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What's Wrong With My Crop? Using Convolutional
Neural Networks to Detect Crop Defects

by

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Final Year Project

Abstract

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Researching the efficacy of using CNN's (Convolutional neural networks to identify crop defects) and creating a suitable platform for users to interact with the network.

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Contents

Abstract	ii
Acknowledgements	vi
1 Background	1
1.1 Problem Definition	1
1.2 Proposed Solution	1
1.3 Aims & Objectives	1
1.3.1 Aims	1
1.3.2 Objectives	2
1.4 Risk Table	3
1.5 Overview	4
2 Introduction	5
2.1 Context	5
2.2 Literature Review	5
2.2.1 General Software Development Practice	5
2.2.2 Disease Detection Using Machine Vision	7
2.2.3 Existing CNN Architectures	9
3 Methodology	16
3.1 Project Management Methodology	16
3.1.1 Workflow	16
3.1.2 Requirements Elicitation	18
3.1.3 Feature management	18
3.1.4 Evaluation Methods	18
3.2 Development Methodology	19
3.2.1 Feature Design	19
3.2.2 Implementation	20
3.2.3 Testing methods	20
3.2.4 Refactoring	21

3.2.5 CNN Model Creation & Integration	24
3.2.6 Version control	25
3.3 Evaluation methods	25
3.3.1 User Interface	25
3.3.2 Convolutional Neural Network (CNN)	25
3.4 Initial Designs	26
3.5 Employed Technologies & Justifications	29
3.5.1 Software Structure	29
3.5.2 Hosting	32
3.5.3 Choosing The CNN Architecture	32
3.5.4 Technologies & Libraries	33
3.6 Requirements	35
4 Results and Discussion	38
4.1 Main Results	38
4.1.1 CNN	38
4.1.2 Architecture	38
4.1.3 Development	39
4.1.4 System Usability	39
4.1.5 Requirements Checklist	40
4.2 Evaluation Results	41
5 Conclusion	42
5.0.1 Further Work	42
References	46
Appendix A Project Proposal	47
Appendix B Ethics Checklist	48

List of Figures

1	Residual Identity Block	11
2	Inception Module Example.	12
3	FractalNet Architecture.	13
4	InceptionNet Filter Activation Maps (Examples taken from OpenAI Microscope) . . .	15
5	Development Lifecycle	17
6	Project Focus Over Time	17
7	Primary development method used in organization across projects (601 respondents) diagram created by Hewlett Packard	18
8	Example 1 : Initial	22
9	Example 1 : Refactor 1	22
10	Example 1 : Refactor 3	23
11	Example 1 : Refactor 4	23
12	Example 2 : Initial	24
13	Example 2 : Refactor	24
14	Example Workflow To Highlight Branch Usage	25
15	Homepage Wireframe	27
16	Defect Information Wireframe	27
17	System Overview	28
18	Input/Output overview	28
19	Input/Data Augmentation Methods	29
20	Backend Class Diagram	30
21	SUS scores table	40

List of Tables

1.1 Risks Table	3
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Chapter 1 - Background

1.1 Problem Definition

As it stands there are currently (09/02/2021) no easily found ¹ web interfaces for interacting with a crop defect identification service.

Although there exists very capable publicly available image classification networks. (Yan 2021) There is no bespoke application catering solely to crop defect identification, that has the benefit of providing recourse and prevention information to the user.

1.2 Proposed Solution

To provide a web service that interacts with a convolutional neural network (CNN) backend to diagnose crop defects such as, nurturing problems e.g. lack of water/nitrogen/C0₂, too hot/cold. And external threats such as crop disease/pest infestation. The interface will be simple and intuitive as possible. The UI should minimise points of interaction and streamline the process of uploading a crop image to be analysed. The web service will return information regarding the percentage likelihood of each kind of crop defect, including images that are of similar nature to the one analysed.

1.3 Aims & Objectives

These should be SMART with clear success criteria defined specific, measurable, achievable, realistic, Timebound

1.3.1 Aims

- To aid gardeners and smallholders in identifying crop defects.
- To aid gardeners and smallholders in taking relevant recourse.

¹(i.e. not present in the first 3 pages of a google search for 'crop defect identification' and 'What's wrong with my crop')

1.3.2 Objectives

- Provide a way for a user to upload an image to be analysed.
- Display information regarding the likelihood of each kind of defect.
- Display recourse information alongside defect information.
- Have gallery of images filtered by crop and disease type.

1.4 Risk Table

Table 1.1: Risks Table

ID	Name	Likelihood	Impact	Control Mechanisms				
1	Improper Time Management	med/low	high	Follow the Gannt chart				
2	HDD/storage failure	low	high	All work will be backed up to github				
3	Illness/Injury	med	med	Should the need arise I will apply for an extention	to the due date.			
4	RSI (repetetive strain injury)	med	low	Work with proper postureand set up workstation properly.And take frequent breaks				
5	Eye strain	med	low	Ensure room is well lit when working on a screen.				
6	Incorrect Task Prioritisation	med	med	Iteratively re-asses the work being done and compare it to the mark scheme.				
7	Postural problems	med	low	Work with proper postureand set up workstation properly.And take frequent breaks				

1.5 Overview

Firstly the introduction will provide additional context to the problem domain and show relevant research. Next, the methodology and justification for the choice of methods will be explored. Including employed technologies, project management methodologies and development methodologies.

Chapter 2 - Introduction

2.1 Context

With the increased availability of smartphones (Sta 2021), digital cameras (Ima 2021) and Internet access (Wik 2021) (Glo 2021), coupled with the increased interest in home food cultivation (Goo 2021) and the large number of people reliant on food grown in smallholdings (Walpole and Hutton 2013); the ability to identify defects with crops using technology has potential to be impactful to many people.

2.2 Literature Review

Firstly one will cover general development practice, Secondly, existing research regarding image classification of plants and plant diseases will be explored. Lastly, an analysis of CNN architecture development.

2.2.1 General Software Development Practice

Software, often complex by nature, benefits from being created with a set of best practices in mind. A key principle one has gleaned from the Pragmatic Programmer (Hunt and Thomas 2000) (a key reference guide that has helped one's understanding of best practice) is that of developing for orthogonality. This means creating software from sub modules that operate as independently as possible from the whole. This means that changes to part of the system do not cascade to unexpected effects elsewhere in the system. In practice this involves reducing, or if possible, entirely eliminating the usage of global variables. As this can make it difficult to trace the source of bugs when one does not know which part of the system is modifying the global. It also forces any changes to the modules that interact with the global to be considering the knock on effects it may have to other modules. Additionally it makes switching the code to a multi-threaded design much more difficult as bugs created by 'race conditions' can arise, whereby both threads of execution only modify the variable in the correct order due to difference in their speed of execution.

Another way of creating orthogonal code involves making interfaces store as little information about their clients as possible, as this allows for the client to be changed more readily without then needing to alter the internal logic of anything it is interfacing with. It also means the interface is able

to be consumed by any client. How to solve it (POLYA 1945) Also reinforces the modular approach to development by encouraging the problem solver to break apart large problems into smaller more manageable problems that one knows how to solve, eventually, reaching a point where the known unknown becomes a smaller and smaller piece of the problem until the remaining steps of the solution are trivial or at the very least clearly defined.

