Healthcare Applications of Convolutional Neural Networks

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Contents

1 Report

1.1 Introduction

Healthcare will always be an essential aspect of society. If the healthcare systems of a society are not adequate, this will affect the well-being of its individuals. Therefore, monitoring the effectiveness of healthcare services and deploying new technology, including tools for diagnosis and treatments, is important for achieving efficient healthcare. Reports suggest that the traditional way of examining patients in radiology is inefficient in meeting the increased demand for medical imaging. The increased demand in radiology is affecting the performance of healthcare services, declining the accessibility of services, lowering the quality of benefits, and potentially compromising safety. Therefore, innovating new systems and technology is required to help healthcare systems cope. Meanwhile, medical imaging is necessary for diagnosing patients, and the use of deep convolutional neural networks (CNNs) for image recognition in medical imaging has received a lot of attention over the last decade. CNN is also used for image-based tasks for fields such as dermatology, pathology and ophthalmology (Hosny *et al.*, 2018). This report summarise the important features of CNNs in radiology, presents current challenges, provides a clear understanding of CNN and its development, and discusses the potential benefits and concerns of implementing CNN. Finally, we will look at how researchers are still working on expanding the use of CNNs in different settings.

1.2 Current Challenges in Radiology

Reports indicate an increasing number of medical imaging requests and a shortage of radiologists. As a result, this has increased the workload for radiologists, with some reporting finding it difficult to finish their daily workload. Studies estimate that radiologists interpret an image every three to four seconds to complete their daily workload. As a result, patients

are waiting a long time for an appointment. In some cases, patients need immediate treatment and waiting may increase their risk for developing poor health outcomes. However, it is challenging for radiologists to perform their jobs to the best of their abilities when they are consistently under pressure to their high workload, which increases their risk of making an error in interpretation. In addition, some tumours are difficult to identify, and detecting subtle abnormalities can be time-consuming, particularly in difficult cases when other expert opinions need to be sought. Mistakes will harm the individuals, especially if tumours are missed (Hosny *et al.*, 2018).

1.2.1 How Can CNNs Become Part of Routine Practice in Radiology?

CNNs were designed to carry out medical tasks that humans can usually do but with more efficiency and accuracy. CNN is popular for image recognition and classification, and is also used for image-based tasks in other medical disciplines such as cardiology and dermatology. CNN is an artificial intelligence (AI) algorithm used for deep learning. It is known for its ability to solve problems and make sense out of nonlinear and complex data without human supervision.CNN is inspired by the natural visual perception in living creatures and can recognise visual patterns from raw pixels with minimal training datasets. CNNs have been used successfully to help radiologists interpret complex medical imaging (Hosny *et al.*, 2018). For example, CNN has been used to detect early abnormalities associated with breast cancer, classify diseases of the lungs, and classify the stage of cancer invasion or spread. Furthermore, CNN has been used to help with image segmentation for some tumours (e.g. in the liver and brain), which reduces noise while at the same time highlights crucial parts (e.g. important organs) (Chartrand *et al.*, 2017; Yamashita *et al.*, 2018).

1.2.2 Current State of CNNs in Radiology

Currently, CNN solutions in radiology are designed for hospitals and tertiary care settings, and the users are predominantly clinicians (Hosny *et al.*, 2018). Studies have shown that

diagnosis and screening are the two most frequent uses for AI solutions in the healthcare industry, and radiology appears to be the most active area for AI technologies within healthcare (NHSX, 2019). Lately, CNN has become part of the radiologist's daily routine, which has caused trepidation by radiologists for fear of being replaced by machines (Hosny *et al.*, 2018). This has affected the number of physicians applying to specialise in radiology higher education. However, CNN is deployed to support the decisions made by radiologists, not replace them, and radiologists would be needed to monitor system performance. Furthermore, radiologists should understand how the system works to avoid any misuse such as over-diagnosis, because CNN has high sensitivity in detecting studies shows approximately 30% of people were diagnosed with asthma where they actually not and identify issues soon as they appear. Overall, radiologists' understanding of CNN will determine success because they will be able to trust it and explain to their patients the decision process (Guo and Li, 2018) Furthermore, it may affect the patients' trust in the radiologist. Introducing AI technologies to healthcare is a responsibility towards improving the health of our society. In general, the Food and Drug Administration (FDA) found people main concerns about entering any AI technology were about the credibility of these systems, privacy of their data and interaction with machines instead of humans. Some studies have found that the adoption of AI was more likely to be supported by adults with higher education (FDA, 2021).

