Ollscoil Teicneolaíochta an Atlantaigh

Atlantic Technological University

COVID - 19 Automated Detection using Convolutional Neural Networks and Generative Adversarial Networks

A thesis submitted
by

Ultan Kearns

in partial fulfillment of the requirements for the degree of
Master of Science in Computing in Big Data Analytics and Artificial Intelligence

Supervisor: Dr Paul Greaney

Submitted to Quality and Qualifications Ireland (QQI)
Dearbhú Cáilíochta agus Cáilíochtaí Éireann
October 2022

Contents

Declaration **3**

Acknowledgements **4**

Acronyms **5**

List of Figures **6**

1 Introduction **1**

1.1 Generative Adversarial Network (GAN) 1
1.2 What is An Artificial Neural Network? (ANN) 2
1.3 What is A Convolutional Neural Network? (CNN) 3
1.4 Supervised Learning 4
1.5 Unsupervised Learning 4
1.6 Tensorflow 5
1.7 Keras 5
1.8 Background of Problem & Aims of This Paper 6
1.9 Datasets 8
1.10 About the datasets 8
1.10.1 COVID-19 Chest X-ray 8
1.10.2 COVID-19 Radiography Database 8
1.10.3 COVID-19 Pneumonia Normal Chest Xray PA Dataset 8
1.10.4 Use of datasets in This Project 9
1.11 Structure of This Thesis 9
1.11.1 Chapter 1 - Introduction 9
1.11.2 Chapter 2 - Literature Review 9
1.11.3 Chapter 3 - Implementation 10
1.11.4 Chapter 4 - Results 10
1.11.5 Chapter 5 - Further Research and Conclusions 10

2 Literature Review **11**
2.1 Introduction to Literature Review . . . 11
2.2 A Deep Learning-Based Diagnosis System for COVID-19 Detection and Pneumonia Screening Using CT Imaging . . . 11
2.2.1 Summary of Abstract . . . 11
2.2.2 Introduction of Paper . . . 12
2.2.3 Related Works . . . 13
2.2.4 Method . . . 13
2.2.5 Experimental Results . . . 13
2.2.6 Discussion . . . 13
2.2.7 Conclusions . . . 13
2.3 A combined deep CNN-LSTM network for the detection of novel coronavirus (COVID-19) using X-ray images . . . 13
2.3.1 Introduction . . . 14
2.3.2 Related Works . . . 14
2.3.3 Methods & Materials . . . 14
2.3.4 Experimental Results Analysis . . . 14
2.3.5 Discussions . . . 14
2.3.6 Conclusion . . . 14
2.4 Data Augmentation Using Generative Adversarial Networks . . . 14
2.4.1 Abstract . . . 14
2.4.2 Introduction . . . 14
2.4.3 Background . . . 14
2.4.4 Proposal & Experimental Design . . . 14
2.4.5 Results & Analysis . . . 14
2.4.6 Conclusions & Future Work . . . 14
2.5 Generative Adversarial Networks in Computer Vision: A Survey and Taxonomy 14

3 Implementation **15**
3.1 Libraries Used . . . 15
3.2 GAN Architectures . . . 15
3.3 CNN Design . . . 15

4 Results of Research **16**

5 Future Work and Research **17**

Declaration

I hereby certify that this material, which l now submit for assessment on the programme of study leading to the award of Master of Science in Computing in . . . , is entirely my own work and has not been taken from the work of others except and to the extent that such work has been cited and acknowledged within the text of my own work. No portion of the work contained in this thesis has been submitted in support of an application for another degree or qualification to this or any other institution. I understand that it is my responsibility to ensure that I have adhered to LYIT's rules and regulations.

I hereby certify that the material on which I have relied on for the purpose of my assessment is not deemed as personal data under the GDPR Regulations. Personal data is any data from living people that can be identified. Any personal data used for the purpose of my assessment has been psuedonymised and the data set and identifiers are not held by LYIT. Alternatively, personal data has been anonymised in line with the Data Protection Commissioners Guidelines on Anonymisation.

I give consent for my work to be held for the purposes of education assistance to future Computing students at LYIT and it will not be shared outside the Department of Computing at LYIT. I understand that my assessment may be shared with any other third party and will be held securely in LYIT in line with the Institute's Records Retention Policy.

Signed: Ultan Kearns

Date: Friday 21st October, 2022

Acknowledgements

I would first of all like to thank my supervisor during this project Dr. Paul Greaney, he was a fantastic help throughout the course of writing this thesis and this work could not have been completed without his input and help.