Another useful development practice outlined in *The Pragmatic Programmer*, is that of 'tracer-code'. This is much the same idea as opting to achieve a Minimum Viable Product (MVP) to provide a framework to build additional features from. For instance creating simple client and server applications that are successfully interfacing with one another to send and respond with simple data, can then be expanded to include the capacity to send more complex data and for the server to perform ever more complex operations on said data. Once a basic outline of the software is constructed it can also be extended to include, better response to erroneous data and provide a greater number of features. This line of development whereby one creates a simple implementation, goes back to the drawing board, adds new features, and repeats is reinforced by Gall's Law which states "A complex system that works is invariably found to have evolved from a simple system that worked. A complex system designed from scratch never works and cannot be patched up to make it work. You have to start over with a working simple system" (Gall 1977)

Development of software is iterative and cyclical. Involving the creation of features to a set of requirements, and then subsequently refactoring their implementation to better align with best practices. Some reasons code may need to be refactored as covered in (Hunt and Thomas 2000) are; Quote "Duplication", "Nonorthogonal design", "Outdated Knowledge" and "Performance". As it is the case with software that it can be configured in infinitely many ways to achieve the same outcome. It is inevitable that sometimes features will be implemented in a way that breaches best practices. Or in a way that is not conducive to the overall 'health' of the codebase. A useful analogy shown in the book is to think of the codebase as a garden, that will grow and change over time, with refactoring (see Refactoring) being analogous to weeding and pruning and feature addition being analogous to planting.

SOLID principles

When writing Object Oriented (OO) code. Robert. C. Martin outlined many principles to follow when designing software architecture, architecture in this case referring to the level of interaction between individual classes. From these principles a subset of these principles was selected by Michael Feathers in 2004 to create the SOLID acronym.

S - Single Responsibility Again we see a focus on modularising and de-coupling parts of the software. Making classes that where possible contribute to a single purpose. This makes the class easier to test, and have by virtue of having less functionality, have less classes dependent upon it.

O - Open to Extension, Closed to Modification When new funtionality is to be added to the software, it should be the case that the existing classes are not modified, but inherited from and extended.

L - Liskovs Substitution Principle Tying in to the above principle. If a parent class is changed for a sub-class, the behaviour of the program should not be affected. For instance, one has a parent class Mammal, and a child class Dog. If the program executes properly when it recieves a mammal object, it should still operate properly when receiving a dog object as the dog object should implement the same contract as stipulated in the Mammal interface.

I - Interface Segregation Large interfaces should be made in to seperate smaller interfaces, therefore inheriting classes do not have to inherit methods they will not use.

D - Dependency Inversion This aims to to prevent high-level modules depending on lower level modules. For instance, rather than declaring an instance of class B inside another class A, one should declare an instance of the parent class of class of B. This way, class A is not dependent on the lower level of abstraction.

Other useful rules of thumb to consider include. Don't repeat yourself (DRY), this means creating a single source of truth for information in the system. And you aren't going to need it (YAGNI) don't create functionality or levels of abstratction that you don't need. The principle being that it creates unecessarry complexity.

2.2.2 Disease Detection Using Machine Vision

Non CNN methods

In 2009 a study (Anthonys and Wickramarachchi 2009) was conducted using deep learning to identify three different disease classes on rice plants. The results showed over 70% classification accuracy on 50 sample images. The method employed used segmentation, followed by image feature extraction using three different algorithms to extract color, shape and texture information from the image. The feature data was input to a classification algorithm whereby the output would be one of the three disease types or no disease present.

In 2015 another experiment (using similar aproach to (Anthonys and Wickramarachchi 2009).

Involved using image segmentation using K means clustering and other image processing techniques, to find features in the image and create a one dimensional binary feature vector, to be processed by an ANN. (Khirade and Patil 2015) The accuracy of detecting powdery mildew, yellow rust and aphids on wheat were 86.5%, 85.2%, 91.6% and 93.5% respectively[4 vals 3 catagories]. This non CNN technique has subsequently been rendered redundant as this method requires a greater number of computational processes and achieves results that have been surpassed by CNN's. However, the image segmentation technique (with the purpose of isolating the leaf from the background) is also sometimes used in CNN approaches.

CNN Methods

A year later and there have been great successes in identifying crop disease with CNN's. In 2016 a paper was published running experiments on a 38 class crop disease dataset over 14 crop species and 26 diseases (or absence thereof). Resulting in 99.35% accuracy on a held-out test set (using GoogLeNet). (Mohanty *et al.* 2016). This study utilized two established CNN architectures, namely AlexNet (Krizhevsky *et al.* 2012) & GoogLeNet. (Szegedy *et al.* 2015a) With GoogLeNet achieving a higher F1 score¹ in almost all cases. This study also highlighted the effectiveness of using colour images when training the models. In all experiments, the color or segmented image models performed better as opposed to grey scale images. A surprising aspect of the results is the fact that the segmented image models almost always performed worse than the colour image models, with the best performing model being trained on colour, non-segmented images. This may be due to some bias being present in backgrounds of the dataset images. Or it may be more effective to not perform segmentation on the images prior to training.

Then in 2018 InceptionNetV3 (a later iteration on the GoogLeNet i.e. InceptionNetV1 architecture) is used on a very similar if not the same dataset of 38 class crop diseases (this paper cites the number of crop species to be 13 as opposed to 14) and 26 diseases. Resulting in a slight increase in classification accuracy of 0.39%, to 99.74%. (Kulkarni 2018) Prior to training the models, the training images were segmented to give the crop leaves a black background. Notably this study began with pre-trained InceptionV3 models and fine tuned them by training a separate model for each type of crop. This allowed a system whereby the network is fed an image, it determines the crop, then it passes the image to the specific network tailored to that crop species. Unfortunately there are no results available of experiments with non-segmented data to compare with the Mohanty paper. Interestingly the author (Omkar Kulkarni) states 'The pre-processing of image is essential for removing noise and segmentation of the image which helps in improving the accuracy of CNN model'. However, the results table [APPENDIX LINK] produced by (Mohanty *et al.* 2016) show

¹see Evaluation methods

non-segmented images achieving higher accuracy. The increase in accuracy for this paper when compared to (Mohanty *et al.* 2016) could be explained by the better performing InceptionNet architecture

A study performed in 2015 by Sungbin Choi (Choi) which involved plant species identification from a multi-image observation query. Found that an ensemble of CNN's performed with better classification performance. The study utilized an ensemble of fine-tuned² GoogLeNet architectures.

This paper (Zhu *et al.* 2018) performed experiments for plant species identification and justified that 'using CNN's can provide better feature representation compared to hand-crafted features.'

From the reviewed sources it is apparent that the best performing architectures have employed the Inception (Szegedy *et al.* 2015b) module, which is consistent with the findings of (Wu *et al.* 2019) for InceptionNets to outperform Resnets. (He *et al.*) and InceptionNet varieties the Inception-ResNet-v2 was the best performing well known architecture. However the researchers crafted a bespoke architecture using inception modules that slightly outperformed the Inception-Resnet-v2.

2.2.3 Existing CNN Architectures

LeNet5 & Precursor

One of the first major pioneering works in the field of machine vision has been (Cun *et al.* 1989) which designed a CNN architecture to be used for character recognition and printed on a chip. With all of its 49 templates (today known as filters) being designed by hand. And later goes on to introduce 'Digit Recognition Using Constrained Automatic Learning' which allows some parameters of the network, including filter values to be updated automatically via backpropagation, removing the problem of having to design all of the filters manually. Manually designing filters can be seen as introducing some priori information to the network. Which also alleviates the problem of having a scarce amount of data. A noteworthy step when training their network is the final stages of training whereby they waited for their model to converge at a minima (minimizing loss, i.e. error) which took 23 learning passes, then trained it for a further 5 passes on a dataset that quote "had undergone slightly different preprocessing", resulting finally in a 5% error rate at classifying handwritten digits. Later in the work of creating LeNet5 (LeCun *et al.* 1998) we see the invention of fully automated parameter tuning via backpropagation (for more on backpropagation see (Cun Yann le 1988)) that led to, achieving 0.8% error rate at identifying hand written digits. This was in part made possible by the increased amount of data available to train the network.