1.2.3 The History of CNNs

In the 1960s, Hubel and Wiesel discovered that simple cells in the visual cortex of cats were moving in a hierarchical mechanism collecting data, while complex cells were processing this data from the simpler cells, based on this finding they presented the "receptive field" concept. In 1980, neurocognition was introduced for a network in a hierarchical structure with neurons and local connectivity, and both concepts were used for developing CNN initially. At its inception, CNN was developed for handwritten digit recognition. Later, LeCunn introduced "LeNet-5" and speculated that it could be used for other image recognition tasks

due to its high performance. However, the number of layers and graphical processing unit (GPU) limited the network, impaired researchers interest as a result. After that, Hinton et al. introduced multiple hidden layers in the network that excelled the learning feature. Later, Krizhevsky presented a CNN model called "AlexNet" at an image classification competition called the ImageNet Large Scale Visual Recognition Challenge in 2012 and achieved a top-5 with error rate of 15.3% in the test. Research into the field of CNN gained popularity after a review article published by LeCun shed new light on the basic principles of CNN and the need for deep learning. Subsequently, many CNNs were introduced, such as
Visual geometry group and GoogleNet, foused on increasing the depth and width of the network to enhance the performance with complex images that have many features, by splitting the image into small patches and identify every feature alone. Then, ResNets introduced identity mapping for more effective optimizing features in layers and avoid bottlenecks. Finally, DenseNet has demonstrated the benefit of building short paths from previous layers to the next layers to send information in the network (Wang *et al.*, 2019).

1.2.4 What are the Major Opportunities and Challenges Ahead?

The growth of medical images combined with GPUs development has contributed to the CNN development. Researchers improved the GPUs performance by parallelising training across multiple GPUs to minimise the time consumption for data processing(Chartrand *et al.*, 2017). Radiology supported CNN more than other fields for two main reasons; their main task is to analyse medical images that are most likely in digital format, so there will be available datasets to train CNN. Moreover, CNN can interpret images and identify and detect tumours from different body parts such as lungs and breasts (NHSX, 2019). CNN can mimic the human brain in learning and solving problems by using a sequence of functions enable it to make decisions, making the network evaluate better than radiologists (Wang *et al.*, 2019). Radiologists using CNN have been able to speed up the diagnostic process with higher accuracy and confidence than the Radiologists not using it (Guo and Li, 2018), reduce waiting times for pa-

tients to access services, and lower the risks that develop because of the late treatment and immediate treatment is needed, and may not be able to treat it anymore like cancer (Hosny *et al.*, 2018) However, new technologies will lead to new uncertainties, and there many challenges affecting CNN such as: 1. The interpretability of CNN; how the decision is decided inside the network. Researchers are still examining new methods to solve this issue which has caused distrust in this system (Chartrand *et al.*, 2017). 2. Shortage of labelled datasets for training purposes and high financial costs of finding experts to interpret images for an accurate diagnosis (Chartrand *et al.*, 2017). 3. Network overfitting due to the limitation of datasets and privacy concerns. Overfitting appears when the model learns all the dataset's noise and can no longer be used for other datasets (Chartrand *et al.*, 2017). 4. The system's design must be intuitive, and all health workers can use it to avoid distracting clinicians with complicated intreface(Guo and Li, 2018).

1.2.5 How do CNNs Work?

Developers use software frameworks to build and train neural networks such as (TensorFlow). CNN is artificial neural network connected by weighted neurons. The weight of each neuron is calculated using a non-linear activation function. This is akin to the biological neuron Chartrand *et al.* (2017).