I would also like to thank the lecturers who taught me so much during my postgraduate course, both Doctors Karla Muñoz-Esqueival and Shagufta Henna provided a fantastic introduction into many areas of Artificial Intelligence and the knowledge they imparted has helped me a lot throughout the course of conducting this research.

I would also like to thank Andrew Ng, his deep learning courses provided a great foundation into the realm of deep learning and Artificial Intelligence.

Acronyms

- AI - Artificial Intelligence
- ANN - Artificial Neural Network
- CNN - Convolutional Neural Network
- GAN - Generative Adversarial Network

List of Figures

1.1 Basic Example of generative adversarial network 2
1.2 Basic Example of Artificial Neural Network 3
1.3 Graph of COVID-19 Statistics by age-range Ireland from October 2021 - December 2021 Courtesy of CSO[16] 6
1.4 Cumulative cases of the COVID-19 virus world-wide courtesy of Our World in Data[17] 7

Abstract

This paper aims to analyze the applications of Generative Adversarial Networks in overcoming issues of data-shortages in relation to COVID-19. There are many COVID-19 data-sets compiled but some suffer from lack of data-quality and data shortages[1][2]. In this paper I aim to create and train a convolutional neural network or CNNs to analyze X-Rays of patients lungs to automate the detection of COVID-19. The CNN will be trained with a number of images generated from different GAN architectures to determine which will prove most efficient in automating the detection of COVID-19. I also aim to use the GANs in conjunction with one and other to try out different combinations to see if feeding images generated by one GAN to other GANs will produce more accurate results when training the model.

Chapter 1

Introduction

1.1 Generative Adversarial Network (GAN)

A generative adversarial network or GAN for short first appeared in a 2014 paper by Ian Goodfellow et al[3]. In this paper Goodfellow et al propose a new way to generate data via an adversarial process. The GAN essentially works as follows: two models are trained, a generative model G which will generate the content from the data and another model D which will be the discriminator, judging if data created by the model came from the dataset rather than G. The goal of this training is to ensure data generated from G is realistic enough to fool the discriminator D into believing that the generated content came from the training set. It is in this way that we can create realistic "fake" data from the generative model.

There are a number of GAN architectures which are useful in different scenarios, such as CycleGans[4] which are useful for translating images from a source domain $X \rightarrow Y$ in which Y is the target domain, StyleGan which was created by NVIDIA which allows more control over the generative process[5] and PixelRNN which can recreate images when given a fraction of the original and can generate new images based on probability[6].

In this dissertation I will examine a number of different generative adversarial network architectures and will use them in conjunction with each other, by feeding content generated by one architecture into another to develop a more diverse training set for the final model.

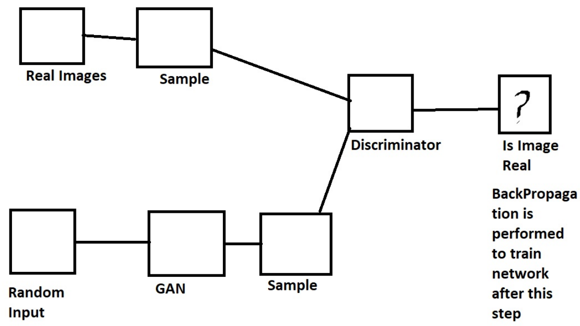

Figure 1.1: Basic Example of generative adversarial network

As we can see from the image above, we start the process by taking a sample of real images from the training data, then passing it to the discriminator. We also take a sample from the GAN created images and pass that to the discriminator which will then determine if the images are real are fake. After the discriminator determines if the image is real or fake then backpropagation is performed to train the model so that it can differentiate better between samples which came from the training set and those which came from G.

1.2 What is An Artificial Neural Network? (ANN)

An artificial neural network, or ANN for short, is a network of neurons or nodes which are used for training a model to perform a certain task. They are made up of an input layer, N hidden layers, and finally an output layer. Each layer has its own activation function, and will adjust its weights and biases to determine the final output of the model.[7] These networks are heavily inspired by biological processes which occur in the brain.
artificial neural networks are a general purpose model used to solve a number of common problems.

