV-2 is transmitted mainly by the emission of respiratory droplets loaded with viral particles when coughing, sneezing or speaking. Indirect droplet transmission can occur through contact with an infected surface via the nasal, oral or conjunctival mucosa. Human coronaviruses are able to survive on steel, metal, wood, aluminum, paper, glass, ceramics ,disposable gowns and surgical gloves for 2-9 days ,high temperature ($\geq$30°C) can reduce the period of virus persistence ,while low temperatures (4°C) increase the time of virus persistence up to 28 days [12].

Faecal-oral transmission

To this very moment, many studies have been inspecting the possibility of the faecal-oral transmission of the virus. There was a recent reported case of an asymptomatic COVID-19 patient with viral detection in feces for up to 42 days while naso-pharyngeal sampling was negative [13]

Ocular transmission

The potential of ocular transmission has been explored lately. Some studies has talked about the detection of viral RNA in conjunctival samples. While others have oppositely shown limited evidence of its presence. The ocular transmission like in tears isn't considerable although this leaves us to the fact that this is one of the ways Covid-19 uses to spread regardless of whether it is weak or strong.[14]

Vertical transmission

Even though more research is needed to determine if SARS-CoV-2 crosses the placental barrier but some newborns with Covid-19 infected moms, have been diagnosed positively too.

Are there any other transmission possibilities?

The isolation of viral RNA in urine has not been described to date.
The possibility of sexual transmission of the virus is still being studied.

What are the factors that can increase the transmission?

Travel or contact with people who have recently visited an endemic region.

Close contact with people diagnosed as positive for the disease, such as health care workers caring for patients with SARS-CoV-2.

Contact with droplets and secretions (produced by sneezing or coughing) from an infected person or from an infected person and eating or handling wild animals such as bats.

1.3.4 People at risk

Mostly the risk is higher for old people and patients who have already existing diseases such as cardiovascular disease, hypertension, chronic diabetes and chronic respiratory diseases.

The reported age-specific mortality rate is 14.8% for people over 80 years of age 1.3% for people between 50 and 59 years old, 0.4% for people between 40 and 49 years old, 0.2% for people between 10 and 39 years of age; no deaths were reported in children under 10 years of age.

Notably, the mortality rate is higher for men (2.8%) than for women (1.7%). [14].

1.3.5 What are Covid-19 symptoms?

The first clinical sign detected about Covid-19 was Pneumonia, although there have been reports of gastrointestinal symptoms and asymptomatic infections as well. Studies have showed that the incubation was from 3 to 5 days, but the clinical manifestations usually show up in less than a week, which are: Fever, nasal congestion, fatigue, cough upper respiratory tract infections, Muscles ache, Diarrhea, Sore throat, New loss of taste and smell. The infection may develop to a severe disease of dyspnoea (Shortness of breath) and severe chest symptoms in about 75% of patients. Pneumonia generally appears in the second or third week.

1.3.6 SARS-CoV-2 in a nutshell :

Covid-19 have proven to be an intelligent virus as it impacts the human body systems starting with the lungs. Here are what occurs to our system from catching the virus until final stages if the disease gets severe:

- Corona is more contagious than the regular flu.
- Droplets of infections when people carrying the virus cough find their destinations in the intestines, the spleen and the lungs where it can have the most dramatic effect and even few corona-viruses can cause quite messy situation.
- The lungs are lined with billions of epithelial cells (the border cells of the body lining the organs and the mucosa which are very vulnerable to infections).
- Corona connects to specific receptors on its victim's membranes to inject its genetic material.
- Inside the cell, the virus gets copied and reassembled, it gets filled with more and more copies of the virus until it reaches -the-cell- a critical point: Self destruction.
- As the cell melts away, it releases new corona viruses particles to attack more cells and the number of infected cells grows exponentially.
- After days, millions of body cells are infected and billions of viruses have swarmed the body.

- As the immune system moves to defend the lungs, corona infects some of its cells and creates Confusion.
- The communication between the cells is through a protein called Cytokines and infected immune cells will overreact and call out more cells.
- The immune system starts fighting each other, sends more cells wasting its resources and causing devastating damage.
- Neutrophils which are very killing interfere they pump their enzymes destroying friendly cells and enemies.
- Killer T-cells order infected cells to commit suicide, in this confusion; they order healthy cells to kill themselves too.
- The more immune system cells arrive, the more damage they do and healthy lungs tissue gets killed.
- This can be so bad causing irreversible damage leading to lifelong disabilities.
- In most cases, immune system gets control and the body goes into recovery.
- In severe cases, the protective lines of the lungs dies, this means Alveoli-tiny air sacs (where breathing occurs) can be infected by Bacteria that once were not a problem at all.
- Patients gets Pneumonia, Respiration becomes very hard and fails so they need ventilators to survive.
- At this stage the full capacity of the immune system is consumed.
- Thousands of bacteria multiply, enter blood, they overrun the body and the situation is overwhelmed.
- Death occurs [15]

1.3.7 Diagnosis of Covid-19

Early diagnosis and isolation of suspected patients play a vital role in controlling the virus outbreak. The specificity and sensitivity of different diagnostic techniques differ between populations and the types of equipment employed. Several procedures have been recommended for the diagnosis of COVID-19.

Molecular methods

there are three major molecular methods which are: real-time reverse transcription polymerase chain reaction (rRT-PCR), isothermal amplification, and clustered regularly interspaced short palindromic repeats (CRISPR) based methods. All these methods follow the same protocol that have been recommended by the Centers for Disease Control and Prevention (CDC) for collecting specimens from COVID-19 patients.
rRT-PCR is the gold standard and the most reliable molecular method to diagnose SARS-Cov2. [16].

Serological methods

Also called antibody test, are applied to detect past and current SARS-CoV-2 infection and observe the progress of the disease periods and immune response. They are able to find the presence of antibodies (e.g., IgG, IgM and IgA) in a COVID-19 patient's serum and plasma [16]

Lateral Flow Assay

It is one of the most popular serological method that has been applied in clinics to detect antigens, antibodies, and amplified nucleic acids in variant biological samples such as blood (serum or plasma) [16].

Enzyme-linked immunosorbent assay

It is another serological method called enzyme immunoassay (EIA). ELISA is a plate-based method that has been used for detecting and quantifying soluble substances such as proteins and antibodies in clinic and research laboratories [16]

Here's a table that resumes the analytical performances of Covid-19 detection methods :

Method	Target analyse	Sample type	Clinical sensitivity (%)	Specificity (%)	Test time (min)	Advantages	Limitations	References
RT-PCR	Virus mRNA	Respiratory swabs, saliva, sputum, BLF	90–100	100	120–140	-High throughput; highly sensitive and specific; -detects active cases; -useful in clinical decision-making	-Labor intensive; -requires numerous reagents; Specialized equipment; -costly; less accurate after 5 days since symptom onset	[17, 18]
CRISPR	Virus mRNA	Respiratory swabs, saliva	95–100	100	45–70	-Simple and efficient; -low-cost; -low turnaround time; -improved specificity; -visual readout	Risk of contamination	[19, 20, 21]
Molecular POC	Virus mRNA	Respiratory swabs	>95	100	13–60	-Requires low technical manpower; -easy to use, faster; -cost-efficient; -visual readout, -community-level testing; -may not need RNA extraction; automation	Less accurate after 5 days since symptom onset	[22, 23, ?]
NGS Virus	mRNA	Respiratory swabs, BLF		Unbiased Unbiased	1–2 days	-Useful for identifying secondary infections and viral evolution; -allows for potential contact tracing	Expensive	[22, 24].
Computed tomography	NA	NA	86–98	25	<60	-Non-invasive,- highly sensitive	May not be stand alone	[24, 25]]
Biosensors/ LFA /RDT	Virus mRNA/ antigen/ antibody	Respiratory swabs, blood	Limited study	Limited study	<60	-Allows real-time detection, -faster; easy to use, -low-cost	Less accurate	[26, 27]
ELISA	Antibody	Blood	86–100	89–100	60–180	-Useful for disease prognosis and prevalence; -needed for identification of convalescent plasma donors.	Not suitable for the identification of active cases	[28, 29]

Table 1.1: A Comparison between different methods of Covid-19 detection

1.3.8 Imaging methods

The rapidity of the virus spreading has created a massive death toll and a lack of detecting the positive cases due to the pressure put on the methods already mentioned. Because of coronavirus being able to cause Pneumonia that can be seen through Imaging techniques, these last ones play an important role in the diagnosis and the treatement assessement of the virus :

- CT,positron emission tomography - CT (PET/CT),
- lung ultrasound,
- and magnetic resonance imaging (MRI)

1.3.9 The role of imaging to detect Covid-19

Clinical Definition

Confirmed positive cases are classified through imaging as : mild, moderate, severe or critically ill.