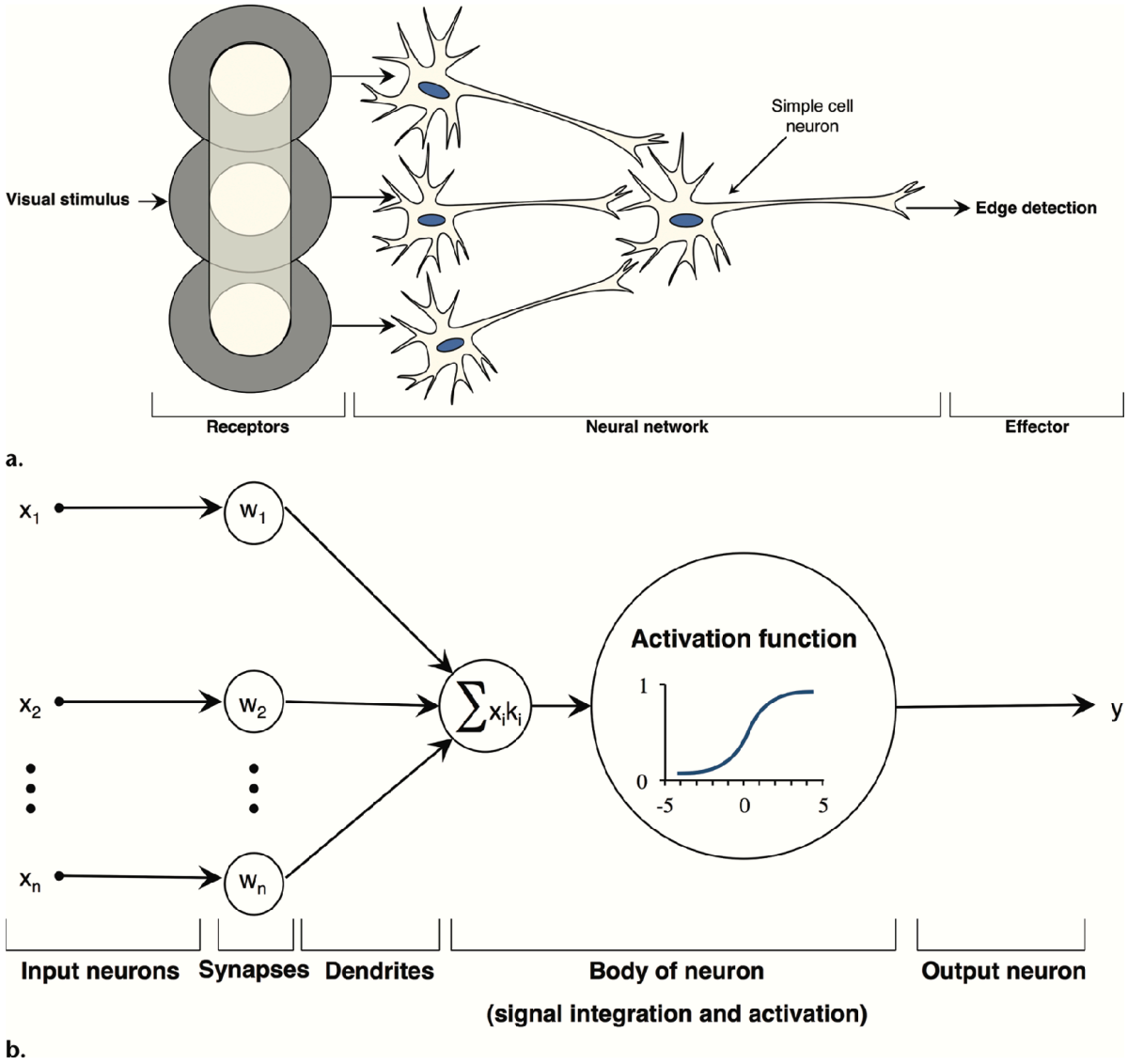

Figure 1: Biological neurons and artificial neuron(Chartrand *et al.*, 2017).

CNN consists of convolutional layers, subsampling or pooling layers, and fully connected layers. The convolution layer based on kernels. These kernels move across the image processing it small section at a time. Each kernel is responsible for calculating the weight of a specific feature. Usually the dimension of a kernel is 3×3. The kernel's output will be stored in feature maps (Chartrand *et al.*, 2017) (Figure 2). The rectified linear unit (ReLU), which is the most used activation function, is applied to these maps to select the features given for the

next layer (Figure 3).

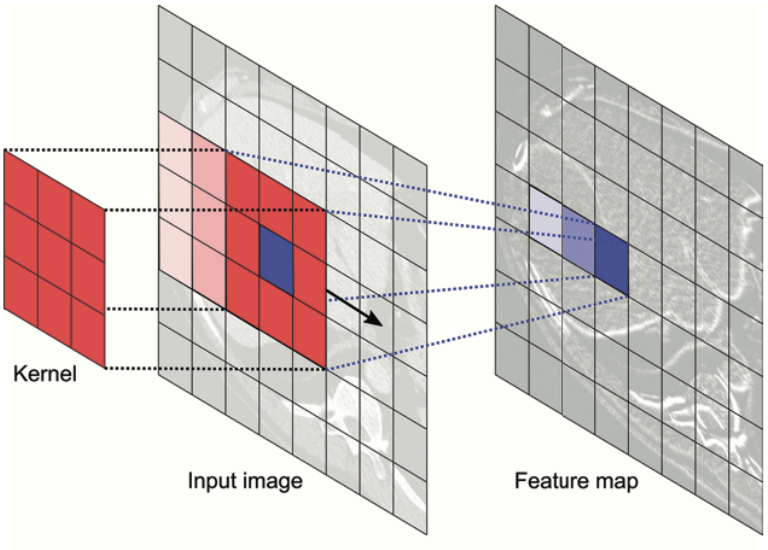

Figure 2: Kernels extracting features from the image (Chartrand *et al.*, 2017).

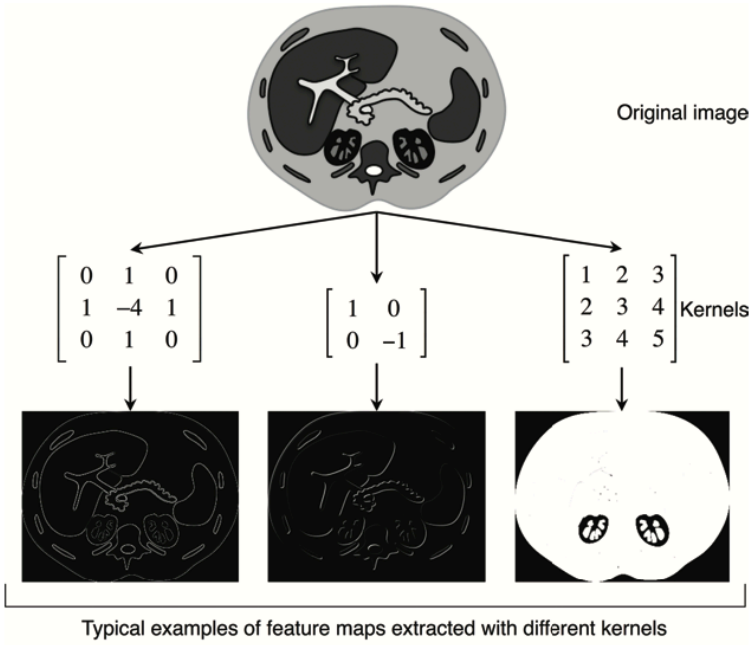

Figure 3: Example of convolution operation on an image (Chartrand *et al.*, 2017).