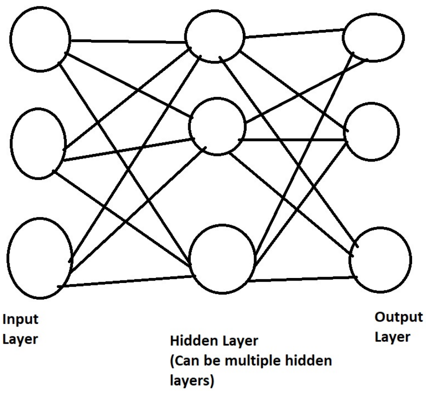

Figure 1.2: Basic Example of Artificial Neural Network

A basic example of an artificial neural network is shown in Figure 1.2. As shown in the figure, the network has an input layer, a hidden layer, and an output layer. Generally when creating these networks we determine the number of neurons in both the input and the output layers based on the different classifications we are trying to predict. The above network could be used to predict if an image is of a cat, a dog or a fish for example. There can multiple hidden layers in an ANN and the number of neurons in each layer can be adjusted. In reality Artificial Neural Networks will typically be far bigger than the example given above in terms of neurons and hidden layers but for illustrative purposes the above diagram will suffice. Each neuron will also have its own weights, biases and activation function which will determine whether a neuron fires or not. Common activation functions include ReLU (Rectified Linear Units), Sigmoidal function and tanh.

1.3 What is A Convolutional Neural Network? (CNN)

A convolutional neural network, or CNN for short, is a type of neural network which is primarily used for tasks involving image and pattern recognition[7] The structure is similar to an ANN in which we have an input layer, N hidden layers, and finally an output layer. As with the Artificial Neural Network each of these layers will have an activation function and it's own weights and biases to determine the final output for a given input. The model will take an image as input, the image is made up of vectors (RGB) or a similar format and from that image the model will determine certain patterns. For example, the output might be a classification of whether or not Covid-19 is present or not. This application will be discussed in more detail later in the dissertation.
There are a few ways in which CNNs differ from ANNs, in that they are comprised of three types of layers which are the convolutional layer, the pooling layer and fully connected lay-

ers[7]. The convolutional layer is responsible for determining the output of a given input (for example if we were trying to detect images of cats then this layer would activate 1 for a cat and 0 for images which were not cats), the pooling layer will reduce the parameters of a given input by means of downsampling, and finally the fully connected layers will then determine and classify the output for a given input. The convolutional layers parameters utilize learnable kernels, and this layer also produces a $2D$ activation map which will be used to determine if a neuron fires or not for a given input. We can adjust hyper parameters in the convolutional layer to greatly reduce the complexity of the model through optimization, which can be achieved by adjusting the following hyper parameters: depth, stride and zero padding.

Depth is related to the output volume produced by the convolutional layers in the model which can be manually set by adjusting the number of neurons in each layer. Reducing the depth of the model can greatly decrease the training time but at the expense of performance. Stride is related to the spatial dimensionality of the input which will determine the receptive field (every neuron is connected only to a small region of the input this region is referred to as the receptive field[7]), if the stride is set to a low integer we will produce extremely large activations, and if it is set too high we won't produce enough activations.

Finally, zero-padding this will pad the border of the images ingested by the model reducing their dimensionality, padding is useful for increasing the accuracy of the model as it can possibly eliminate areas of the image which are not useful for the model and can also improve training time times in some use cases.[8]

Through the adjustment of the hyper parameters mentioned above, and through the utilization of different activation functions, the accuracy of the convolutional neural network can be improved through a process of trial and error.

1.4 Supervised Learning

Supervised learning is a type of learning involving labelled data to train the model[9]. The data is labelled manually by a data scientist which can be a long and laborious process depending on a number of factors (size of the data, number of classes, etc.), but offers many benefits when it comes to training models. Supervised learning performs extremely well at tasks involving classification (classifying data into a given category), and regression (understanding the relationships between independent and dependent variables).

1.5 Unsupervised Learning

Unsupervised learning is a type of machine learning which involves using unlabelled data to train machine learning models[9]. This type of machine learning requires no human interven-

tion since the data is unlabelled and will detect relationships between data based on the raw data fed in to the model. This type of machine learning is used for the following tasks: clustering(grouping data together based on shared characteristics or features), association(Finding relationships between features), and dimensionality reduction (Reducing the number of features in a given dataset without compromising the integrity of said data). The key differences between supervised and unsupervised learning are: labelled vs unlabelled datasets, and finding relationships in data (unsupervised) or trying to predict and classify data (supervised).
In this dissertation we examine the use of both labelled and unlabelled datasets to train and test the model.