²meaning pre-trained on generalized data and then improved with domain specific data

AlexNet

Following from LeCun we see the next popular architecture (winner of the 2011 ImageNet Large-Scale Visual Recognition Challenge (ILSVRC)) that is often used as a benchmark in later papers AlexNet(Krizhevsky *et al.* 2012). A noteworthy aspect of it's design is the choice to change from using the tanh activation function that we find in (?) to the relu activation function, which has been adopted in all state of the art aproaches today. The relu funciton is linear so we see a decrease in training time by virtue of using a function that is less computationally expensive. Another finding was that due to the large number of paramters in the network, it had a tendency to overfit the training set. To mitigate this, data augmentation is used including reflections and zooming in on only parts of the image such as corners/middle. Other augmentation included normalizing the RGB intensity across the image as it stated that 'object identity is invariant to changes in the intensity and color of the illumination'. This network also employs dropout as discussed later. When training the model stochastic gradient descent is used, whereby the parameters of the network are updated based on the loss of each training example. We also see mention of the concept of 'fine tuning' a network, whereby one takes a network that is pre-trained on a generalized dataset and then further trains it on domain or dataset specific input. Furthermore, we see evidence for the virtue of using ensembles of CNN's to reduce classification error. Finally the paper concludes stressing the importance of depth for classification accuracy citing a 2% reduction in classification accuracy for top-1 performance if any convolutional layers are removed. However a later paper (Zagoruyko and Komodakis) has established that 'widening' networks can be just as or more effective than deepening. The concept of widening can also be used to explain the effectiveness of InceptionNets.

VGGNet

Another major improvement in CNN architecture comes in the form of VGGNet (Visual Geometry Group) (Simonyan and Zisserman 2015). In this paper they studied a range of different network depths. They take the aproach of further deepening the network to improve accuracy, citing their use of small receptive feild filters (3x3) as the main key to their success. This logically follows as the smaller the receptive field, less weights need to be tuned. This fact coupled with using a moderate amount of filter channels (512 at most) allows for more conv layers. Earlier designs were using larger filters especially in the first layer namely (Krizhevsky *et al.* 2012)&(Sermanet *et al.* 2013). To aid in training their deeper network variations, pre trained layers of shallower networks are used as the initial and final layers, with the middle layers remaining randomly initilaized. When training the network mini-batch training is employed whereby the weights of the network are not updated until a batch of training examples has been seen, as apose to stochastic whereby the

weights are updated after a single example. Data augmentation is also important in the approach; each training image was cropped and zoomed etc. Their best performing ensemble of 2 VGG nets achieved 6.8% top-5 test error on the ILSVRC test classification dataset. VGG Much like its predecessor AlexNet, employs max pooling layers and Relu activation function.

Resnets

Continuing the theme of deepening networks we are introduced to the ResNet (He *et al.*) Winner of the ILSVRC 2015 classification task. ResNets introduce the concept of the skip/shortcut/residual connection. Meaning output from an earlier layer is added to the output of a layer some convolutions ahead of it. The emergent result is performance no longer degrading with greater network depths. A reason for this, is less feature information is lost through the convolution operations. Due to the fact that every conv operation reduces the volume of input to the next layer, information is lost after each operation. The skip connection mitigates this by adding earlier information to later layers. With an ensemble of ResNets it's top-5 err on the ILSVRC test set was 3.57%

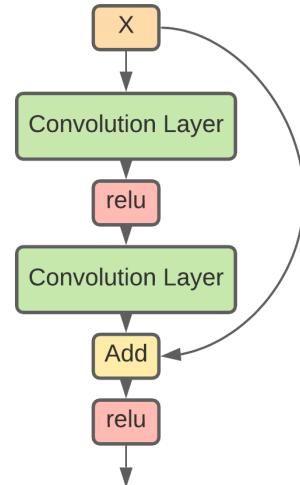


Figure 1: Residual Identity

Taking the residual connection further is the DenseNet. In this architecture we see a stack of dense blocks, in a dense block each layers output is concatenated with each proceeding layer, notably a ResNet adds the output of the previous layer whereas DenseNets concatenate. This has the benefit of preventing the network learning redundant feature maps and preventing the vanishing gradient problem. The network also employs 1x1 convolution layers to reduce input size to the more expensive 3x3 layers, much like the InceptionNet. After each dense block is a transition layer which consists of a 1x1 convolution operation and a 2x2 average pool with stride 2, the transition layer has the purpose of compressing the output volume. It is unusual to see average pooling used as it is typical to see max pooling, no justification is given for this choice. The authors also claim on the basis that models with over 25m parameters still see increase in accuracy that the DenseNet architecture prevents overfitting. For comparison the original ResNet contains 1.7m parameters.

InceptionNets

An earlier but more distinctive when compared to earlier iterations of design, comes in the form of InceptionNet/GoogLeNet (Szegedy *et al.* 2015b). Part of their philosophy when creating the network was to make something that could perform well on hardware that was more widely available quote “the models were designed to keep a computational budget of 1.5 billion multiply-adds at inference time, so that they do not end up to be a purely academic curiosity.”(Szegedy *et al.* 2015b).The feature

that sets InceptionNet architectures apart is the different varieties of Inception Module. An inception module is multiple convolutional operations occurring in parallel and finally being concatenated together. This approach of adding more channels in a single layer is commonly referred to as ‘widening’ the network. Later iterations of the Inception net (aside from the addition of skip connections) focus on preventing the more expensive computations such as 5x5 convolution operations from bottlenecking the network, this is achieved by using less expensive 1x1 conv operations to reduce the volume of the input prior to the expensive operations.

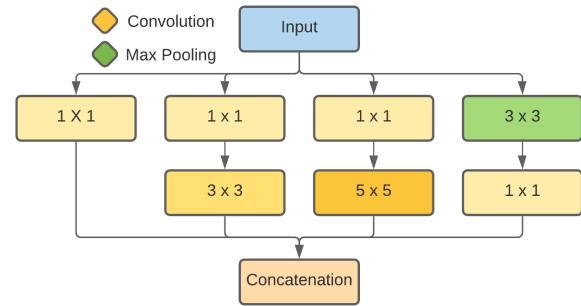


Figure 2: Inception Module Example.

FractalNet

As it stands, there are few, (if any) papers exploring the efficacy of the novel fractalNet architecture (Larsson *et al.* 2016) for crop disease detection or on any other dataset aside from the commonly used CIFAR10 & 100. The Inventors of the fractalNet performed experiments that justified their use over ResNets. Demonstrating results that showed improved classification accuracy. Another feature of the fractalNet architecture is the ability for the user to choose between speed of prediction and accuracy of prediction as it is possible to take longer or shorter paths through the network. Longer paths being more accurate and more time consuming. Drop-out is also applied during training but at a coarser level than individual filters, rather, entire paths are dropped at join layers, leading to the creation of pathways of equally strong predictors. It is said in the paper they see their architecture as a more generic design that is not in its final form as the best configuration of convolutional module and join layer has not been determined. The architecture can also be seen as a harness for creating an ensemble of networks of different depths.

Additional CNN research

Research has been conducted in 2016 (Zagoruyko and Komodakis) that determined 'wider' networks perform better than their deep narrow counterparts. They found that their 16-layer deep network had the same accuracy as a 1000 layer thin deep network with a comparable number of parameters. With the wider network being faster to train.

A key feature of CNN design is size and number of filters. In all examples mentioned (Resnet, InceptionNet, AlexNet etc), filter size is always odd and square. For instance 1x1, 3x3, 5x5 and so on. Size of filter will determine the size of the feature the filter will encode for. Number of filters will determine the depth of the convolution output. It is noteworthy that the Resnet50 architecture (He *et al.*) uses almost entirely 3x3 size filters. Whereas, the Inception module employs a mixture of 1x1 through to 5x5 convolutions.