The pooling layer applies the max-pooling function to downsize the feature maps. By mini-

mizing the resolution of each feature map to a 2×2 dimension. Basically, the function takes the features' maximum values to keep the important features only. Later, in the fully connected layer features will be transferred into a one-dimensional array and connected with previous layers. Finally, the softmax function will calculate the features' probability. Based on these probabilities, the network classifies the image (Chartrand *et al.*, 2017) (Figure 4).

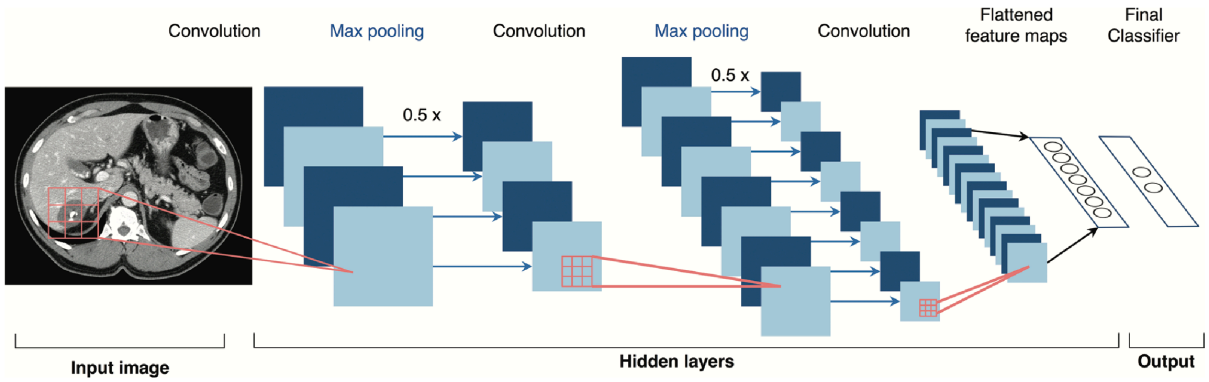

Figure 4: Convolutional neural network (Chartrand *et al.*, 2017).

The network learns when it is trained with a data set and apply the loss function to calculate the difference between the network results and the actual results, it takes the differences to learn and fix the decision parameters, parameters are fixed with gradient descent algorithm, these steps are repeated till we achieve the minimum amount of loss (Figure 5) (Chartrand *et al.*, 2017).

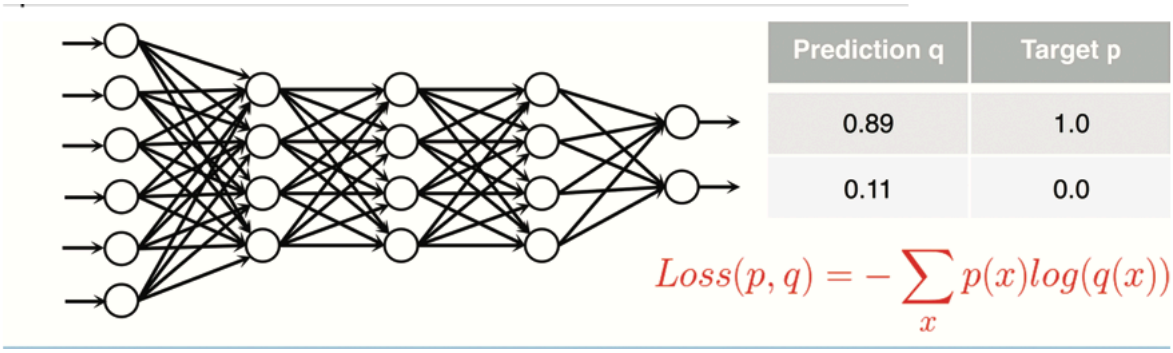

Figure 5: Parameters adjusted with the loss function (Chartrand *et al.*, 2017).

1.3 Measuring the success and impact of CNN

The metrics that used to assess CNN performance are based on the task they are performing: - The Accuracy for Image classification: measured by comparing predicted results with actual results, then we take the top 5 results. *Application:* The task is classifying labels, it achieved the top five accuracy between 61%–66% and 93%–95%. - The Dice score for images segmentation tasks, where CNN needs to detect many objects in the image, comparing the network results and the actual results, taking one score for matched one and zero if not. *Application* The task is segmenting liver from a tumour (from 100 CT scans), the dice scored 94%, and in prostate segmentation (from 50 MR images) the dice scores were between 81% and 87%. - The Receiver operating characteristic (ROC) curve for disease detection, it measure the sensitivity of the network known as precision or F-score *Application:* The task is detecting malignant lesions from mammographic images, the area under the ROC curve was 0.93 compared to three radiologists they achieved 0.84 and 0.88, which indicates that CNN has better sensitivities but lower specificities than radiologist (Chartrand *et al.*, 2017).