- COVID-19 cases with mild clinical symptoms and with no sign of pneumonia on chest imaging are confirmed as mild cases.
- Cases with fever, respiratory symptoms, and chest imaging findings of pneumonia are categorised as moderate cases.
- Besides the respiratory distress, oxygen saturation, and arterial partial pressure of oxygen (PaO2)/fraction of inspired oxygen (FiO2), an adult case with chest imaging showing obvious lesion progression >50% within 24-48 hours should be managed as a severe case[3].

The figues shows a:
a. Early stage patient
b. Progression stage patient
c. Outcome stage patient
d. Severe stage patient (critically ill)

Detection

The chest imaging characteristics is adopted as one of the clinical manifestations. Abnormal chest imaging characteristics of COVID-19 include multiple small patchy shadows and interstitial changes, more apparent in the peripheral zone of lungs (early stage), multiple ground glass opacities

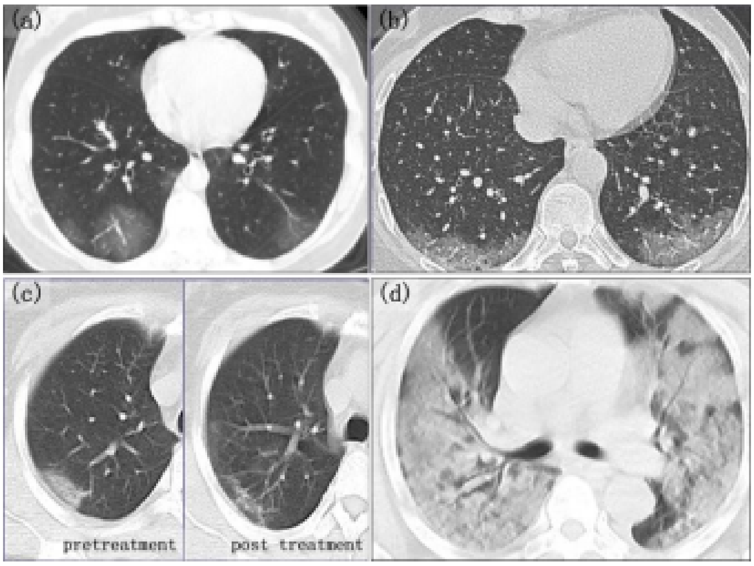


Figure 1.3: Four examples of COVID-19 patients from Beijing Youan Hospital. showing different disease stages [3]

and infiltration in both lungs (progression stage), pulmonary consolidation (severe stage). Any suspected case with a biological positive test is confirmed as a Covid-19[3].

Chest X-ray images are known to have potential in the monitoring and examination of various lung diseases such as tuberculosis, infiltration, atelectasis, pneumonia and COVID-19. With the phenomenal number of infected people, hospitals could not rely only on biological tests to manage the disease hence the use of different imaging techniques along with artificial intelligence to help detect, visualise, analyse and control the virus. This method have proven its efficiency all over the pandemic and helped gain efforts, times and lives as well.

1.4 Conclusion

Over this chapter, the anatomy of human lung was presented because it is the main organ attacked by the virus of Covid-19 which was defined later on with its properties and impact on our bodies.

Due to the rapidity of the virus which manifests in our bodies as Pneumonia and its spreading that was nearly impossible to handle, using imaging techniques was necessary to manage the disease as it is a step to connect it with artificial intelligence (Image classification and Segmentation) in order to help the healthcare personal diagnose positive cases and facilitate the complexity of the overwhelming pandemic hence the next chapter that will overview this solution.

Chapter 2

State of the art of classification of Covid-19

2.1 Introduction

Since the pandemic has grown rapidly and uncontrollably all over the world leaving governments helpless when dealing with the unforeseen challenges caused by Covid-19, many countries have faced the slow pace in the detection of positive cases, therefore many techniques have been used to help fasten this detection. Deep learning and image processing provided promising results and a high performance in the army formed against the virus,thanks to the big amount of data and self-learning. In this chapter, we are going to present Deep Learning and then some of the most recent state-of-art works that applied image segmentation and classification to help control the pandemic.

2.2 Artificial Intelligence

Is the effort to automate the human reflection and implement it in machines, as it first appeared in 1950 proving its effectiveness to solve simple and complicated problems in a short time. [30].

2.3 Deep Learning

2.3.1 Definition

Deep Learning is one of the main data science elements. It is a form of machine learning (ML) and Artificial Intelligence (AI) that qualifies computers to experience and understand the world imitating the way human analyze and using algorithms driven by the brain with or without the human supervision. [4].

The following figure shows the AI subsets

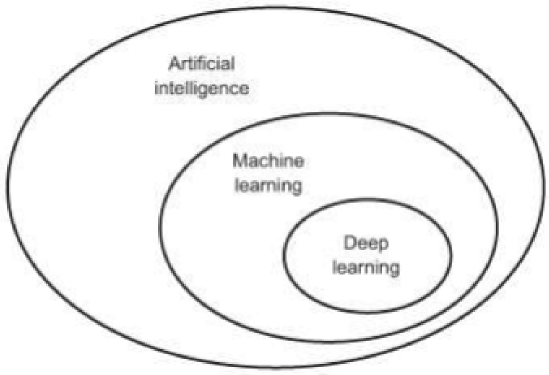


Figure 2.1: Artificial Intelligence subsets [4]

2.3.2 Architectures of Deep Networks

Deep learning models are classified into three major families: Supervised methods, unsupervised methods and reinforcement methods.

Unsupervised methods

It mainly deals with unlabeled data, allowing the model to work on its own to discover patterns and information that was previously undiscovered. The difference between supervised methods and clustering is that clustering is applied in an unsupervised manner, so no class labels are provided, and sometimes even the quantity of clusters is not known a-priory. [31].

Supervised Learning It is defined by its use of labeled datasets to train algorithms that to classify data or predict outcomes accurately. As input data is fed into the model, it adjusts its weights until the model has been fitted appropriately, which occurs as part of the cross validation process. Supervised learning helps solve a variety of real-world problems at scale. The best known architectures in supervised learning are Convolutional Neural Network (CNN).

a) **Convolutional Neural Network**
   This type of neural networks is trained by using big data and owns the capability of extracting features from data via convolutions without manual extraction of features. It is composed by several kinds of layers: an input layer, output layer, and hidden layers. The hidden layers consist of convolutional layers, ReLU layers, pooling layers, and fully

connected layers as is presented in the figure. [5]. Convolution neural network is one of the most popular deep learning architectures used for classification and recognition of images, texts, and sounds, figure 2.2 is a the general CNN architecture :

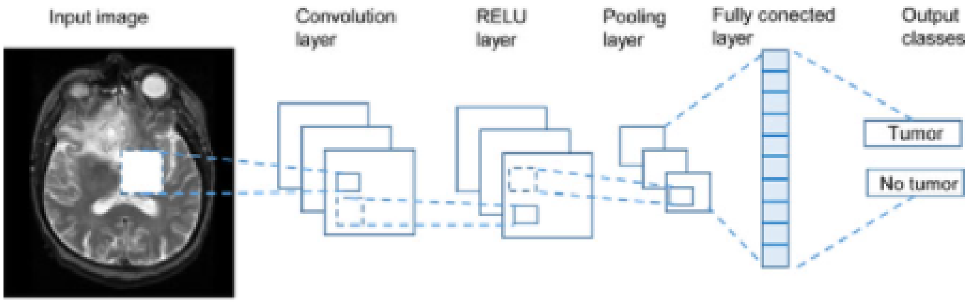


Figure 2.2: General CNN Architecture [5]

CNN have gained a reputation for its high performance in all data science fields through its architectures, here's some of the most popular ones :

- **LeNet-5 (1998):** Is a very simple network consists of two convolutional layers, and three fully-connected layers; in addition to input and output layers and sub-sampling layers [32].
- **AlexNet (2012):** AlexNet contains 5 Convolutional Layers and 3 Fully Connected Layers as well Overlapping Max Pooling layers [33].
- **GoogLeNet(2014):** It is a convolutional neural network that contains 22 layers; the basic convolutional block in GoogLeNet is named an Inception block [34].
- **VGG-16 (2014):** It has 13 convolutional with 3 fully-connected layers, in addition of the ReLU and max-pooling layers. VGG-19 is a deeper variant of VGG16. [35].
- **Inception-v3 (2015):** (the 3rd version of inception networks) is a convolutional neural network that composes of 48 layers deep and adds batch normalization[36].
- **ResNet-50 (2015):** Deep Residual Network is one of the deeper architecture of CNNs that based on the convolutional and identity blocks; contains up to 152 layers [36].
- **Xception (2016):** It represent an adaptation from Inception network; they involve depthwise separable convolutions layers in place of the Inception modules. It uses 36 convolutional layers [36].

- **ResNeXt-50 (2017):** Based on ResNet-50 and add parallel branches or paths within each module[36].

b) **Recurrent Neural Networks** They are the best powerful networks used to recognize patterns sequences of data and suited to processing time-series data and other sequential data The Recurrent neural networks take as input the current input, and add time and sequence into account, we can say that they got a new dimension "temporal dimension"[37].

Reinforcement Learning Reinforcement learning is all about the agent deciding what to do to perform a given task and solve any upcoming problem [38].