A technique known as dropout is a feature that has been employed in increasingly deep networks to prevent overfitting and was first introduced by (Srivastava *et al.* 2014). The principle behind its operation is randomly dropping paths between feature activations during training. This ensures that predictions do not become overly reliant on a single (or group of) neuronal activation(s), that can correlate to some bias in the training data. And prevents neurons from becoming co-adaptive. This technique was employed in AlexNet (Krizhevsky *et al.* 2012) whereby they used dropout in the first two fully connected layers of their model. They found that using dropout prevented overfitting but made training take twice as long. This exact method whereby dropout is used in the first two fully-connected layers is seen again in VGGNet(Simonyan and Zisserman 2015); both methods choosing to employ a dropout chance of 50%. The fully-connectd layers typically occur at the end of the network prior to the final softmax operation that condenses the matrices into a single prediction vector, with each position in the vector containing a prediction value and the position in the vector corresponding to the class.

Another aspect of CNN's is the process by which they progressively narrow down the possibilities until they arrive at their conclusion. This is done by encoding loose abstract forms that relate to groupings of objects in the early layers and gradually arriving at very generalized forms such

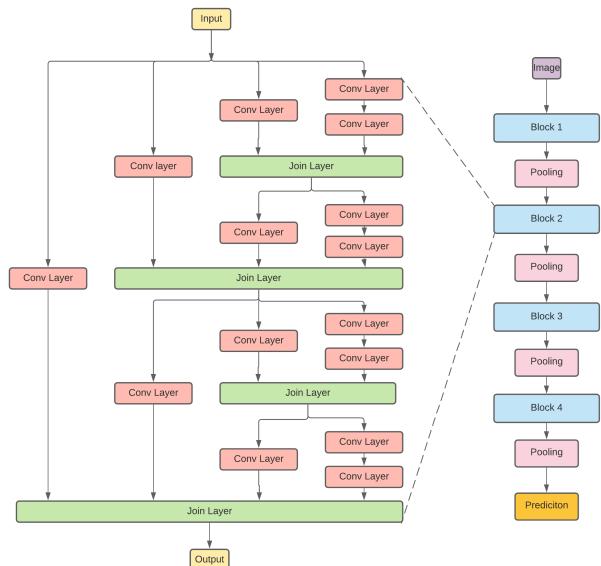


Figure 3: FractalNet Architecture.

as horizontal lines or sine waves in the later layers. So to give an example drawn from the AI microscope (<https://microscope.openai.com/models>). In an early layer we may find a neuron that encodes for two semantically unrelated objects, yet objects that have a form in common such as dogs and turnstiles, a middle layer may encode for things under the sea or star shaped objects. Final layers encode for more generic features such as diagonal lines or squares. In the case of the dog and the turnstile, one can observe that a 'branch' of a turnstile is equateable to the leg of a dog and the 'console?' of the turnstile be equateable to the dogs body.

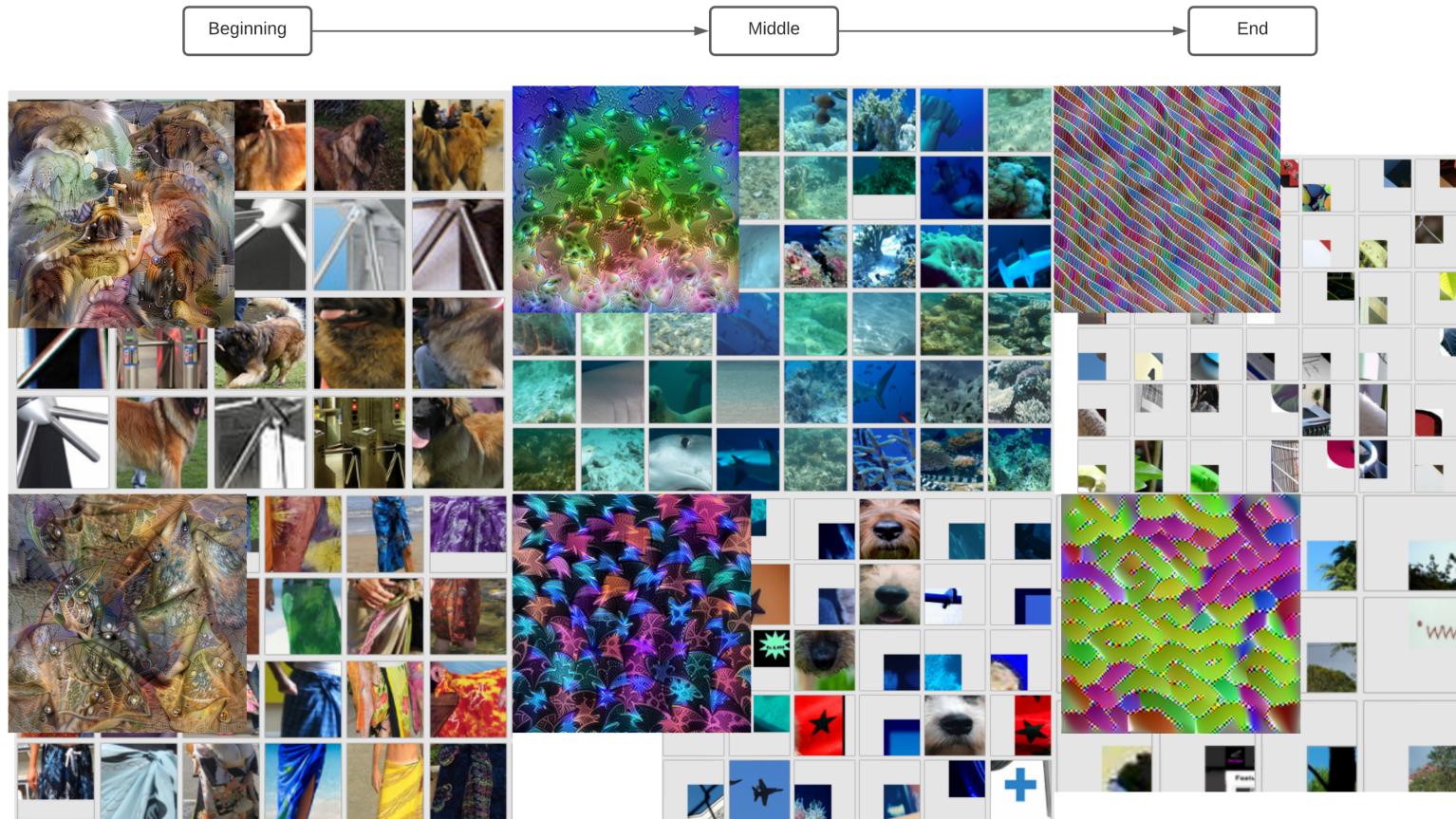


Figure 4: InceptionNet Filter Activation Maps (Examples taken from OpenAI Microscope)

Chapter 3 - Methodology

3.1 Project Management Methodology

3.1.1 Workflow

The workflow one has designed has been inspired by existing agile methods. It will consist of a single cyclical workflow, with two nested "sub workflows" whereby upon completion of a step, it is sometimes necessary to loop back on oneself to perform further refinement. As illustrated by the diagram below. Throughout the project the focus of the workflow will shift as illustrated by the diagram below.

The paper (Highsmith and Cockburn 2001) makes a compelling argument for the usage of agile methodologies over more linear project management methodology (PMM) styles such as waterfall. Agile focuses on design being done 'on an ongoing basis in smaller chunks' (Highsmith and Cockburn 2001). It is also highlighted that agile allows development to respond to feedback and change. In fact agile has customer, designer and developer feedback baked in to its formula in the form of regular team meetings, especially if using the SCRUM 'flavour'.

For a lone developer Agile with Kanban is the PMM of choice for this project as it allows the flexibility to iterate on designs as one learns more about the technologies being used and gives the freedom to modify one's requirements in light of newly found research and technical limitations. Additionally the nature of agile is to have short lifecycles which has the virtue of frequent milestones. This allows one to better track progress of the project by being able to see how many tasks have been completed on the Kanban board during the development cycle⁴.