Integrating computer science with the medical sciences will lead to huge transformation and impressive innovation that will improve the qualify of healthcare industry. CNN have been a great example for solving healthcare services issues. A study demonstrated that the diagnosis error rate in the United States is around 12 million adults per year (Guo and Li, 2018). Another study reported that CNN enhanced the quality of diagnosis and reduced the false-negative rate of pathologists by 25% (Guo and Li, 2018). CNN supported diagnostic precision by using previous data about patients to advance their treating plans and monitor their disease. By this application, scientists can develop significant knowledge about rare diseases (NHSX, 2019). CNN has also been successful in early diagnosis for some diseases such as cancer, and monitoring genetic mutation so it can predict if the person have chance to have a disease in the future, so patients will be able to follow some recommendation from the doctor to minimise the chance of developing the disease, if applicable. CNN classifying feature was able to detect the disease stage such as cancer stages, to provide the patient with a treat-

ment depends in the disease level. These CNN features has helped with increasing individuals' survival rate (NHSX, 2019). Some abnormalities are hard to be identified by eye and may need many expert's opinion, CNN has diagnosed these abnormalities quickly and helped the radiologist to recognize it so the radiologist can request more information about the patient or further tests to ensure the results (NHSX, 2019). As a result, society will be provided with better diagnoses (Hosny *et al.*, 2018). According to recent survey, we have 300 applications of deep learning methods developed for medical images (Chartrand *et al.*, 2017). Using these methods have advanced the health services by 63% with a faster diagnosis and treatment by 79% and 63% (NHSX, 2019). Developing countries have also benefited from CNN where quality health care is not accessible (Guo and Li, 2018).

1.4 Legal, Ethical and Professional Issues

Despite the power of CNN in solving healthcare problems, many issues and concerns were raised with the deployment process, such as: 1. The network's interpretability caused people to never fully trust this system. Researchers still do not understand how these "black boxes" make decisions. This has caused ethical issues such as algorithmic discrimination (Zhang *et al.*, 2021). 2. Algorithmic bias issue have presented from bias in the training datasets. The massive amount of parameters that control the network decision. Sometimes, these parameters behave in strange ways, and it is impossible to identify all the biases in substantial datasets (Zhang *et al.*, 2021). Therefore, we need to ensure that the system diagnoses people with different backgrounds without bias. 5. Gaining the trust of healthcare and individuals for using CNN in healthcare (Reddy *et al.*, 2019). 6. Radiologists' understanding of systems and constraints will protect society and prevent any harm; therefore, professionals must be provided with support and training to ensure system safety and success (NHSX, 2019). 7. Radiologists are worried about being replaced by machines (Fogel and Kvedar, 2018). 8. Raise people concerns about the lack of human interaction (FDA, 2021).

In the General Data Protection Regulation (GDPR) for the automated decision, data privacy

states that a human must answer patients' questions and concerns around the decision and how their data will be used. However, the interpretability of CNN remains not clear for researchers, and they still lack the understanding of how CNN works and cannot explain how decisions are actually made. Therefore, radiologists will be not able to answer the patient questions and raise privacy issues. The code of conduct for anyone involved in deploying or producing new technologies in the National Health Services (NHS) has to understand users needs and determine the outcome and the impact of the new system and use the data within the guideline with translucency and define how it will be used. Any limitation in data has to be declared. The algorithm must be explained with examples of how performance will be tested, validated and used in healthcare to prove the effectiveness and value of the system and guarantee system security. The system implementation process and commercial plans have to be reported. The following questions can assist in avoiding algorithmic issues: 1. What is the extent of bias, if any, in the training datasets? 2. Are the algorithmic processes fair? 3. Is the guidance for system use provided? 4. Has the output been validated and tested? 5. Does the regulation need to be updated and developed? 6. Are the decisions transparent or do they need more explanation? 7. Do the users have the skills to use the system, or do they need more support? 8. Is the system being used for social good?

The Medicines and Healthcare Products Regulatory Agency (MHRA) has guidance for software as a Medical Device (SaMD). This covers products based on adaptive algorithms that continually and automatically evolve. The regulation categorises software based on risk levels and actual use. To ensure safety rules are applied throughout the development process, these devices are always in the improvement circle, which is very crucial to determine the impact. Hence, regulations are still unclear for adaptive algorithms (NHSX, 2019).

1.5 Conclusions and Future Directions

A summary of this report is shown in Figure 6. The field of CNN aims is to develop new tools to help solve health problems. I believe CNN can improve our quality of life by utilising com-

putational power and big data. CNN applications are being used clinically to improve healthcare quality and this remains a field with many possibilities. Despite the transparency issue requiring further studies to use CNN more widely, it may become a resource for education to discover new findings in medicine. Some researchers predict that by 2053, surgical technology incorporating AI will perform better than surgeons (Fogel and Kvedar, 2018). Studies have shown that CNN algorithms can improve with improvement in GPU computational power. This will increase the capacity for more hidden layers to achieve a deeper neural network that can analyse complex images. In addition, using digital infrastructure to store data, such as cloud-based systems for medical image-sharing, will help advance and improve data accessibility worldwide. This will increase the availability of rich datasets which can make the CNN more powerful, enriching opportunities for developing different tools (NHSX, 2019). Finally, with respect to data privacy, new technologies such as blockchain can make it easier for patients to control their data by controlling permissions for specific use (Brady and Neri, 2020). Furthermore, constant system updates has been associated with system success. For example, reports have shown that health workers are more likely to use devices with constant updates from trusted sources (Guo and Li, 2018).