2.3.3 Contribution of Deep Learning

Deep learning has provided us with a whole new research era. It helps clinicians in healthcare diagnose diseases, identify and and understand cancers and infections, predict infectious disease outbreaks with high accuracy and explore all of this changing human lives and making it easier to control the amount of data we perceive each day and turn into something of knowledge that can actually help us better defend and ready ourselves to solve problems as complicated as they may seem [39].

2.4 Classification of Covid-19

2.4.1 Classification

Definition

Classification is a supervised learning approach in which the computer program learns from the input data and then uses this learning to classify new observation[**?**]. Image classification is assigning one or more labels to an image according to a pre-defined category following an algorithm that teaches to which category belongs the image.

How does CNN work?

Convolutional Networks (ConvNets) are currently the most efficient deep models for classifying images data. Their multistage architectures are inspired from the science of biology. Through these models, invariant features are learned hierarchically and automatically. They first identify low level features and then learn to recognize and combine these features to learn more complicated patterns [40].

Layers in CNN

There are five different layers in CNN [6] :

Input Layer

It contains image data .Figure 2.3, that has he following dimensions: [width x height x depth]and it is a matrix of pixel values. -Convolutional Layer (Convo+ReLU): It is also called feature extraction layer. The convolution of an image with different filters can carry out operations such as edge detection. -Calculate the dot product between receptive field (local region of the input image that has the same size as that of filter) and the filter, it results in a single integer which is the output volume (feature map). - Slide the filter over the next receptive field of the same input image by a Stride (number of pixels shifts over the input matrix) and compute again the dot products between the new receptive field and the same kernel. - Repeat this procedure until going over the entire input image, the output will be the input for the next layer.

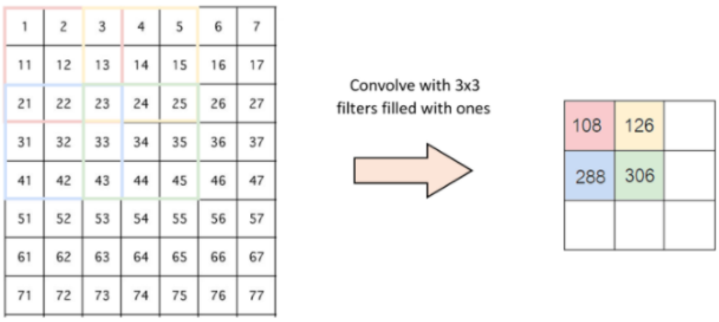


Figure 2.3: Convolutional Layer [6]

Non Linearity (ReLU)

ReLU (Figure 2.4) stands for Rectified Linear Unit for a non-linear operation. The output is $f(x) = \max(0,x)$. **Why ReLU is important?**
ReLU's purpose is to introduce non-linearity in our ConvNet. Since, the real world data would want our ConvNet to learn would be non-negative linear values.

Some other non-linear functions do exist such as tanh, sigmoid. Although, most of the time data scientists use ReLU is better performing.

Pooling layer

Pooling layers Figure 2.5, section is used to reduce the number of parameters

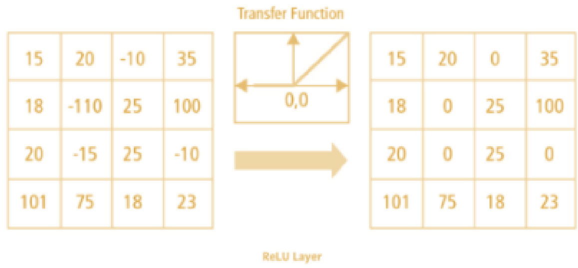


Figure 2.4: ReLU Operation[6]

when the images are too large. it has different types :
- Max Pooling.
- Average Pooling.
-Sum Pooling .

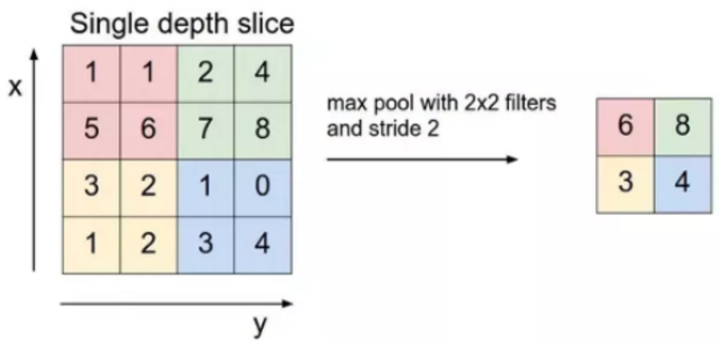


Figure 2.5: Max Pooling[6]

Fully Connected Layer

It flattens the matrix into a vector and feed it into a fully connected layer like neural network. Figure 2.6

Output layer

The last fully-connected layer uses an activation function such as sigmoid or softmax to get probabilities of the outputs.

CNN Architectures

There are many variants of Convolutional Neural Network architectures that have been developed to solve real life problems, here are some of the most

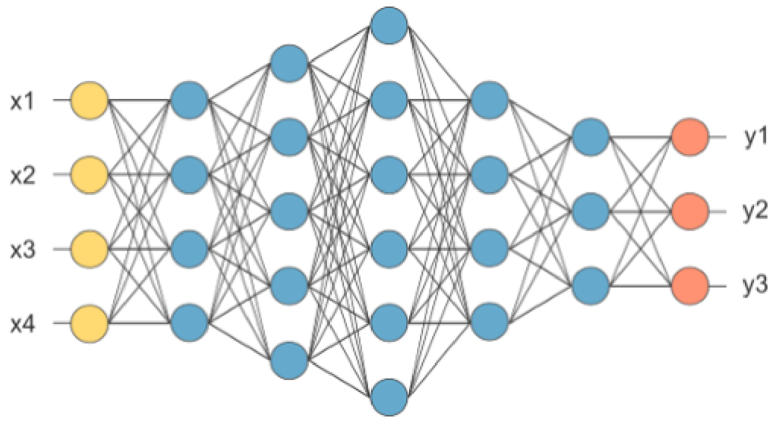


Figure 2.6: Fully Connected Layer[6]

famous CNN architectures :

ResNet
Residual Networks 'ResNets' are nearly similar to networks that have layers of convolution, pooling, activation and fully-connected layers. The basic building block for ResNets is the convolutional and identity blocks, which connect the output of one layer with the input of an earlier layer[41].

VGG Net :
VGG is presented with much more details, because it is basically the main architecture used in the proposed application. **Definition**
Is invented by Visual Geometry Group (by Oxford University), VGG is a Convolutional Neural Network architecture based off of AlexNet. There are two architectures of VGG: VGG16 VGG19. **Architecture:**
- Input: VGG used RGB image in a 224x224 pixel. - Convolutional Layers: In VGG, the convolutional layers use a very small receptive field 3x3.

There are also 1x1 convolution filters which can be seen as a linear transformation of the input channels, followed by a ReLU layer. The convolution stride is fixed to 1 pixel.

- Max Pooling: is performed over a 2×2 pixel window.

- Fully-Connected Layers. VGG contained 3 fully-connected layers.

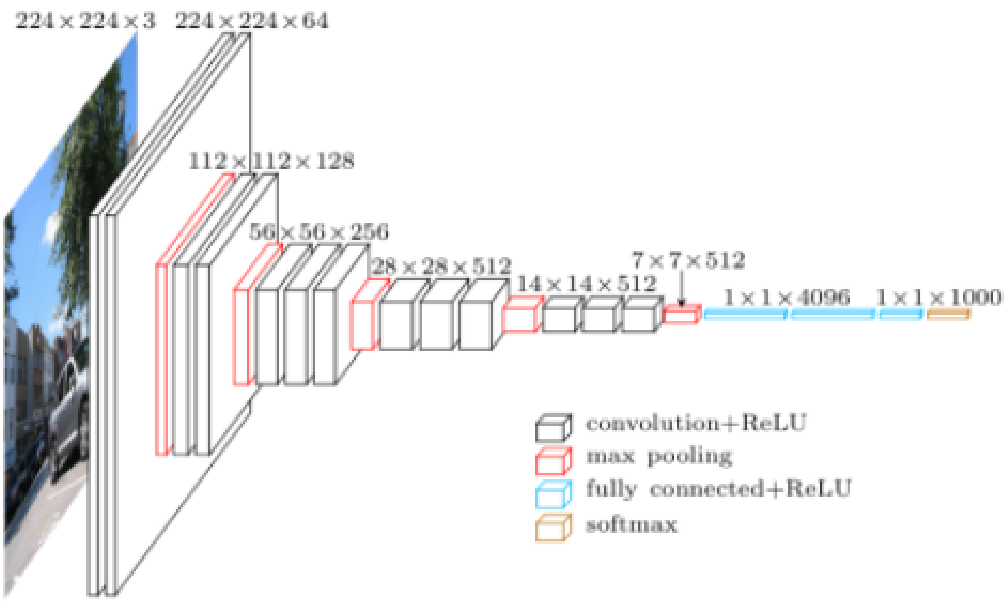
- Hidden Layers: All hidden layers are equipped with the non-linearity layer(ReLU). It is also noted that not all of networks contain Local Response Normalisation (LRN) due to their consumption of memory and time and does not improve the performance [42]