Using Kanban to track tasks makes sense for a single developer as opposed to using feature driven development. As this allows for non-programming tasks to be tracked in the same way as programming tasks.

Furthermore, agile is a worthwhile methodology to use and familiarise oneself with as it is becoming the new norm in industry. As shown by a study conducted by Hewlett Packard.

⁴Granted tasks alone are not the be-all, end-all metric but it does give some idea of progress

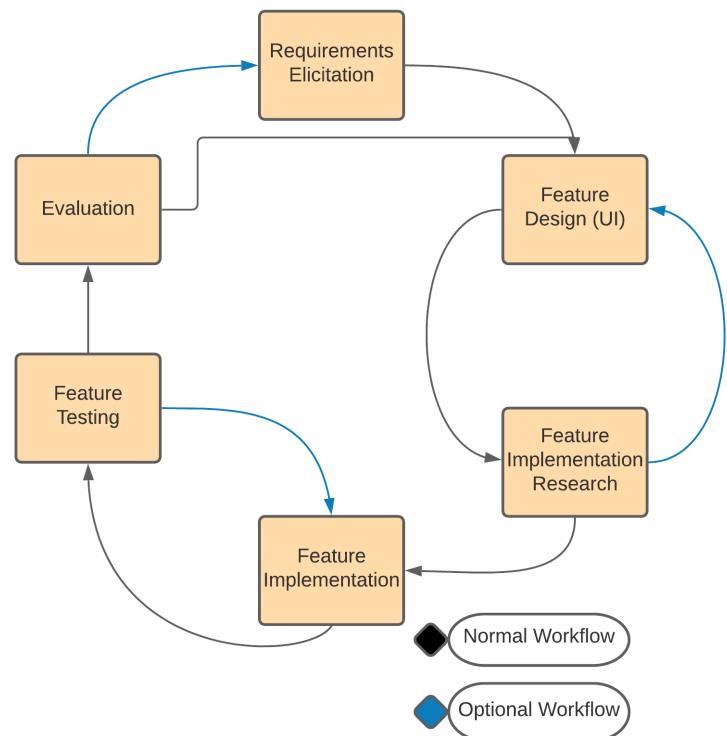


Figure 5: Development Lifecycle

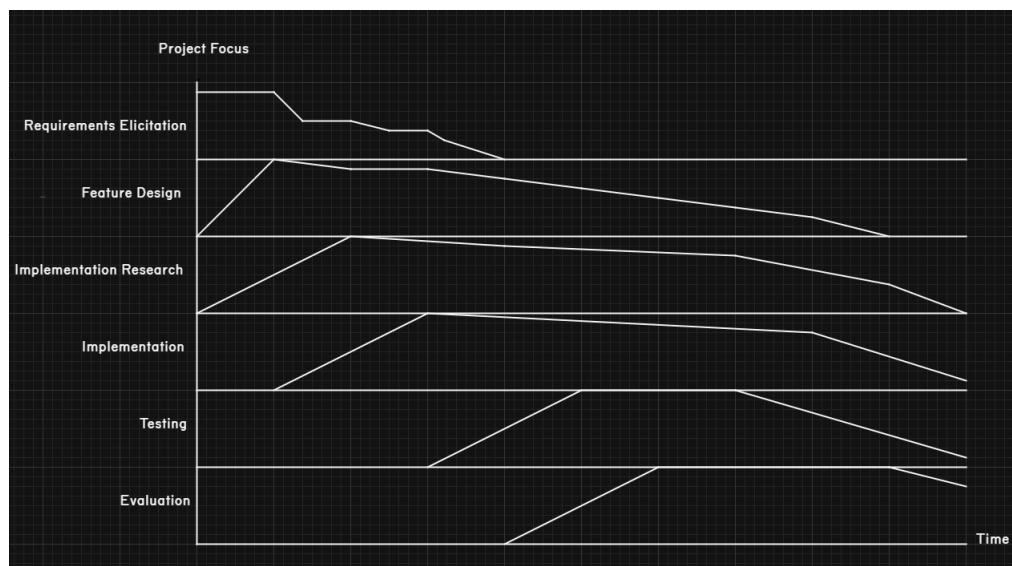


Figure 6: Project Focus Over Time

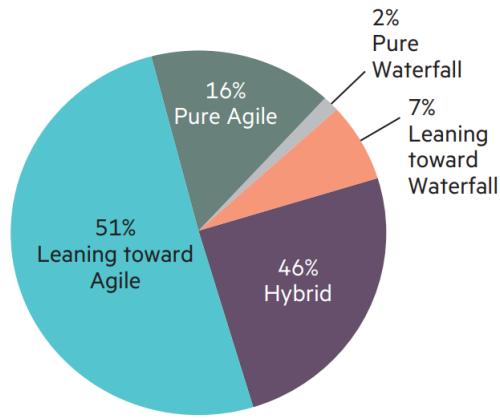


Figure 7: Primary development method used in organization across projects (601 respondents)
diagram created by Hewlett Packard

3.1.2 Requirements Elicitation

This involves determining the needs of the user and defining requirements to meet those needs. As the requirements will be determined by the developer in this case, reason being, the scope of the problem domain is narrow in terms of interaction points for the user. The following rationale will be used. One will create requirements that contribute towards providing information about crop defects to the user. Also, as the system is intended for use by non-technical persons, the interaction should be minimal, and clear. This means not cluttering the UI with too many points of interaction, making it clear what the application is doing at any given time. And using non-technical language, especially avoiding jargon.

3.1.3 Feature management

To track the creation and completion of features, a Kanban board will be used. This will include columns for 'To do', 'Doing' and 'Done'. To determine which features will be prioritised one will employ the MOSCOW method see Feature Management.

3.1.4 Evaluation Methods

This will be conducted by linking users to the website with a link to an online survey alongside a link to a google drive folder containing relevant test images. With the questionnaire mostly consisting of System Usability Survey (SUS) questions. And some additional bespoke questions regarding accuracy of prediction. User feedback aside from the data collected from the SUS survey will also be valuable for this project, it is a good way to be alerted to any usability issues. Such as bugs, difficulty understanding how to use the application (what icons mean, order to carry out steps etc)

and difficulty seeing UI elements due to poor colour choice.

3.2 Development Methodology

3.2.1 Feature Design

UI

Wireframes will be utilized to establish interface element placement i.e. layout. Then more mockups that align better with the possible implementation will be created superseding the original prototype wireframes. A colour picker that takes predetermined segments of the colour wheel, will be utilized to define the colour scheme. In later iterations of the design, once there is a functioning UI, usability will continue to be refined with the help of existing usability research, to guide the usage of font/colour/highlight on hover/font size etc. Additionally once a desktop friendly layout has been established, work will begin on optimizing a version for mobile.

Backend

To better conceptualize the needs of the user. Use case diagrams and activity diagrams will be utilized. Then the main types of code to help with design are psuedocode which is written loosely in a programming style but does not execute. Prototype code, which runs but is intended to be discarded. And tracer code, which is a kind of MVP but on the individual feature level.

Design & Implementation Coupling

An iterative approach has been chosen because the design of the software is affected by factors of the implementation. Before implementing a feature it is not always clear how the solution will look and which possibilities will be simplest to meet the requirements. Therefore, an initial design will be created to guide the first steps of implementation, then as more information is learned and perhaps an easier to make design is realised, the new design can be checked against the requirements. If satisfactory, the new design can become canon and development on the updated design can continue.

This coupling brings about the necessity of Won't have category in the MOSCOW method. This prevents future iterations of design and additional requirements encroaching on what the program will not be able to do. This can arise as an implementation choice may rule out the possibility of other features being included. For example the choice to use a sub-optimized javascript library may rule out the possibility of the application running on mobile.