1.6 Tensorflow

Tensorflow is an open-source library used for machine-learning and artificial intelligence research worldwide[10]. Tensorflow provides numerous modules and classes which form the foundation of building both the generative adversarial network and the convolutional neural network. There have been numerous case studies proving the efficacy of Tensorflow in solving many AI / ML problems and the library is used by research teams in organisations such as Google, Airbnb, ARM, Coca-Cola, Intel, and many more[11].
Given the reputation and widespread use of Tensorflow, and the vast amount of documentation around the framework it seems an ideal library for the implementation of GANs and CNNs for this study.

1.7 Keras

Keras is a deep-learning framework for Python which provides a number of helpful functions and methods for creating and training the CNN[12]. Keras is built on top of Tensorflow and simplifies data loading, pre-processing and the overall building of the model. Keras is commonly used by data-scientists and researchers due to the powerful methods it offers and the time it saves. The additional classes and modules Keras provides on top of Tensorflow will help to reduce the time taken to build and develop of building both the convolutional neural network and the generative adversarial network.
Like Tensorflow, Keras has been used by a number of companies and is well recognised in the Artificial Intelligence community. Its uses include Computer Vision, Natural Language Processing, Generative Deep-Learning and Reinforcement Learning amongst others[13].

1.8 Background of Problem & Aims of This Paper

COVID-19 is a highly transmissible virus which has caused a worldwide pandemic and has claimed many lives. There have been 616,951,418 cases worldwide and 6,530,281 deaths as of the 4th of October 2022[14]. During the pandemic, Ireland alone had a total of over 1.6 million confirmed cases and nearly 8,000 deaths[15]. This has led many researchers to pursue the goal of automating the detection of COVID-19 to partially relieve the immense pressure put on medical staff throughout the pandemic.

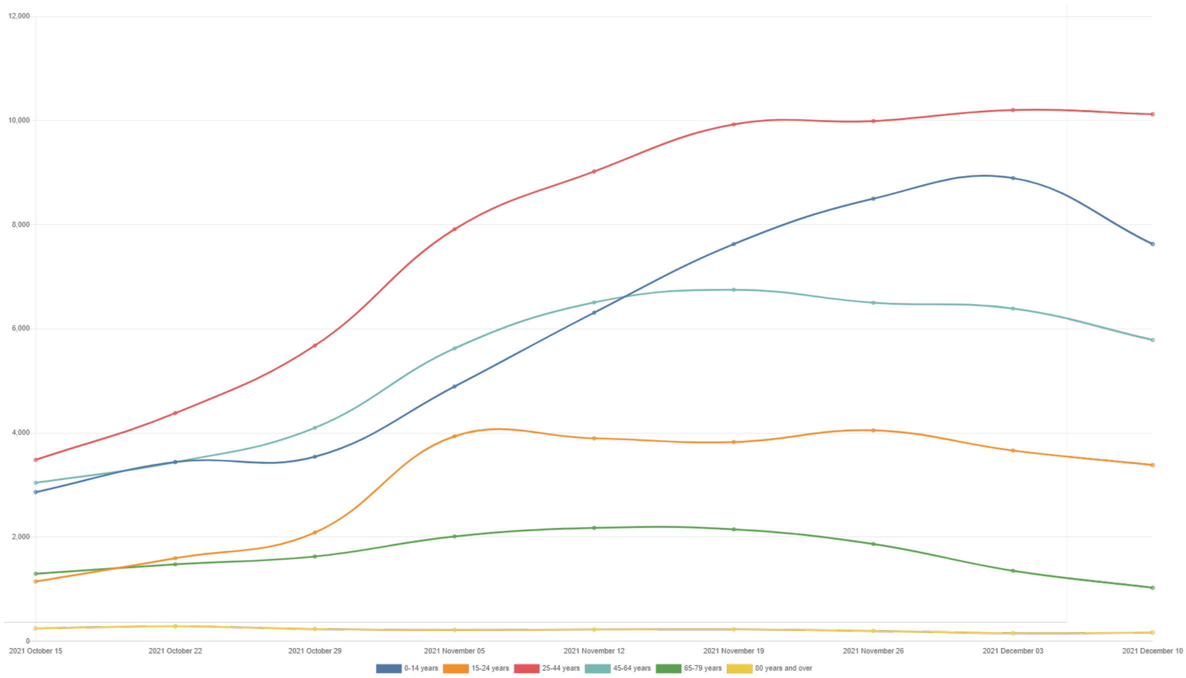

Figure 1.3: Graph of COVID-19 Statistics by age-range Ireland from October 2021 - December 2021 Courtesy of CSO[16]