VGG16:

is a variant of VGG with 16 Convolutional layers. It has only 3x3 convolutions, but a lot of filters.It can be trained on 4 GPUs for 2–3 weeks. VGG16 is currently the most preferred choice in the community for extracting features from images [43]

16 layers of VGG16 1.Convolution using 64 filters
2.Convolution using 64 filters + Max pooling
3.Convolution using 128 filters
4. Convolution using 128 filters + Max pooling
5. Convolution using 256 filters
6. Convolution using 256 filters
7. Convolution using 256 filters + Max pooling
8. Convolution using 512 filters
9. Convolution using 512 filters
10. Convolution using 512 filters+Max pooling
11. Convolution using 512 filters
12. Convolution using 512 filters
13. Convolution using 512 filters+Max pooling
14. Fully connected with 4096 nodes
15. Fully connected with 4096 nodes
16. Output layer with Softmax activation with 1000 nodes.
Figure 2.

figure[htp]



VGG16 Overview [43]

Inception network:

It is basically a convolutional neural network (CNN) but it's characterized -in addition to its common layers- by its unique module "Inception module" which was designed to solve the problem of computational expense, as well as overfitting, among other issues. In general Inception network is one of the possible solutions for computer vision problems [41].
The popular versions of inception networks are as follows:

- Inception v1 or GoogLeNet
- Inception v2 and Inception v3.
- Inception v4 and Inception-ResNet.

Xception
Xception is an adaptation from Inception, where the Inception modules have been replaced with depthwise separable convolutions. It has also roughly the same number of parameters as Inception-v1 [42].

Transfer learning

It enables us to utilize knowledge from previously learned tasks and apply them to newer, related ones. If we have significantly more data for task T1, we may utilize its learning, and generalize this knowledge (features, weights) for task T2 (which has significantly less data) [**?**].

2.5 Related works

Over this year, Databases related to Covis-19 were used to by researchers to the segmentation and the classification to help the detection of the disease. The following table summarizes the most recent works related to this :

@

Author & Date	Title	Used Dataset	Task	Used Methods	Results Obtained:
Harsh Panwar et al. [[44]]	A deep learning and grad-CAM based colour visualization approach for fast detection of COVID-19 cases using chest X-ray and CT-Scan images	Cohen et al. Dataset	Binary Classification of Covid-19 and NonCovid 19 positive cases.	A deep transfer learning algorithm Grad-Cam colour visualization approach.	· Accuracy of 95.61% · A better interpretation and explanation

Parisa gifani et al. [45]	Automated detection of COVID-19 using ensemble of transfer learning with deep convolution neural network based on CT scans.	Xingyi Y et al. COVID-CT-Dataset	Binary Classifica -tion of Covid19 and NonCovid 19 positive cases.	15 pre-trained CNNs architec -tures: Efficient Nets (B0- B5) NasNet Large NasNet Mobile Inception V3 ResNet-50 SeResnet 50 Xception DenseNet 121 ResNext50 and Inception $_{r}esnet$ $_{v}2$	The 5 deep learning architectures had higher results than the individual transfer learning structure based on precision.

Mostafa El Habib Daho et al. [5]	Explainable Deep Learning Model for COVID-19 Screening in Chest CT Images.	Three Datasets: CHU Tlemcen-Algeria. Another dataset collected from several articles, and the third one from infected cases in the hospital of Sao Paolo - Brazil.	Binary Classifica -tion of Covid-19 and Non Covid19 positive cases.	ResNet50 Transfer Learning Grad-Cam algorithm.	Accuracy of 97,63% · Heatmap for a better explicability
Pedro Silva et al. [46]	COVID-19 detection in CT images with deep learning: A voting-based scheme and cross-datasets analysis.	Two Datasets: SARS-CoV-2 CT-scan dataset. COVID-CT dataset.	Binary Classifica -tion of Covid-19 and Non Covid - 19 positive cases.	· Extention of EfficientNet family . Data Augmenta -tion Transfer Learning	A highest accuracy on both datasets with smaller parameters and can be used on devices.

Amine Amyar et al. [47]	Multi-task deep learning based CT imaging analysis for COVID-19 pneumonia: Classification and segmentation	Three datasets	Segmentation of chest CT images, Classification and a Reconstruction.	COVID vs Normal vs Other Infections classification, COVID lesion segmentation, image reconstruction	Dice coefficient of 88% for image segmentation Accuracy of 94.67%.
Aayush Jaiswal et al. [48]	Classification of the COVID-19 infected patients using DenseNet201 based deep transfer learning.	The SARS - CoV-2 CT scan dataset on kaggle.	Binary Classification of Covid-19 and Non Covid - 19 positive cases.	A deep transfer learning model pre-trained DenseNet201 model.	An accuracy of 97%
Adnan Saood et al. [49]	COVID-19 lung CT image segmentation using deep learning methods: U- Net versus SegNet.	Collection of the Italian Society of Medical and Interventional Radiology.	Segmentation of infected Tissue CT images of lungs.	· SegNet · U-Net	· SegNet 0.95 mean accuracy · U-NET 0.91 mean accuracy

Table 2.1: State of art related to Classification and Segmentation of Covid-19

The detection of Covid-19 has known many studies in 2020, The binary classification that Pedro Silva and his group [46] applied gave them good results and was a reliable work to start our study while the most interesting work we remarked is the one that belongs to Harsh Panwar et al. [44] who added a visualization using Grad-cam to the detection task for a better explicability of results which inspired us to use as he got a 95.6% accuracy. Segmentation was also among the interesting tasks applied in the Covid-19 automed intelligent systems that allows the model to only focus on the lungs when classifying a Covid-19 image since we don't need the rest of the thoracic cage.

2.6 Conclusion

Deep learning is a vast domain developing everyday and opening doors towards exploration and answering to many human needs and problems, notably Classification and Segmentation who play a major role in helping facilitate the healthcare. Since Pneumonia is one of the most damaging symptoms caused by Coronavirus, many related works have been performed to detect and control it through imaging which was spoken about through this chapter. Based on these capacities of AI and the recent studies mentioned in table 2.1 and explained previously, we decided to build a web application that can d both : Classification and Visualization.

Chapter 3

Proposed application

3.1 Introduction

Covid-19 pandemic was a real challenge and issue to laboratories, the virus is highly contagious, which is why it must be quickly detected, the amount of suspect cases in a short time in addition of the constant risk on the staff is still a problem hence using automated application is a a real life changer. Identifying COVID-19 at an early stage through imaging allows the isolation of the patient and therefore limits the spread of the disease. In this chapter, we are going to present our classification methodology and the web application of Covid-19 Detection with the steps made to achieve it.

3.2 Conception and Modeling

3.2.1 Used tools

Python

Python is an interpreted, object-oriented, high-level programming language with dynamic semantics. Its high-level built in data structures, combined with dynamic typing and dynamic binding, make it very attractive for Rapid Application Development [50]

Django 3.2.3

Django is a high-level Python Web framework that encourages rapid development and clean, pragmatic design. Built by experienced developers, it takes care of much of the hassle of Web development, so you can focus on writing your app without needing to reinvent the wheel. It's free and open source [51].

What is a framework?

When software developers are creating an application, the same steps are always the same which makes the process tedious, long and boring. Therefore, using a reused pieces is a solution.

Why Django?

- Easy to learn.
- Quality of realized applications.
- The application can be developed very quickly.
- Security of the the final web page.
- Very flexible and easy to fix all along.

Many developers can be working on the exact same code, thanks to Python which can enhance the work quality and help develop anything very fast from scratch.

The code was written in 4 files :

1. **models.py** file, it describes the table in which data is stored in a form of a python class called model.
2. **views.py** is the file that contains the logic of the page in a form of a python function called view.
3. **urls.py** defines which view will be called for a given URL template.
4. **html file** is an HTML template that defines the look of the page called a template.

Pycharm

PyCharm is an integrated development environment used in computer programming, specifically for the Python language [52].

Tensorflow 2.5.0

TensorFlow is an open source Python library for large-scale machine learning. it is one of machine learning frameworks released by Google Brain team used to design, build, and train deep learning models. [53]

3.2.2 UML

Unified Modeling language is a used for the designing and visual representation of all sorts of computer systems.
UML is called a universal language because it is independent of programming languages. UML consist of 13 diagrams grouped 2 Diagram Structure:

1. structural diagrams:

- Class Diagram.
- Component Diagram.
- Deployment Diagram.
- Object Diagram.
- Package Diagram.
- Composite Structure Diagram.
- Profile Diagram

2. behavioral diagrams:

- Use Case Diagram.
- Activity Diagram.
- State Machine Diagram.
- Sequence Diagram.
- Communication Diagram.
- Interaction Overview Diagram.