Design Methods

3.2.2 Implementation

This step involves determining the appropriate technologies and libraries to achieve the design. This is necessary to realize the constraints that are imposed by the implementation method and know to what extent the design is feasible.

Writing the code to create the feature is carried out iteratively. When development begins we first arrive at a base-case often known as a Minimum Viable Product (MVP), often hard-coded solution and subsequently make the code more dynamic, flexible, and robust to erroneous data. Then if necessary optimize the performance of the code to improve run-time. Some programming rules of thumb are. “premature abstraction is the root of all evil”(Knuth 1974) This is due to the fact optimizing code often comes with the drawback of making the code more complex and harder to understand, so it is best practice to not optimize code prematurely. Don’t repeat yourself (DRY)(Hunt and Thomas 2000) which equates to, have a single source of truth for each piece of information in a system. However a possible pitfall of this approach is to prematurely abstract functionality. For example if two methods contain the same sequence of operations one may make this sequence a separate method. However later in the development process it becomes apparent that in one of the original methods the sequence must be slightly different based on a condition. Now the new abstracted method must contain branching logic and the code has had unnecessary complexity added, as now branching logic is present at two places in the code, when the decision could have remained encapsulated inside only the method that needed it.

The ideal MVP will be one that fulfills the ‘must have’ requirements. Then it will be possible to expand its features to include ‘could have’ features etc. Additionally, once the MVP is achieved, design considerations such as ease of extensibility and addition of new features will be more heavily focused on. Sometimes with major code refactor occurring at this point (see Refactoring), as to achieve the MVP quickly it is sometimes necessary to implement features in a way that may not be conducive to easy maintenance, efficiency, readability or serving content dynamically. As noted in the literature review, this process of gradual addition of complexity is supported by many authors.

3.2.3 Testing methods

Testing will be conducted iteratively as the functionality expands, with unit tests being introduced for some components depending on time constraints. Testing will consist of firstly confirming that when interfaces are interrogated with sound data, the responses are consistent with requirements.

And secondly stress testing the interfaces with extraneous data to ensure that appropriate error responses are given and the application does not simply crash. And if in the case of crashing, is able to automatically re-start.

On a larger project, especially if working with multiple developers, developing to test and having unit tests for each module is imperative. These test the module with valid and extraneous data against its interface 'contract' i.e. what it promises to produce upon interaction. Secondly, integration tests would be created that test the interaction between modules. As integration is the most likely point for bugs to occur. When discovering a bug, it is good practice to create a test to reproduce it, firstly to cut down time checking if the bug is fixed, and to ensure it does not occur again.

On a sufficiently large project it is also good practice to test the tests, by creating branches of the software that deliberately fail, to ensure the tests are functioning correctly, and catching the errors you expect them to catch.

3.2.4 Refactoring

an example to illustrate the process of refactoring that will be utilized during development. The first piece of code was arrived at because the base case was to retrieve the most likely defect. The extended requirement was to find the top three most likely defects. This has resulted in two methods being created for each case as the base case was coded first and extended requirement added in later. Although this is still functional, it's unnecessary and the code can be simplified, by using the result produced by the newly created method, the base-case method and any calls to it can be deleted. (note the method is declared in Model class which has been omitted for clarity) Refactor example one, three, is entirely debateable as to whether or not it is an improvement. It is certainly more terse, which makes it arguably more difficult to read. The counterpoint to this being, one is not allocating a computationally redundant variable at runtime. This being moreso notable in the language of Python. Given its interpreted nature, the interpreter will guarantee cause the machine to execute this operation (granted it's a fairly inexpensive one). If it were a compiled however, it is likely the compiler would ignore this redundancy and it would have no bearing on the speed of the program. Finally, comments are either added or updated.

```

● ● ●

def determineClass(self, predictionArray):
    return np.argmax(predictionArray, axis=1)

def determineTopClasses(self, predictionArray):
    predictDict = {}
    topClasses = []
    for idx, prediction in enumerate(predictionArray):
        predictDict[idx] = prediction
    predictDict = sorted(predictDict.items(), key=operator.itemgetter(1), reverse=True)

    for entries in list(predictDict)[0:3]:
        topClasses.append(entries[0])

    return topClasses

predictedClass = determineClass(results)
topClasses = model.determineTopClasses(results)

return{
    "classNo" : predictedClass,
    "topClasses": topClasses,
}

```

Figure 8: Example 1 : Initial

```

● ● ●

def determineTopClasses(self, predictionArray):
    predictDict = {}
    topClasses = []
    for idx, prediction in enumerate(predictionArray):
        predictDict[idx] = prediction
    predictDict = sorted(predictDict.items(), key=operator.itemgetter(1), reverse=True)

    for entries in list(predictDict)[0:3]:
        topClasses.append(entries[0])

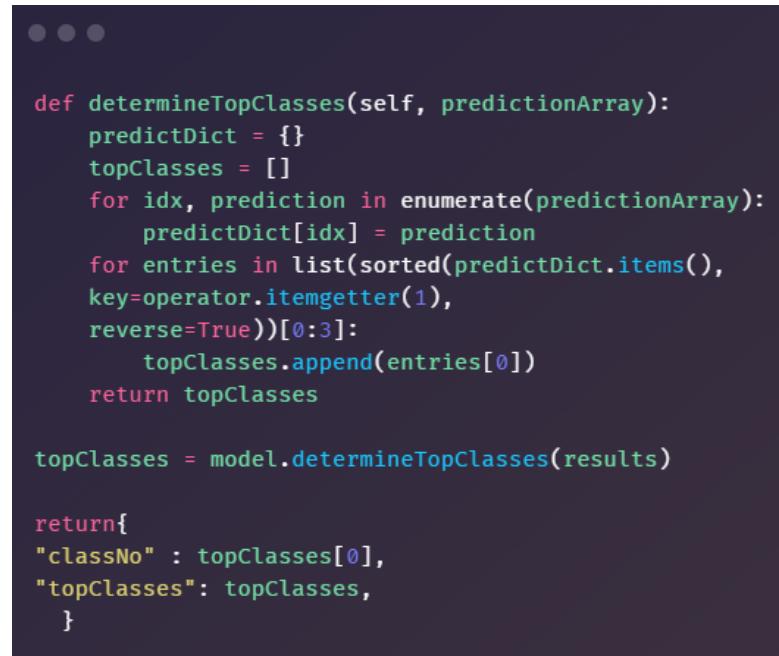
    return topClasses

topClasses = model.determineTopClasses(results)

return{
    "classNo" : topClasses[0],
    "topClasses": topClasses,
}