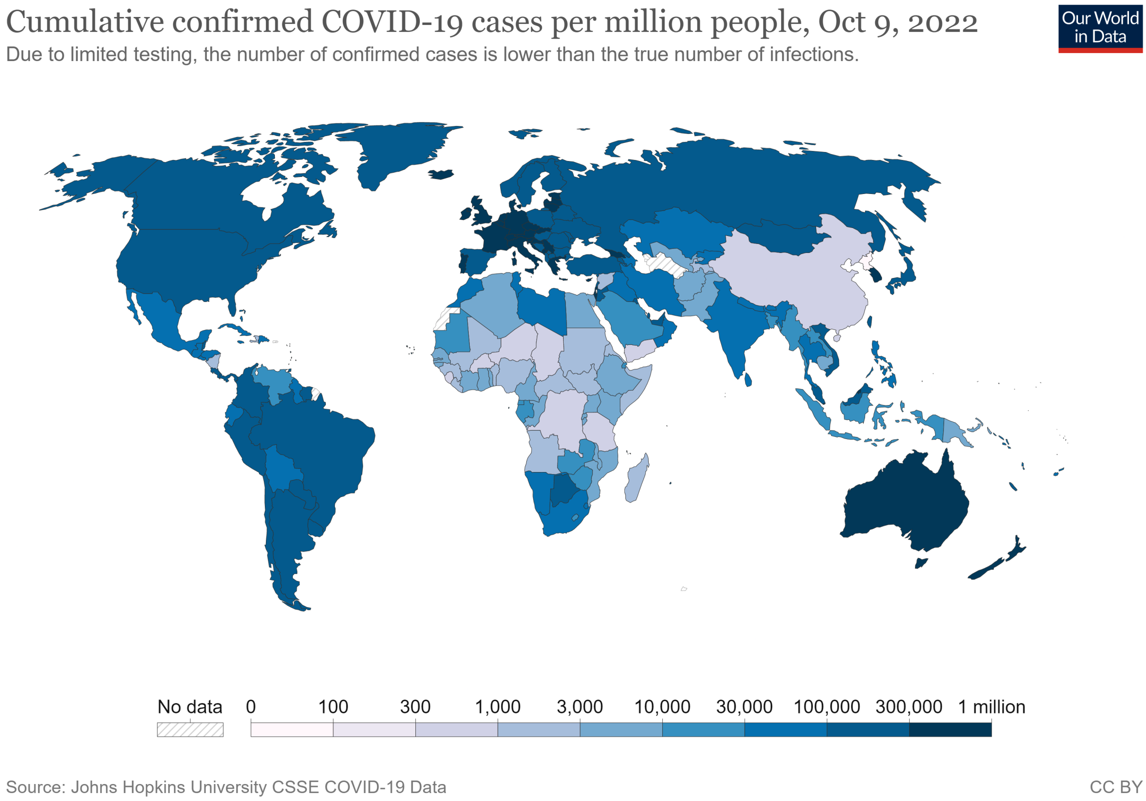

Figure 1.4: Cumulative cases of the COVID-19 virus world-wide courtesy of Our World in Data[17]

The main objective of this research is to develop a robust model which can accurately analyze X-Rays of patients and determine from said X-rays if the patient is afflicted with COVID-19. This will be achieved by utilizing a number of different GAN architectures which will create realistic "fake" data which will then be used to train a number of models. From this training I plan to compare and contrast the results when generating data with different architectures to determine the best configuration for data generation to train the CNN model. There has been some success in utilizing convolutional neural networks to automate the detection of the virus[18][19]. Through the use of data-augmentation utilizing a variety of GAN architectures that such Convolutional Models will be improved upon and made more accurate.

I plan on utilizing existing data sets which I will list in the next section when training the Generative Adversarial Models, through trial and error I plan on determining the best architecture of GANs to use for training the model for this use-case.

1.9 Datasets

1.10 About the datasets

Before beginning the training of the model it is important to explore and understand each of the datasets. There are a total of three datasets which will be used in the course of this research, I will explain more about these datasets below.

1.10.1 COVID-19 Chest X-ray

The COVID-19 Chest X-ray data set is a data set which is comprised of labelled X-Ray Images taken from a number of patients. This dataset contains 357 X-ray images of COVID positive patients, and Chest X-Rays of those afflicted with another disease (MERS, SARS, and ARDS). This dataset also includes a metadata file listing the diagnosis of the patient along with a number of other features.