Use case

The Use case diagram is composed of: Actors (human person or robot) that use the system and Use Cases (the functionalities proposed by the system). Figure 3.1.
Below is the use case diagram " User" :

The user can use the application for medical purpose. He can upload an image or several images to be classified and visualized.

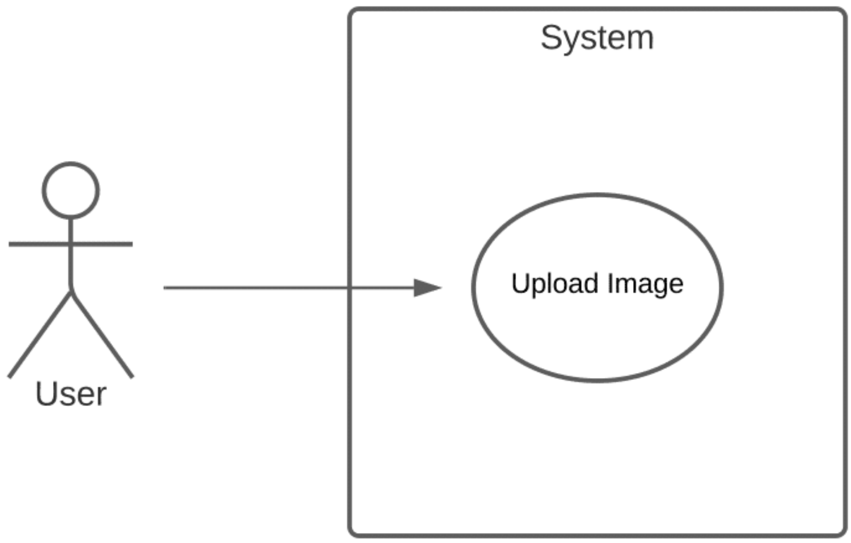


Figure 3.1: Use case diagram

Class Diagram

it describes the structure of a system by showing the system's classes, Figure 3.2, their attributes, operations, and the relationships among objects. The user can upload an image that enters into the classification model to categorize it whether it belongs to a covid or non covid patient. If the entered image was classified as Covid, the visualization of the disease is shown with the result.

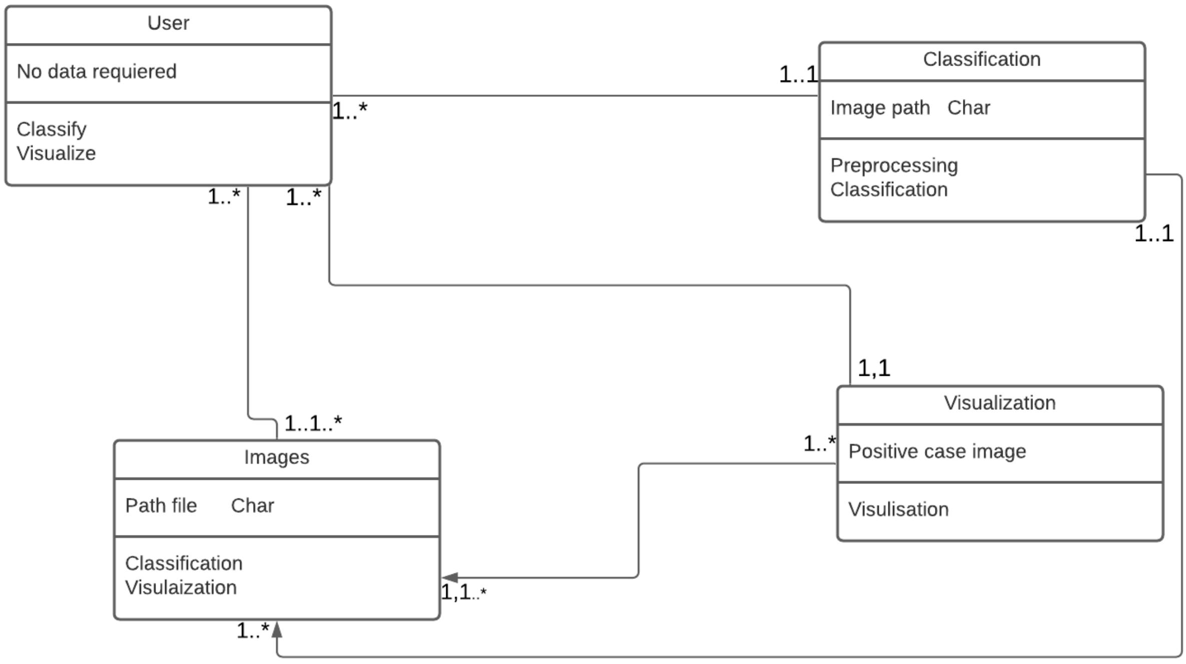


Figure 3.2: Class diagram

Sequence Diagram

This diagram in Figure 3.3, presents the manner how the users interact with others in a particular scenario of a use case.