```

Figure 9: Example 1 : Refactor 1



```

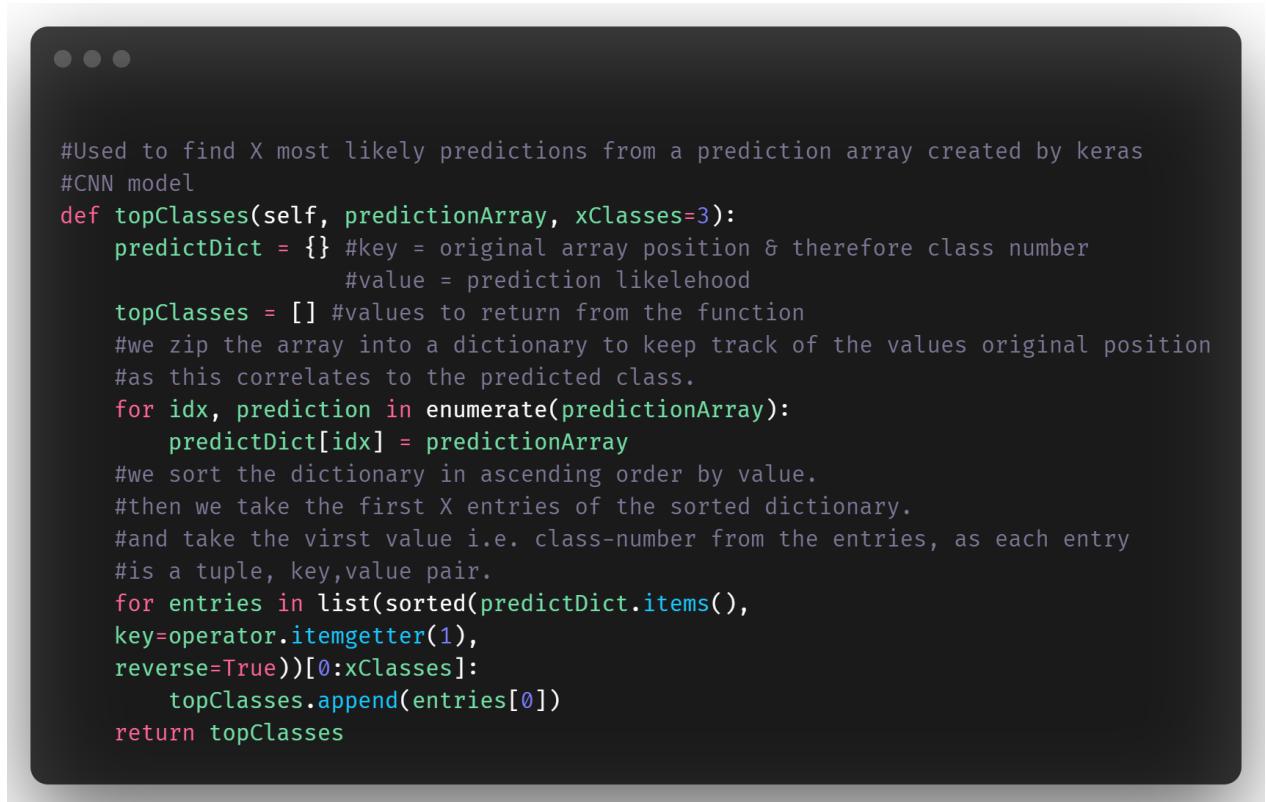
def determineTopClasses(self, predictionArray):
    predictDict = {}
    topClasses = []
    for idx, prediction in enumerate(predictionArray):
        predictDict[idx] = prediction
    for entries in list(sorted(predictDict.items(),
                               key=operator.itemgetter(1),
                               reverse=True))[0:3]:
        topClasses.append(entries[0])
    return topClasses

topClasses = model.determineTopClasses(results)

return{
    "classNo" : topClasses[0],
    "topClasses": topClasses,
}

```

Figure 10: Example 1 : Refactor 3



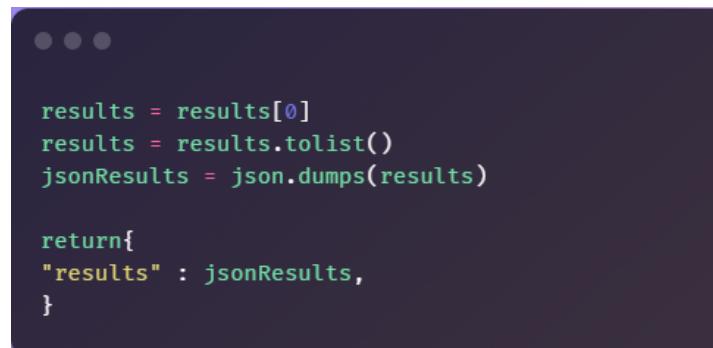
```

#Used to find X most likely predictions from a prediction array created by keras
#CNN model
def topClasses(self, predictionArray, xClasses=3):
    predictDict = {} #key = original array position & therefore class number
                      #value = prediction likelehood
    topClasses = [] #values to return from the function
    #we zip the array into a dictionary to keep track of the values original position
    #as this correlates to the predicted class.
    for idx, prediction in enumerate(predictionArray):
        predictDict[idx] = prediction
    #we sort the dictionary in ascending order by value.
    #then we take the first X entries of the sorted dictionary.
    #and take the virst value i.e. class-number from the entries, as each entry
    #is a tuple, key,value pair.
    for entries in list(sorted(predictDict.items(),
                               key=operator.itemgetter(1),
                               reverse=True))[0:xClasses]:
        topClasses.append(entries[0])
    return topClasses

```

Figure 11: Example 1 : Refactor 4

In this example of refactoring we see how multiple redundant variable allocations can be condensed into a single line.



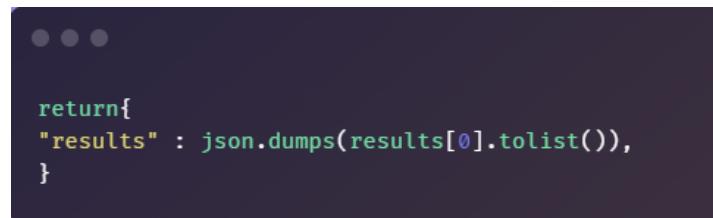
```

    results = results[0]
    results = results.tolist()
    jsonResults = json.dumps(results)

    return{
        "results" : jsonResults,
    }

```

Figure 12: Example 2 : Initial



```

    return{
        "results" : json.dumps(results[0].tolist()),
    }

```

Figure 13: Example 2 : Refactor

Given these examples it's easy to see why lines of code created is a rather ineffective way (in isolation) of determining programmer productivity.

3.2.5 CNN Model Creation & Integration

To create the CNN it is possible to perform modifications to an 'off the shelf' model included in the Keras library. The modifications involve changing the first and last layers to match the input image size and number of output classes respectively.

A fast to train model will be essential due to the limitations of using Google Colab, which requires frequent user interaction to prevent from stopping computation or entirely disconnecting the runtime. Therefore a model with low-number of parameters will be chosen.

The weights of the CNN will need to be saved after each epoch to ensure that if a disconnect occurs, less training progress will be lost. Once the model is finished training it will have its class list extracted and be saved into a .h5 file to be loaded on the API. The JSON class list will also be added to the API.

When training the CNN one will utilize a pre-trained (on the ILSVRC dataset) to further cut down training time, as this will mean the CNN already has a set of generic feature maps. The focus on reducing training time is based on the fact that training large networks with millions of parameters can take days or weeks, even when utilizing high end GPU's. as discovered in the literature.

For the tradeoff in training time it is unlikely the model will achieve state of the art performance, but it is likely to achieve within a few percent. This has driven the requirement that the model must be easily replaced.

3.2.6 Version control

I will be using Git and Github. This will allow the creation of branches to explore experimental parts of the solution space without disrupting the progress of the main branch. If the experimental implementation is successful it will be merged with the main branch. It also allows the development of features in parallel, with any conflicts in their implementation being resolved at the merge stage. The inclusion of a remote repository allows for work to continue on a separate machine if necessary and later be synced with the local main branch.