1.10.2 COVID-19 Radiography Database

The COVID-19 Radiography Database is made up of 3,616 images of chest X-Rays taken from COVID positive patients, 10,192 Images of lung X-Rays taken from healthy patients, and 1,345 X-ray images of viral pneumonia positive patients. All images in this dataset are PNG (Portable Network Graphic) images and are at a resolution of height 299 pixels and width 299 pixels eliminating the need for pre processing of the images, the dataset also includes metadata for each of the images in this dataset showing a number of features with the diagnosis of the patient as well. This data in this dataset was gathered by a team of researchers from Qatar University, Doha, Qatar, and the University of Dhaka, Bangladesh along with their collaborators from Pakistan and Malaysia.

1.10.3 COVID-19 Pneumonia Normal Chest Xray PA Dataset

The COVID-19 Pneumonia Normal Chest X-Ray PA dataset is comprised of a train set containing 74 Normal X-Ray Images taken from healthy Patients and afflicted with Pneumonia and a test-set containing a Normal set containing 20 chest X-Rays taken from healthy patients and a Pneumonia set containing 20 images. The images in this dataset are unlabelled and no metadata is offered, however the images are segregated into separate files listing the diagnosis.

1.10.4 Use of datasets in This Project

I plan to use each of these datasets to train and test the model and use data-augmentation to increase the train and test-sets by utilizing Generalized Adversarial Networks. When using these datasets in conjunction it is my hope that the GAN will have enough data to be effective when generating new sample images to train the final model.

1.11 Structure of This Thesis

This thesis is broken into 6 chapters in total, this section will include the headings of the chapters and a brief summary of each chapter below:

1.11.1 Chapter 1 - Introduction

This chapter will offer the reader of this thesis a brief introduction to a number of core concepts which will be necessary to understand before diving deeper into this thesis. It is important that the reader has a basic understanding of generative adversarial networks, convolutional neural networks, artificial neural networks, supervised & unsupervised learning, and the overall question that this research proposes before discussing the implementation or discussing pertinent literature in this field.
In this section I will frame the research question, explain what a generative adversarial network is, it's function, and how it works, I will also explain artificial neural networks and convolutional neural networks, and I will discuss the basic methodologies relating to the implementation of this project. I will also discuss the libraries used to implement the practical artifact, datasets used to train the model and give the reader of this thesis a clear understanding of the key aims of this research.

1.11.2 Chapter 2 - Literature Review

In this section I will review pertinent literature related to the problem domain and discuss the ideas and concepts presented in these papers. I will also review the results from the research conducted in these papers and use them as a metric to gauge the performance of my own model. The papers will also be compared and contrasted and I will discuss the findings and how useful these papers were when conducting my own research. It is very important to understand the problem domain before beginning implementation of this project to ensure that I am not "reinventing the wheel". This section will also provide the reader of this thesis with the most up-to-date progress made within the problem domain.

1.11.3 Chapter 3 - Implementation

In this section I will discuss the architecture of the convolutional model, the various architectures of generative adversarial networks implemented, how the models were trained and the overall design of the code implemented and the rationale behind certain design choices. I will also show the results from training the models and discuss how through trial and error I was able to improve the various models and will include code samples so that the models can be reviewed by the reader or re-implemented by them.

1.11.4 Chapter 4 - Results

In this section I will review the results achieved from training the best models and suggest how they may possibly be improved. I will be showing lots of graphs / tables in this section to gauge each model's test / dev set errors and I will also be comparing and contrasting the effects of the different GAN architectures implemented as well as discussing the results of the convolutional model.

1.11.5 Chapter 5 - Further Research and Conclusions

In this section I will discuss further research that may need to be done by any researchers who would like to build upon this research. I will also review where the models could be improved and what I'd do differently if I were to conduct this research again. I will also discuss common issues I faced during the implementation of this project and how I overcame them. This section will be a summary of all the research conducted, the code, and my experience overall throughout the writing of this thesis.
This will be the final section of the paper and will tie the entire thesis together.

Chapter 2

Literature Review

2.1 Introduction to Literature Review

In this section I will be examining papers related to the problem domain and reviewing their findings and research methodologies. This section will cover a number of papers by various researchers to offer a better understanding of the problem domain and recent progress made in Convolutional Neural Networks and Generative Adversarial Networks for classification problems and data-augmentation respectively.