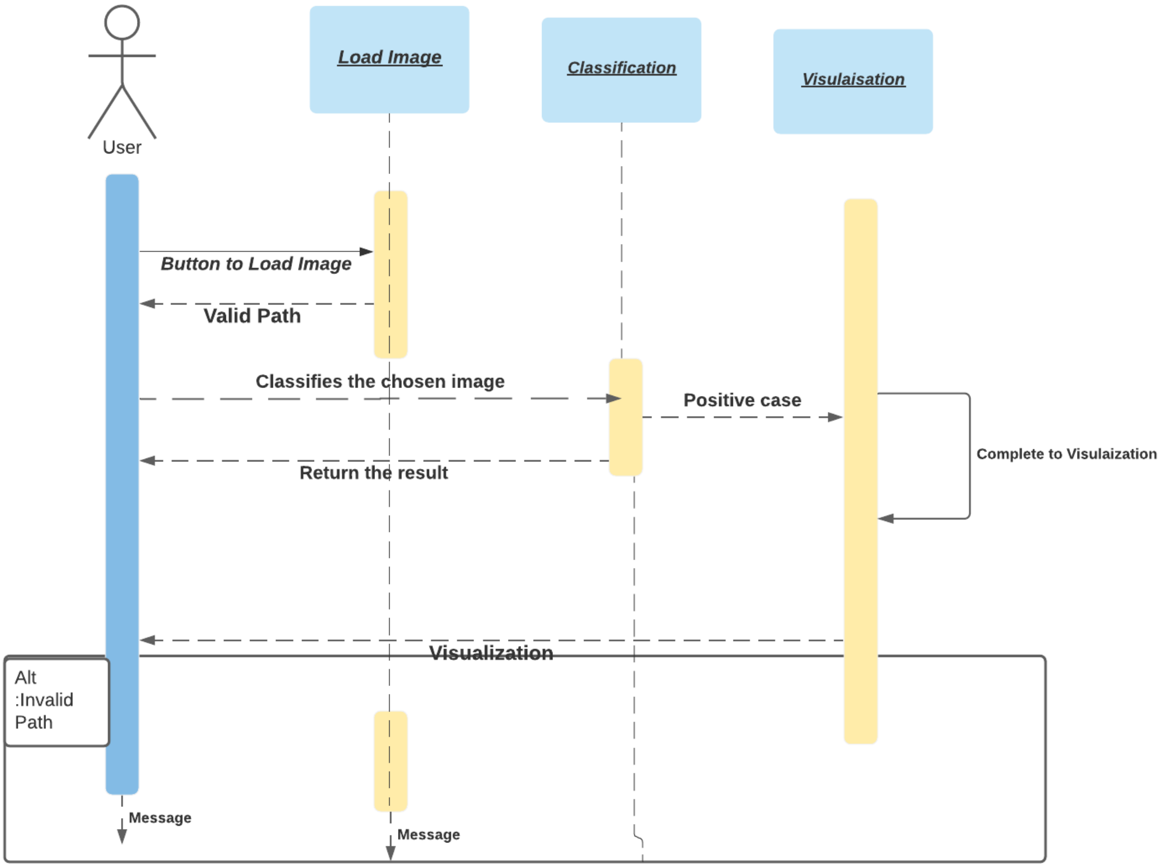


Figure 3.3: Sequence Diagram: Classification and Visualisation

3.3 Methodology and Results

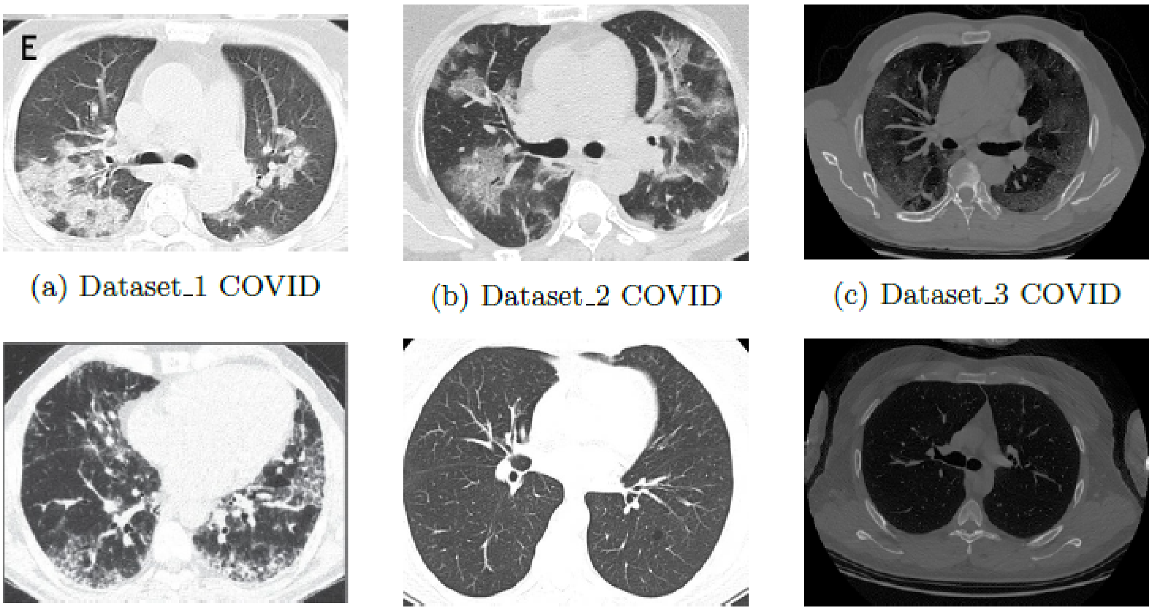
3.3.1 Dataset

In this work, we used three different datasets, two of them are available for free access on the internet and the third one we collected from the Hospital of Tlemcen (CHU Tlemcen). The first dataset was published by Yang et al [54], it contains 349 COVID and 397 non-COVID images. This database has been collected from several articles published on medRxiv, bioRxiv, NEJM, JAMA, Lancet, etc. The second one is also public and has been published by Soares et al [55], it contains 1252 COVID and 1230 non-COVID images. This dataset was collected from patients in hospitals in Sao Paulo, Brazil. The third dataset was collected by [56] from the Hospital of Tlemcen in Algeria, it contains 180 COVID and 180 non-COVID images. Table 3.1 summarizes the databases used in this study.

Table 3.1: Used datasets

	Authors	#COVID-19	#Non COVID-19
Dataset_1	Yang et al [54]	349	397
Dataset_2	Soares et al [55]	1252	1230
Dataset_3	El Habib Daho et al. [56]	180	180
Dataset_X	Total	1781	1807

The following figure 3.4 shows examples of images with and without the presence of COVID-19 in the three datasets. On the figure, we can see that the three datasets present variations in color and texture, which will allow the model to be more robust to the difference in quality and type of the image presented during the test phase.



(a) Dataset_1 COVID (b) Dataset_2 COVID (c) Dataset_3 COVID

(d) Dataset_1 Non-COVID (e) Dataset_2 Non-COVID (f) Dataset_3 Non-COVID

Figure 3.4: Some of the images from the Dataset

3.3.2 CNN Classification

Covid-19 classification was done using google colab. The model is trained with CT images from healthy and infected patients coming from the database described below and then undergo a preprocessing of images and data augmentation.
We used 80% for training, an average of 2870 images. The rest 20% for the validation which is about 718 image. We took the validation as a test too.

Preprocessing:

Pre-processing being very useful and common in computer vision applications for removing unwanted noise, emphasize aspects of the image that can help with the recognition task and help with the deep learning training phase for this purpose we resized the images to maintain compatibility with the network architecture.
In addition, a simple pixel intensity normalization in the range of [0, 1] is applied. This pre-processing is necessary for model convergence during the training phase.
The used dataset contains images of different sizes, we have readjusted it so that all images will be 224x224 in size.

Data Augmentation :

Data augmentation like shown in Figure 3.5 which is a rotation operation is about increasing the training samples by transforming the images without losing semantic information. We applied three transformations to the training samples: rotation, horizontal flip, and scaling.

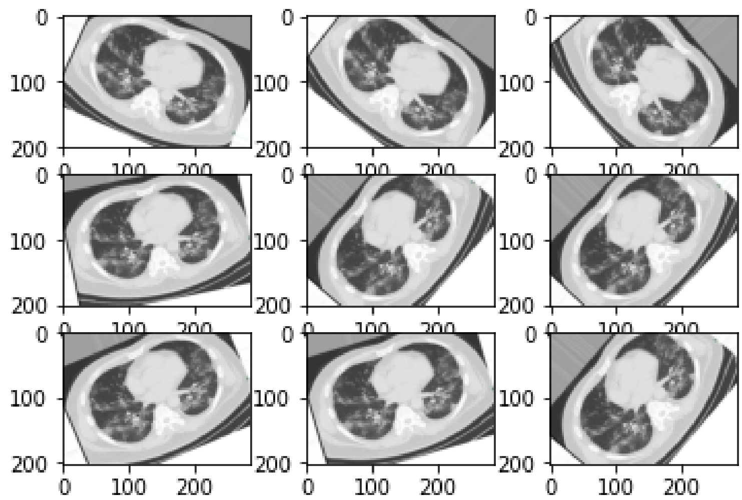


Figure 3.5: Example of Data Augmentation applied on the data base : Rotation

Classification

We used three pre-trained models on ImageNet database: Resnet50, VGG16 and Inception v3.
Followed by the configuration of the trainble and the untrainable layers, in our study we took all the layers.
In order to adjust our output that has only two classes with the ImageNet output that has 1000 class, we have used two fully connected layers after the flatten (512 and 256 neurons) followed by the Softmax function because this last one is preferred for giving the output as a probability and the target class will get the highest one, which will solve problems of similarities between classes. We have trained all models for 50 epochs using a batch size of 32 and Stochastic Gradient Descent (SGD) method to minimize the loss function.

All the process of the work is presented in the next block diagram :

From the confusion matrix in Figures 3.8,3.10, and 3.12 we can evaluate the quality of each model by measuring the accuracy, the sensitivity, and the specificity on the validation set using the following equations:
Accuracy = (TP + TN) /Total no. of predictions.
Specificity = (TN) /(TN + FP): The ability of a test to correctly identify

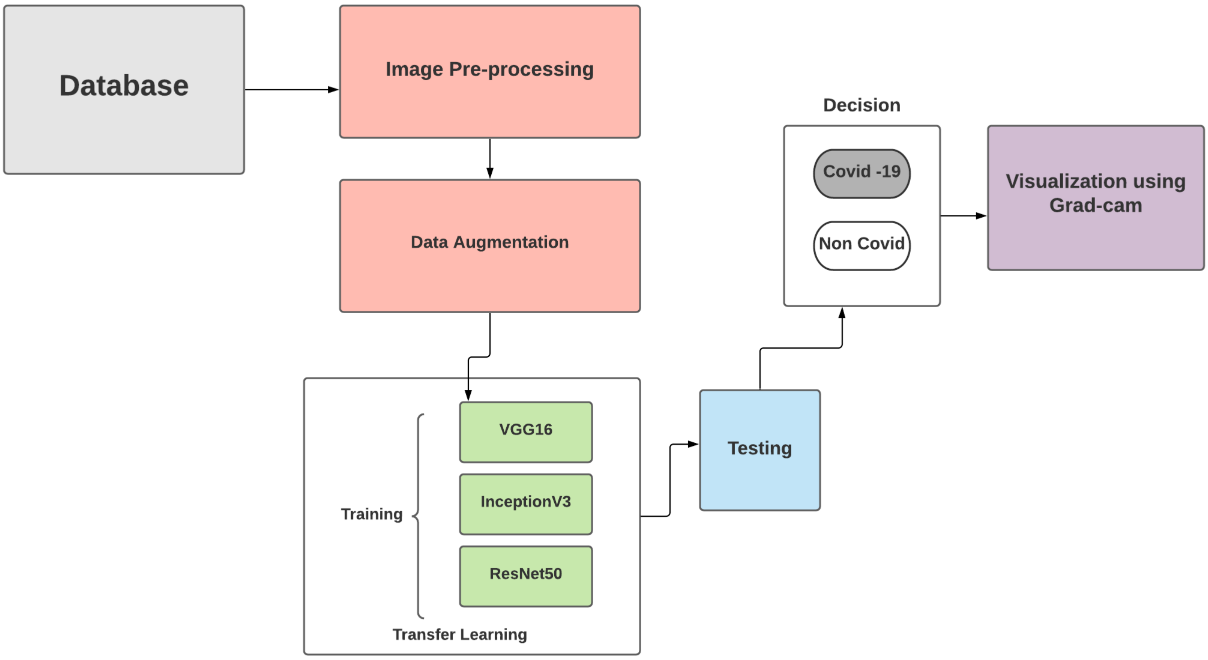


Figure 3.6: The classification process of positive cases and visualization

people without the disease.
Sensitivity= (TP) /(TP + FN): The ability of a test to correctly identify patients with a disease.