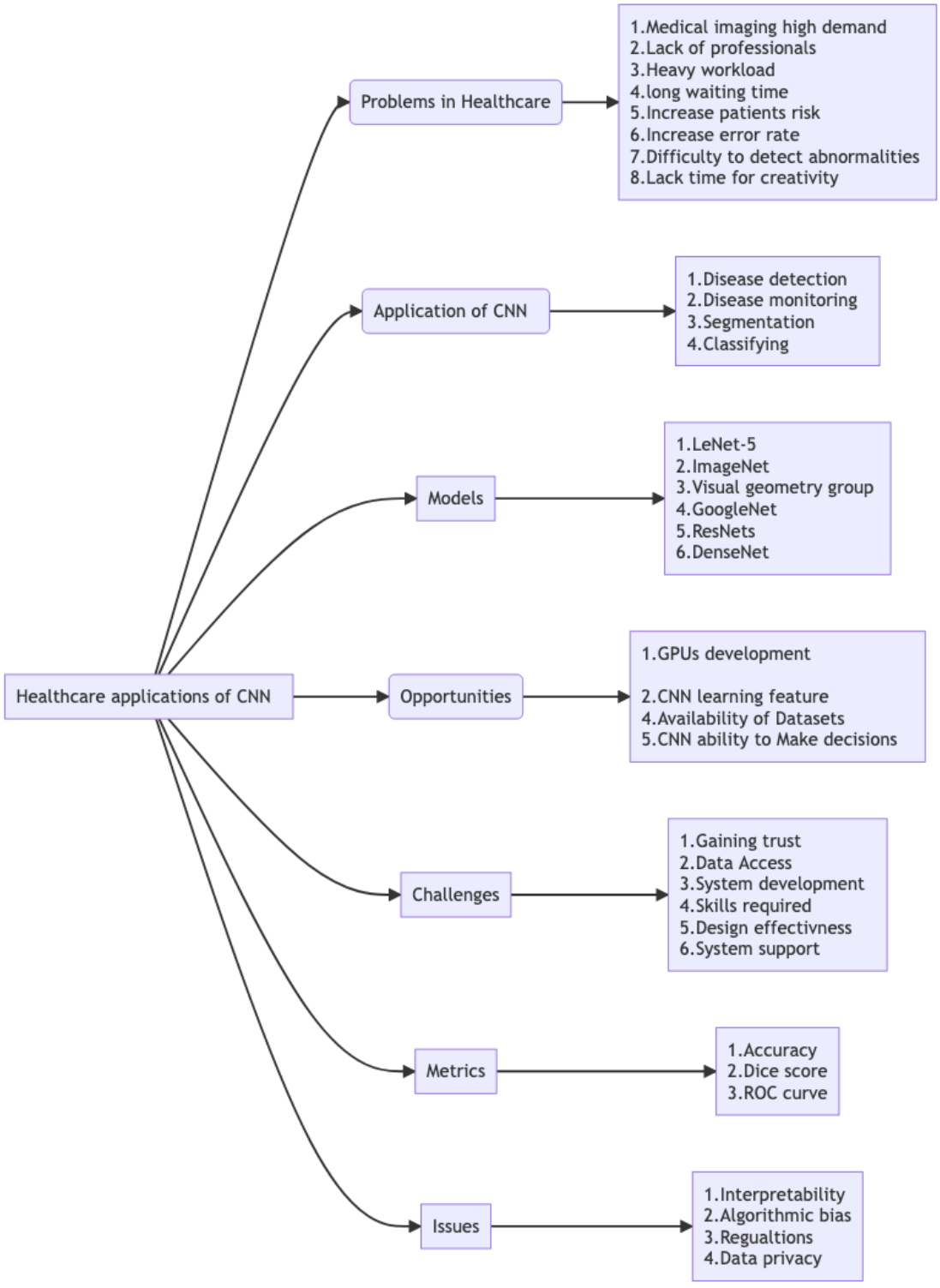

Figure 6: Summary

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2 Portfolio

2.1 Week One

- This week, we studied Boole algebra, Algorithms, computer hardware, discovering the systems software, how Leibniz, Boole and Turing contributed to the growth of computer science.
- Lectures: The logic that Boole wrote are used today to write any algorithm in the programming language.
- Activity: Transferring human languages into Boole algebra. Sentence 1 (AND) => If you passed test 1 and test 2, then you can get your certificate. Otherwise, you will not get a certificate. In Boole Algebra, the logic for AND means if A is true and B is true = C is True; otherwise, C is False. Sentence 2 (OR) => If you passed at least one test, either Test 1 or Test 2, you can get the certificate, otherwise, you will not get it. In Boole Algebra, It means if A or B is True = C is True. Otherwise, C is False.
- Exercise: Writing an algorithm in pseudo-code:

```
Step 1 => Ingredients = { Water, Teabags}
Step 2 => if (Teabags > 0)
kettle.addwater() else
print ('we need to buy tea bags');
Step 3 => addwater() {
for (kettle == full)
kettle() else
print ('add more water')}
Step 4 => Kettle(){
if (Kettle == "on")
print ("wait") else
kettle.on() }
```

```
Step 5 => Tea =cup()
Tea=Tea.add (Tools.Tea)
Tea=Tea.add(Water)
Tea.stir()
```