2.2 A Deep Learning-Based Diagnosis System for COVID-19 Detection and Pneumonia Screening Using CT Imaging

[20]

2.2.1 Summary of Abstract

This paper begins with an abstract detailing the rationale for this research and explaining the drastic effects of the COVID-19 pandemic, the abstract also contains a methodology and results section. This paper aims to develop an automated detection tool and a diagnostic system utilizing deep-learning to accurately detect and diagnose COVID-19 in afflicted patients. The researchers also use Contrast Limited Adaptive Histogram Equalization for pre-processing the images, this method is used to reduce and remove noise therefore increasing the homogenity of the data and the accuracy of the model. They also discuss how black slices were removed so that only the lungs remained in the images and the U-Net architecture behind the Convolutional Neural Network. The U-net architecture is used to provide a fast and precise image segmentation to crop out regions of interest from the data. The researchers also utilized four-fold cross-validation as a resampling procedure and a three layered CNN architecture with additional fully connected layers they also used Softmax activation function for determining

the output for a given input. The researchers end the abstract by listing the results, 20CT scans with a train / test split of 0.7 for the training set and 0.3 for the test set experimental results had achieved 0.98% dice score and a 0.98% for classification tasks.
There may have been possible over-fitting of the model occurring in this research due to a lack of a dev set to test on and the researchers do mention use of a reduced data-set. We will explore more of this paper to see if this was a limitation present in the research.

2.2.2 Introduction of Paper

The paper starts with detailing the global health crisis caused by the COVID-19 virus and it's exponential spread across the globe. The researchers also discuss how this virus was the biggest threat towards humanity during it's peak. They then go on to discuss the statistics as of April 5th 2021 there were 131,309,792 worldwide cases of COVID-19 and 2,854,276 deaths with a mortality rate exceeding 2% as declared by the World Health Orgranization(it has since risen dramatically[14]). The researchers go on to explain the need for accurate and rapid testing to reduce the spread of the virus and the lack of tests available during the time in which the paper was written.
After explaining the uses of RT-PCR tests and their shortage, the researchers discuss the use of X-rays and CT scans to detect and diagnose COVID-19 in patients. This is their rationale behind using Artificial Intelligence to automatically detect the virus in patients. They explain how deep learning technologies and Convolutional Neural Networks in particular would prove useful in automating the diagnosis of COVID-19 from X-Ray images and CT Scans. They discuss how CNNs are already used in medical image processing and have shown promise in automating and diagnosing many diseases such as cancer. The researchers then go on to explain that the previous achievements of CNNs in detecting and diagnosing other diseases show that they could achieve the same results when detecting and classifying COVID-19 in patients. They discuss how the CNNs could detect abnormal features and regions of interest through the process of deep-learning. They then go on to discuss the model trained to diagnosis covid in this research was trained using CT images extracted from a public dataset and go on to explain that in order to train a robus and accurate model they would need sufficient annotated medical imaging data, and explain how there is a data-shortage in the publicly available model. They discuss how data-shortages are caused by costly labelling and privacy restrictions and that combing data-sets collected under different labelling regimes may prove problematic to their research. The framework developed focuses on obtaining good performance for the system's components.

2.2.3 Related Works

In this section the authors examine related works concerning the same problem domain. They discuss how medical imagining processing techniques have been applied to monitor several diseases. Many researchers have proposed methodologies for the detection and segmentation of images of a patients lungs using the chest X-Rays and CT-Scans. Through researching other papers the authors of this paper have found that "a carefully designed image examination procedure plays a vital role in reducing the diagnostic burden" - this can be taken to mean that through the use of pre-processing of the images the diagnosis will become clearer. The researchers propose three categories of methods:

- Classification techniques
- Infected regions and segmentation techniques
- & diagnosis systems that work on both tasks.

They also include a table which details a summary of recently published studies on COVID-19 at the time.

2.2.4 Method

2.2.5 Experimental Results

2.2.6 Discussion

2.2.7 Conclusions

2.3 A combined deep CNN-LSTM network for the detection of novel coronavirus (COVID-19) using X-ray images

[21]

2.3.1 Introduction

2.3.2 Related Works

2.3.3 Methods & Materials

2.3.4 Experimental Results Analysis

2.3.5 Discussions

2.3.6 Conclusion

2.4 Data Augmentation Using Generative Adversarial Networks

[22]

2.4.1 Abstract

2.4.2 Introduction

2.4.3 Background

2.4.4 Proposal & Experimental Design

2.4.5 Results & Analysis

2.4.6 Conclusions & Future Work

2.5 Generative Adversarial Networks in Computer Vision: A Survey and Taxonomy

[23]

Chapter 3

Implementation

3.1 Libraries Used

3.2 GAN Architectures

3.3 CNN Design

Chapter 4

Results of Research

Chapter 5

Future Work and Research

Bibliography

[1] A. Binkheder *et al.*, "Covid-19 data explorer," [Online]. Available: `https://www.ncbi.nlm.nih.gov/pmc/articles/PMC8701465/`.