With:
True Positive (TP): If a COVID-19 infected person is detected as COVID-19.
True Negative (TN): If a person is correctly detected as NONCOVID-19.
False Positive (FP): represents incorrect detection where a normal person is detected positive for COVID-19.
False Negative (FN): represents incorrect detection where a person infected with COVID-19 is detected as normal one.

Results

The following figures show the accuracy curves and the confusion matrix results of the classification using the three architectures, VGG16, InceptionV3 and Resnet50

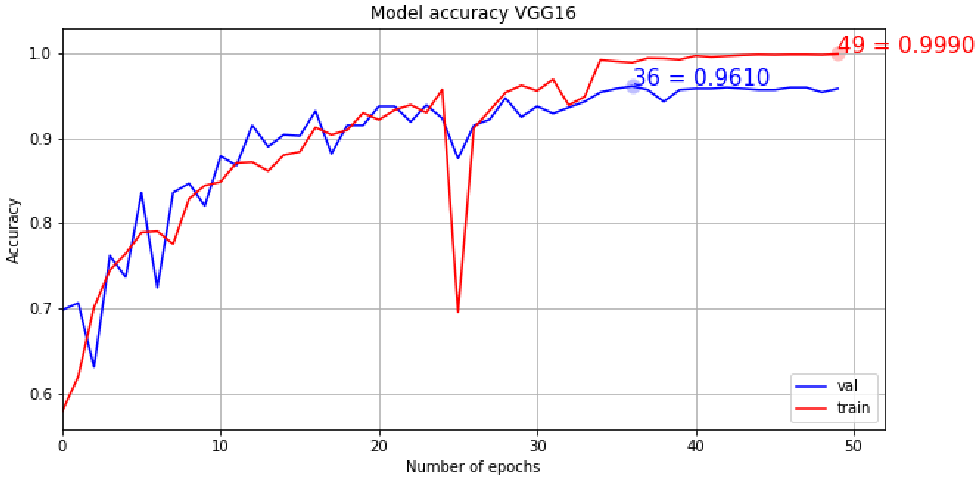


Figure 3.7: Accuracy curve for VGG16

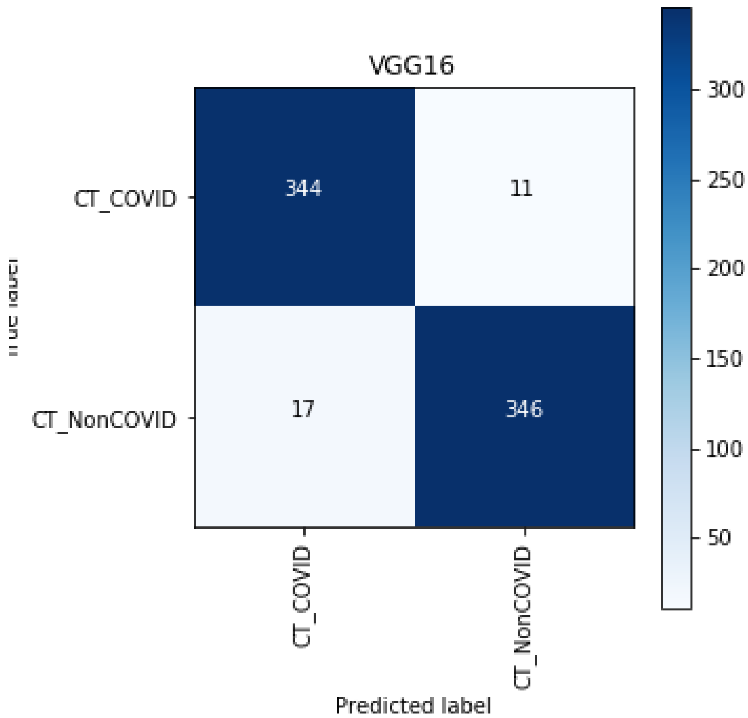


Figure 3.8: Confusion Matrix of VGG16 based model.

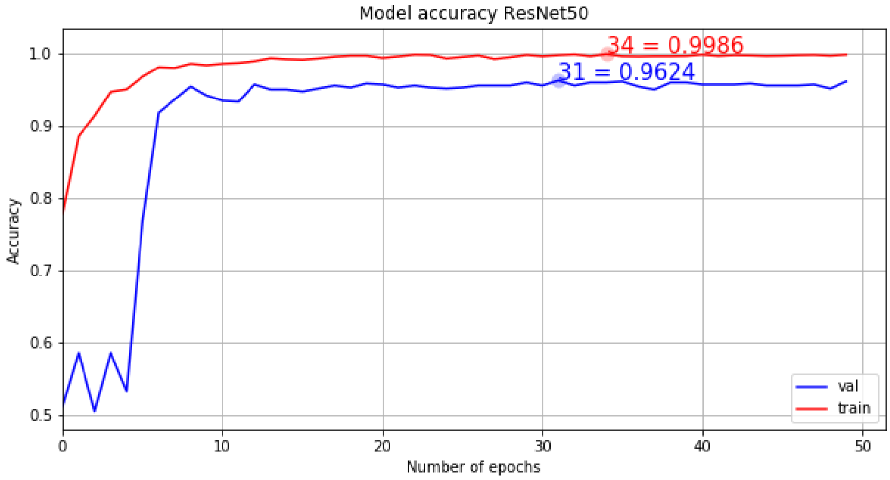


Figure 3.9: Accuracy curve for ResNet50

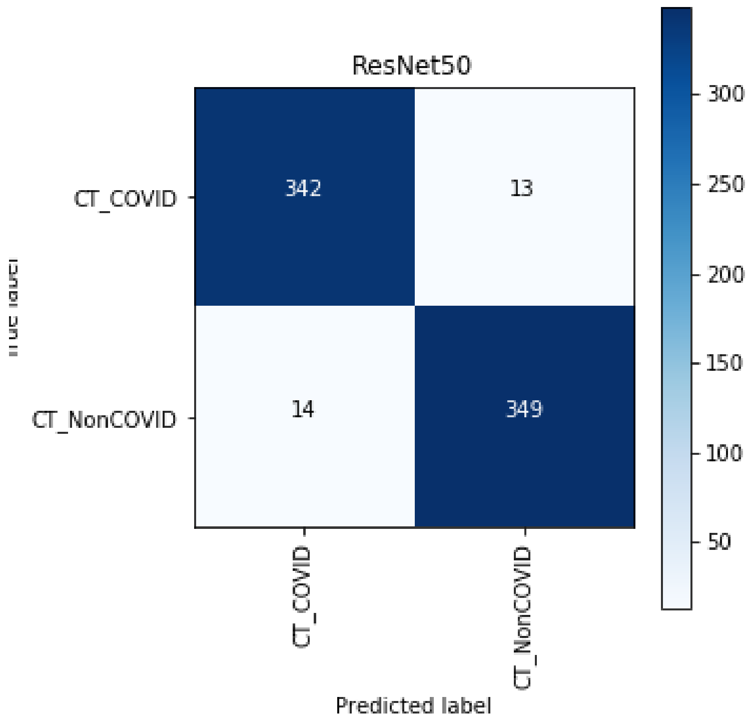


Figure 3.10: Confusion Matrix of ResNet50 based model.