- Activity: The massive amount of data from many sources and the developments in graphics processing units has contributed to a substantial growth in CNN (Gu *et al.*, 2018). I chose to write about this system because I believe it can help with solving various problems in medicine. When we refer to artificial intelligence, we might think about Siri (Apple, Cupertino, USA) or Alexa (Amazon, Seattle, USA); however, there are more important applications of artificial intelligence that can significantly impact our daily lives. Because of the potential benefits of deep learning techniques, I believe that we will see more CNN models used in daily clinical practice in the near future (Yasaka *et al.*, 2018).
- Discussion: We discussed the majority of systems. I realized that sometimes we forget the number of systems around us that works in silence. In this discussion, we pointed out the importance of each system and the reason for making it and how much IT is effecting our daily routine.

2.2 Week Two

- This week, we got more familiar with the system software, the history of system development, Women effectiveness in this field and the invention of the web. Every system has cons and pros, but we keep fixing the systems till we minimise the number of problems. It all started from the division idea in physics with the logic in the mathematical calculation to computable machines and algorithms. the systems' improvement made the people pay more attention to creative stuff rather than do tedious tasks that machines could handle (Hosny *et al.*, 2018).

- Activity: CNNs have been used for visual recognition and widely adopted in many scientific areas (Wang *et al.*, 2019). However, the main challenges in the initial development of CNN was the limitations of GPUs (Cheng *et al.*, 2018).Some of the benefits of using CNNs include simple structures, fewer training parameters, and adaptability (Liu *et al.*, 2015). Furthermore, CNNs are similar to biological neural networks (Liu *et al.*, 2015).
- Discussion: Computer Science has been used in many fields, contributed to the world development and made our life much easier. However, we need to keep in mind that every system has cons and pros. but we keep fixing this system until we minimise the number of problems. One of the challenges I believe has many concerns is the security of our stored data in the systems. These systems have information about us, and some of this information is critical and can be leaked and used for destructive purposes. This will harm the targeted person or the environment in general from many aspects. This is the reason why we have to keep an eye on this critical problem.

2.3 Week Three

- This week, we looked at the social issues, the code of conduct for developers, professional issues, the Guidance for General Data Protection Regulation and how systems were designed for a good purpose, but it is used in a wrong way and how users need to be aware of the system effect. As a practitioner, I need to be aware of all the ethical and legal rules to make sure my practice will positively contribute to society development.
- Lectures: Systems have made a massive improvement in our life from many aspects such as providing better services, effective work environment, reducing the wasted energy, and offering information from all around the world while holding information about us as well. Hackers and viruses have made us realize how much we are vulnerable in our society, due to all the systems we use daily. On the other hand, some people may not be able to afford this technology, or develop the skills, Because of their age, education, or many other factors, even the cost of access. As a result, some people will

not be treated equally, which means some will be excluded from opportunities like vacancies because they may not have the skill set or tools.

- Activity: CNN has many ethical and legal issues, especially because it works with individual personal information, which is critical. People have many concerns about how it makes decisions, and lead to data privacy issues. In automated decisions, any individual has the rights to understand the way his information was processed and how the decision was made. Therefore, CNN will lack the accessibility to big data set due to data privacy issues. In Addition, the accuracy of CNN depends on the size of the data set that has access to it.In some cases, CNN detects rare diseases. Unfortunately, those who have this disease sometimes will not permit their crucial information for some reason. In this case, we want to train CNN for this rare disease until we get data (Yamashita *et al.*, 2018).
- Discussion: In the neural network, the network understands the data set and starts making decisions based on this understanding. If this data set has any bias, it will result in algorithmic bias. Researchers in CNN still have difficulty gaining a comprehensive understanding of how this network processes its decisions. While The General Data Protection Regulation has a rule for peoples' rights when it comes to automated decisions, Radiologist must answer all the patients concerns and explain how the decision was made the CNN lacks transparency.

2.4 Week Four

- In the week: Information technology has enrolled with every aspect in our life. Each individual has at least one system use it everyday. Showing us the major effect of this new technologies in our life. Especially when the system have a big role in sensitive places. Systems have to be always updated and maintained by professions to avoid any mistakes that can harm people.
- Activity: The process of the development cycle has to always be under safety rules. The

failure of AI in healthcare is a crucial concern (i.e. false diagnosis) (Ledford, 2019).In Addition, the regulation will always have lag because the continuous development. Many regulations bodies are working in presenting more effective regulations where the safety rules are met with high excellence.The problem with CNN is that it lacks transparency, which has been a complicated area to control by regulation.Patients main concerns was about the credibility of these systems, privacy of their data and interaction with machines instead of humans. AI adoption was more supported by adults with higher education than those with less education. the level of trust in AI applications by radiology patients was associated with their level of education.The concerned party who will use their data has also been a factor in their approval (FDA, 2021).

- Discussion: Radiologist need to be trained before using CNN. Because if they lack the understanding it will present negative results in both performances. In developing a new system, the design of the interface has to be easy for users.. So developers need to keep in mind that CNN used to make the process more efficient, not more complicated (FDA, 2021). In Addition, the errors of complicated design will be higher and distract the radiologist (FDA, 2021).