[2] S. Maior *et al.*, "Convolutional neural network model based on radiological images to support covid-19 diagnosis: Evaluating database biases," [Online]. Available: `https://journals.plos.org/plosone/article?id=10.1371/journal.pone.0247839#sec025/`.

[3] A. Goodfellow *et al.*, "Generative adversarial nets," 2014. [Online]. Available: `https://arxiv.org/pdf/1406.2661.pdf`.

[4] P. Zhu *et al.*, "Unpaired image-to-image translation using cycle-consistent adversarial networks," 2020. [Online]. Available: `https://arxiv.org/pdf/1703.10593.pdf`.

[5] A. Karras Laine, "A style-based generator architecture for generative adversarial networks," 2019. [Online]. Available: `https://arxiv.org/pdf/1812.04948.pdf`.

[6] K. Oord Kalchbrenner, "Pixel recurrent neural networks," 2016. [Online]. Available: `https://arxiv.org/pdf/1601.06759.pdf`.

[7] K. O'Shea and R. Nash, "An introduction to convolutional neural networks," [Online]. Available: `https://arxiv.org/pdf/1511.08458.pdf`.

[8] M. Hashemi, "Enlarging smaller images before inputting into convolutional neural network: Zero-padding vs. interpolation," [Online]. Available: `https://journalofbigdata.springeropen.com/articles/10.1186/s40537-019-0263-7`.

[9] J. Delua, "Supervised vs. unsupervised learning: What's the difference?," [Online]. Available: `https://www.ibm.com/cloud/blog/supervised-vs-unsupervised-learning`.

[10] Multiple, "Tensorflow," [Online]. Available: `https://www.tensorflow.org/`.

[11] Multiple, "Tensorflow case studies," [Online]. Available: `https://www.tensorflow.org/about/case-studies/`.

[12] Multiple, "Keras," [Online]. Available: `https://keras.io/`.

[13] Multiple, "Keras examples," [Online]. Available: `https://keras.io/examples/`.

[14] Multiple, "Who coronavirus (covid-19) dashboard," [Online]. Available: `https://covid19.who.int/`.

[15] Multiple, "Who coronavirus (covid-19) dashboard ireland," [Online]. Available: `https://covid19.who.int/region/euro/country/ie/`.

[16] Multiple, "Covid-19 deaths and cases statistics," [Online]. Available: `https://www.cso.ie/en/releasesandpublications/ep/p-covid19/covid-19informationhub/health/covid-19deathsandcasesstatistics/`.

[17] O. W. I. Data(multiple), "Covid-19 data explorer," [Online]. Available: `https://ourworldindata.org/explorers/coronavirus-data-explorer?tab=map&facet=none&Metric=Confirmed+cases&Interval=Cumulative&Relative+to+Population=true&Color+by+test+positivity=false&country=USA~ITA~CAN~DEU~GBR~FRA~JPN`.

[18] a. o. Ahmed Wang, "Automated detection of covid-19 through convolutional neural network using chest x-ray images," [Online]. Available: `https://journals.plos.org/plosone/article?id=10.1371/journal.pone.0262052/`.

[19] C. E. Belman-López, "Detection of covid-19 and other pneumonia cases using convolutional neural networks and x-ray images," [Online]. Available: `http://www.scielo.org.co/scielo.php?script=sci_arttext&pid=S0120-56092022000100108/`.

[20] B. Mahmoudi *et al.*, "A deep learning-based diagnosis system for covid-19 detection and pneumonia screening using ct imaging," [Online]. Available: `https://www.mdpi.com/2076-3417/12/10/4825/`.

[21] I. Islam and Asraf, "A combined deep cnn-lstm network for the detection of novel coronavirus (covid-19) using x-ray images," [Online]. Available: `https://www.sciencedirect.com/science/article/pii/S2352914820305621`.

[22] Tanaka and Aranha, "Data augmentation using gans," [Online]. Available: `https://arxiv.org/pdf/1904.09135.pdf/`.

[23] S. Whang and ward, "Generative adversarial networks in computer vision: A survey and taxonomy," [Online]. Available: `https://arxiv.org/pdf/1906.01529.pdf`.