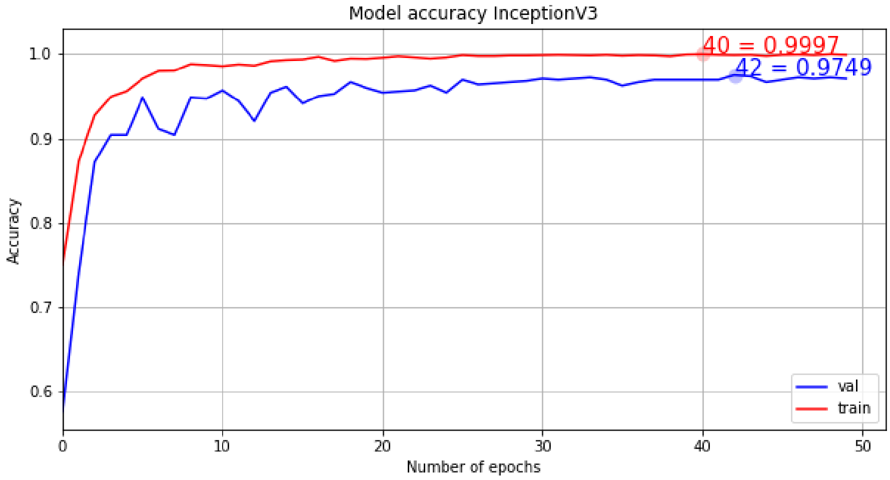


Figure 3.11: Accuracy curve for InceptionV3

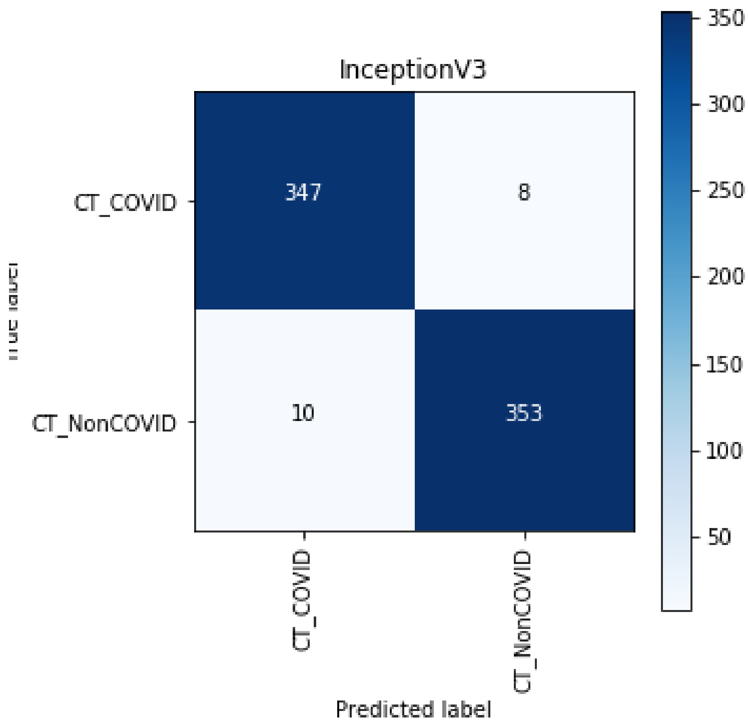


Figure 3.12: Confusion Matrix of InceptionV3 based model.

The Accuracy curves start to converge by the 30th epoch, which is why we stopped by the epoch 50. The results of both of VGG16 and Resnet50 are good while the highest accuracy was gotten using InceptionV3 (97%)

The obtained results of performances of training three models:

Model	ResNet50	VGG16	InceptionV3
Accuracy	0.9624	0.9610	0.9749
Specificity	0.9614	0.9531	0.9725
Sensitivity	0.9634	0.9690	0.9775

Table 3.2: The obtained results of performances of training he three models

The sensitivity of the test gives back the probability that the test will be positive among those who are diseased. While, the specificity of the test shows the probability that the test will be negative among those who, in fact, are not diseased.

Table 3.2 summarizes the obtained results by the different models. We can notice that the Inception V3 model outperforms the other models in terms of accuracy, specificity and sensitivity. In medical diagnostic aid in general and decision support for COVID-19 in particular the sensitivity is very important. Indeed, a high sensitivity is equivalent to a very low false negative rate. False negatives are patients who have been diagnosed as Non-COVID by the system but are actually positive patients. Such an error can cause the death of the patient and does not have the same impact as a false positive error that can be quickly corrected with additional tests. We can therefore deduce that our model and Inception V3 are the best in terms of performance compared to our dataset.

Visualization::

To improve the interpretability of our model, we have adopted Grad-CAM [57] to visualize the important regions leading to the decision of the deep learning model. Grad-CAM technique, Gradient-weighted Class Activation Mapping, creates the visual explanation for any deeply connected Neural Network and helps in determining more about the model while performing detection or prediction work. Once the predicted label has been calculated using the full model, Grad-CAM is applied to any of the Conv layers.

Grad-cam will allow us to retrieve the feature map from a specific layer in order to know where our model is looking when it decided or to to debug any mistake as well as explaining the obtained results by highlighting the regions for which the model gave it the output class.

We applied activation heatmap in the last layer using Keras library, figure3.3 [58] .

The infected region in the lung is highlighted, helping us understand the decision way better.

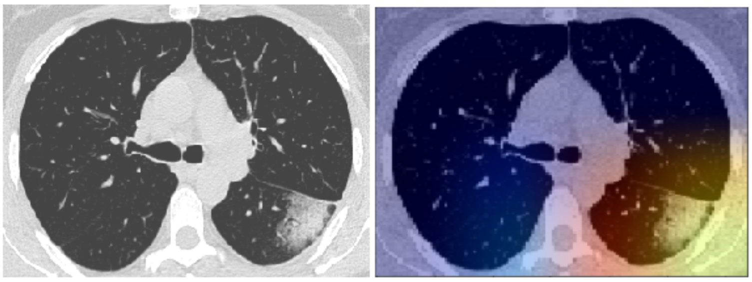


Figure 3.13: Visualisation of COVID-19 infected person using Grad-CAM on the trained model

3.4 Application

The web application was realized using python and django on pycharm based on the design already shown with UML and the classification model. The application allows the user to upload one or several CT-Scan chest images and classifies them to positive or negative cases.

The image belonging to a covid-19 infected person will be visulized using grad-cam for better explanation of the decision.

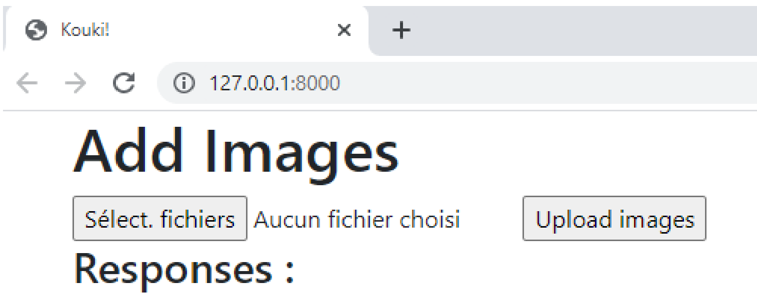


Figure 3.14: Application main page

After selecting an image from the computer by clicking the select button it allows the user to choose one or different images in order to classify them.

3.5 Conclusion

To conclude this chapter, we'd say that relying on traditional ways to detect such disease isn't a good solution and conceiving such application can help gain so much efforts and time and save people's lives.
The realized application using the tools mentioned all along the chapter gave good results especially with InceptionV3 in the classification and the visualization too in addition of responding to both of the design model and

Figure 3.15: Application result after a classification of a covid-19 patient + Visualization

Figure 3.16: Application result after a classification of a non covid-19 patient

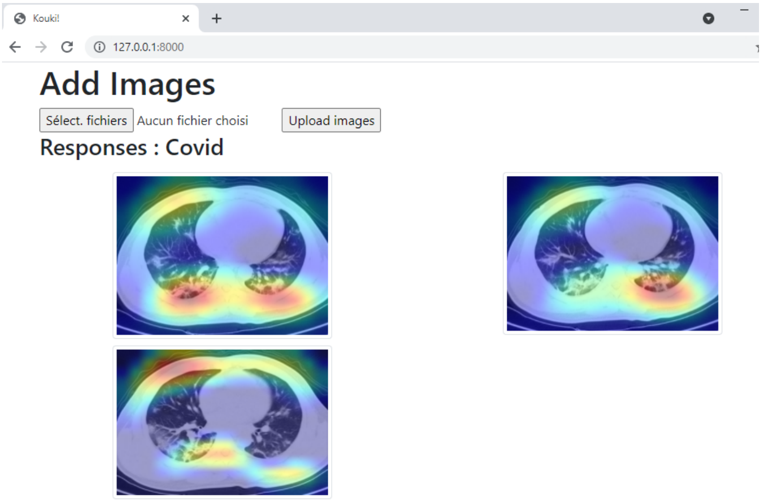


Figure 3.17: Selecting several images to be classified

the need of a deep learning systems to help healthcare through this overwhelming pandemic.

Conclusion and Perspectives

The pandemic was no easy to literally everyone on the planet, it is a disease that the humanity was newly exposed to and not ready to control.

SARS CoV-2 being highly contagious has made the priority of early detection a critical factor to control its spreading. all along 2020. Many ways to decide whether a person is infected of Covid-19 or no were proposed and used including imaging that was very efficient due to Pneumonia being number one damage caused by the virus, and with the massive amount of data we receive everyday building an application to help the detection was certainly an effective way to offer aid to the healthcare staff and to limit the damage in general.

In this work, our proposed web application insisted of creating a tool that facilitates the classification of Covid-19. Based on the state of art we did and inspired us to contribute in the army facing this virus. Python and Django were chosen to realize this application and this choice can be justified by saying that Python is number one in data science programming languages while also Django being very compatible with Python.
This environment supports the stability and the facility of the creation of an application that contains intelligent models coded using Python with Deep Learning libraries such as TensorFlow.

The version of the realized application can be used to classify a CT-scan chest image into Covid-19 or non Covid-19 with very good results, we can see an improvement in our model with a 97% accuracy on a very variant Dataset, a robust model to any image modification in the acquisition phase, using three different pre-trained architecture. Among them, InceptionV3 has shown the highest performance. In addition of the availability of visualizing the infected cases using Grad-Cam which helps the user understand better the reason of the decision taken by the classifier by highlighting the infected regions.

We learned so much things when building the application, new tools and programming language, taking us a step ahead towards the professional field and letting us genuinely manage our own project through several steps from analyzing to designing to coding.

A 3D reconstruction is absolutely a perspective in our presented work,with good results in classification and a web application, this possibility can enhance the quality of visualizing and controlling the infected cases and can be helpful to be used as a record to each patient during their infection in the purpose of helping doctors actually compare the stages of the virus invasion of the body with better monitoring and management.

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