2.5 Week Five

- In computer science, when we want to solve any problem, we need to follow Polya's methods; Polya's method is a technique to solve the problem in stages, stage 1: Understand the problem stage 2: Find the connection between data and unknown stage 3:Check the proposed solution and improve the plan 4:Examine the solution. Moreover, we discussed the phases for developing any computer science solution, which is 1. Analysis phase 2. Algorithm development phase 3. Implementation phase 4. Maintenance phase

2.6 Week Six

- There are two development methods in computer science 1: Agile method and 2. The waterfall method. Both followed to control the development progress, from planning, efficiency of the process to finishing the software and testing. In waterfall development, the phases are sequential, but agile have the scrum tools, which allow for developers reviewing the completed tasks and make any changes.

2.7 Week Seven

Lectures: The skills required for using new technologies, the impact of digital literacy, how some people are affected. Because they may not get a chance to develop their skills due to other problems, and may affect their opportunities to find a job. Activity: The radiologist needs to understand how CNN works to use it in their diagnosing routine and get the most of it and be more reliable on it. The training will contribute directly to the success of adopting this new technology in any medical field. It is essential to make sure they get technical support and appropriate training in order to benefit from these tools (Hedderich *et al.*, 2021)

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Appendix

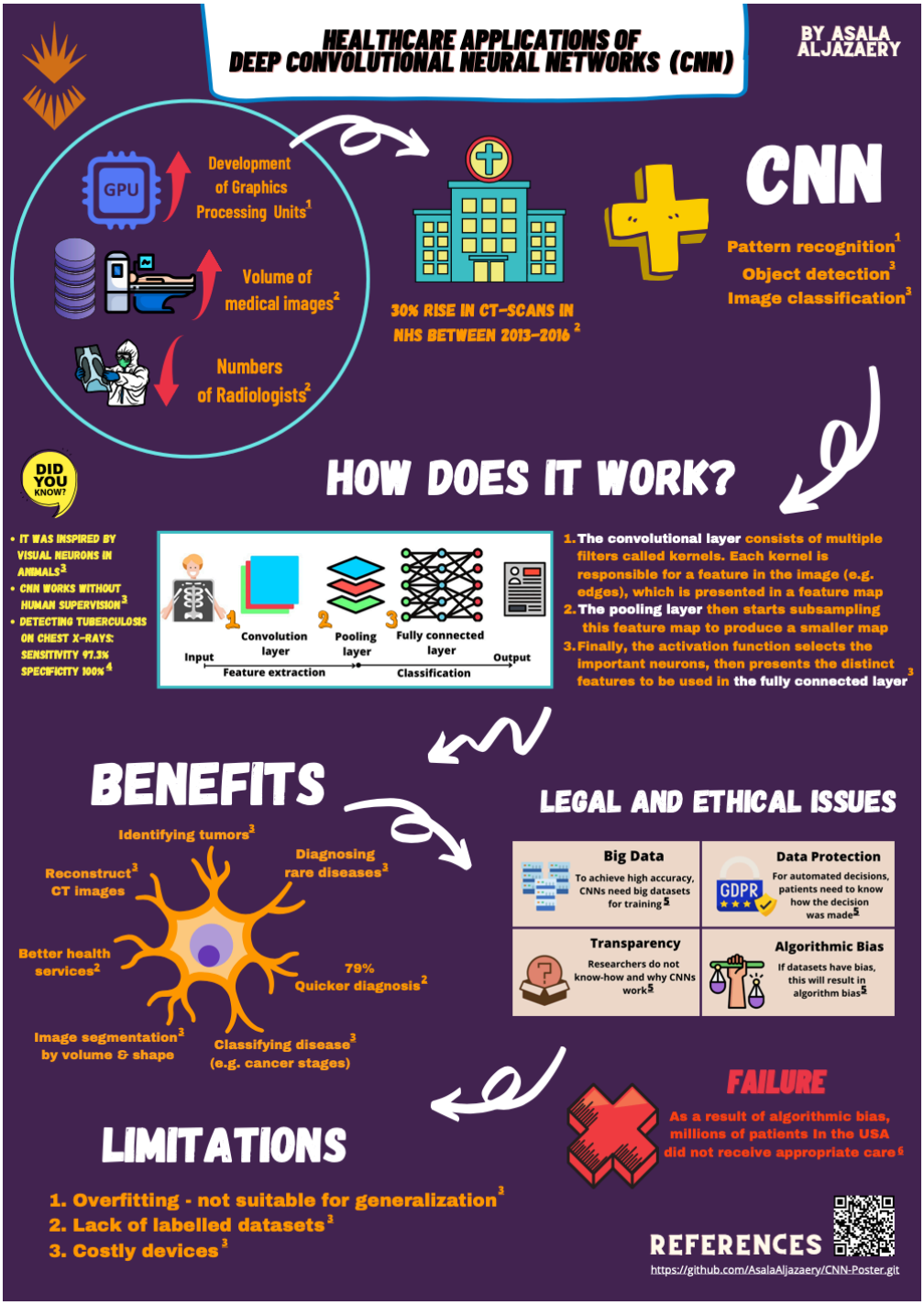

Figure 7: First assesment