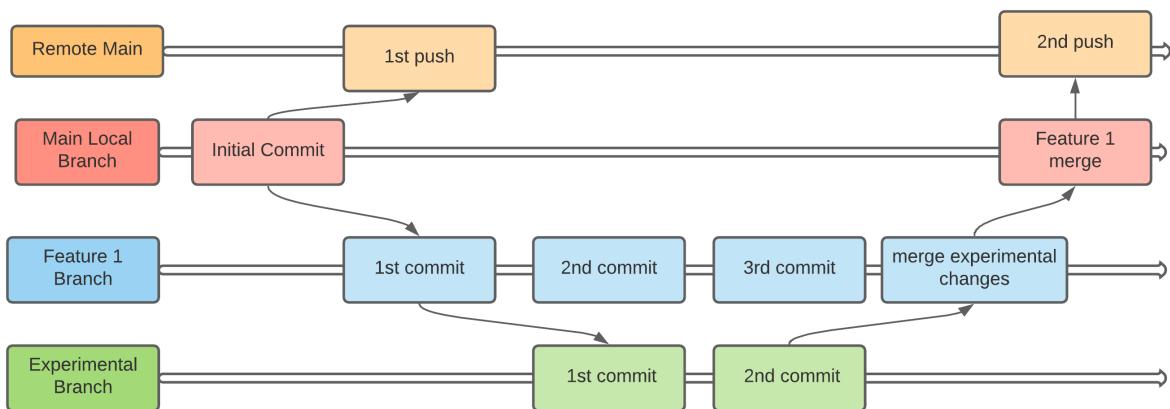


Figure 14: Example Workflow To Highlight Branch Usage

3.3 Evaluation methods

3.3.1 User Interface

The main method that will be utilized to determine the quality of the user interface will be the System Usability Scale (SUS) which can be seen here. (CITATION) The evaluator will be given remote access to the webservice. They will also be provided with some sample images to test the performance of the CNN in case they do not have suitable images of their own. The opinion data will be collected via online questionnaire.

3.3.2 Convolutional Neural Network (CNN)

Metrics for the evaluation of the CNN will be:

- Time to train the network on available hardware

- The constraint here being if the network cannot be trained on the available hardware in under sixteen hours. Purely for practical considerations.
- Accuracy of CNN predictions. (which will be most effective when there are equal numbers of samples belonging to each class) $Accuracy = \frac{CorrectPredictions}{TotalPredictions}$ Else if the samples are skewed, the network could be a failure at detecting a specific under-represented class, yet still score high accuracy.
- Precision. This is the number of correctly predicted images out of all predictions of that class. $Precision = \frac{CorrectlyPredictedforClass}{TotalPredictedforClass}$ The network is precise for a class when the predictions it does make for the measured class are correct. Precision cannot be used in isolation due to the fact that the network can have a high prediction for a class but still fail to identify the majority of images for that class. Succeeding solely on the fact that the images it has classified as the class being measured are correct.
- Recall. Is the correct number of predictions for a class out of the number present of that class. $Recall = \frac{CorrectPredictedforClass}{No.PresentForClass}$ This metric can also not be used in isolation due to the fact it does not take into account the number of false positives. i.e. The number of images incorrectly classified as the class in question. For example, if an image dataset contained three classes A, B, C, and the classifier labeled all images A. The recall for A would be 100 percent.
- F1 score. This metric tries to find the balance between precision and recall and can be expressed as $F1 = 2 \times \frac{1}{\frac{1}{Precision} + \frac{1}{Recall}}$

3.4 Initial Designs

Firstly I have created a wireframe UI

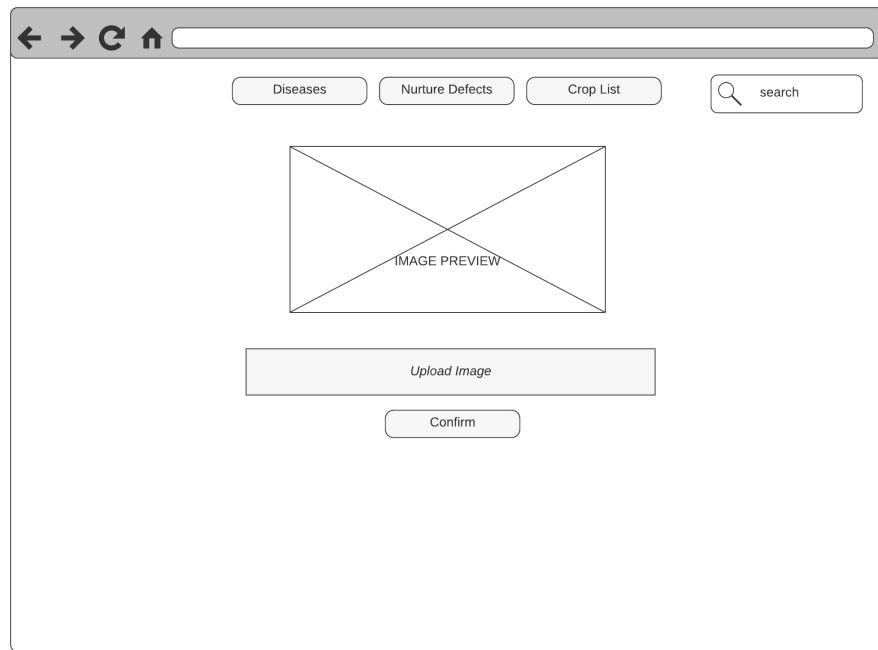


Figure 15: Homepage Wireframe

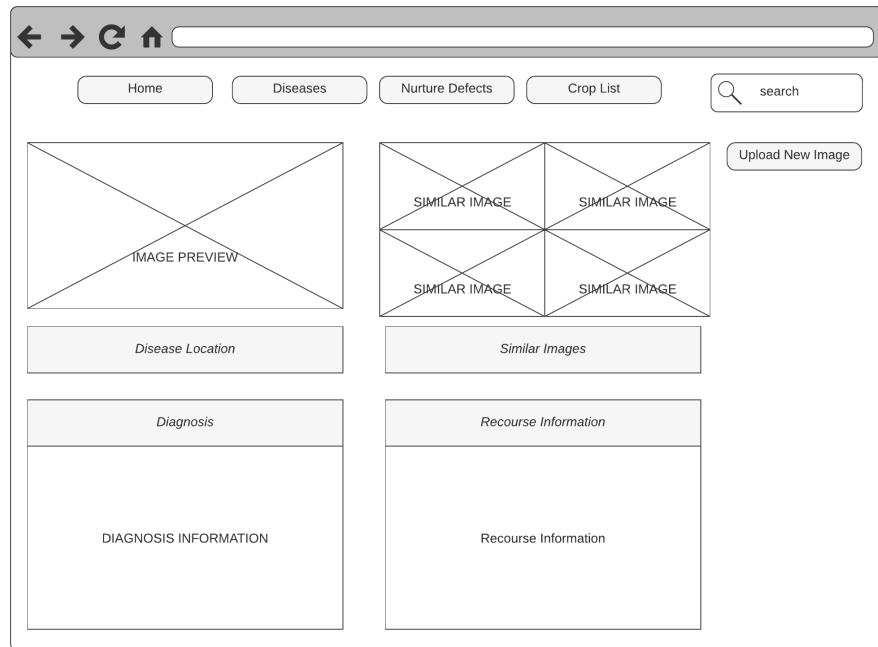


Figure 16: Defect Information Wireframe

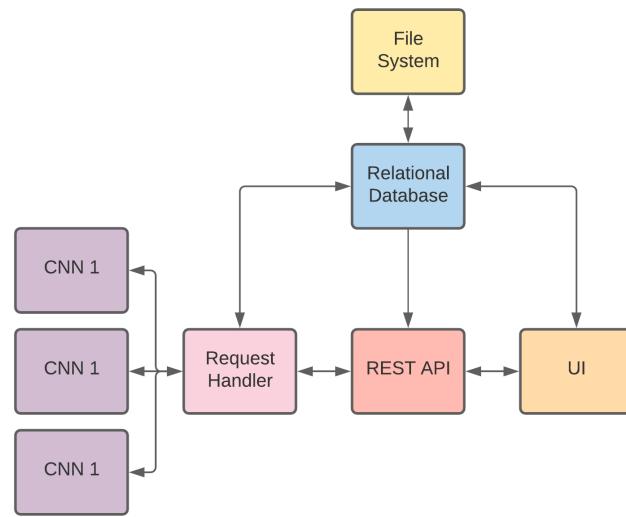


Figure 17: System Overview

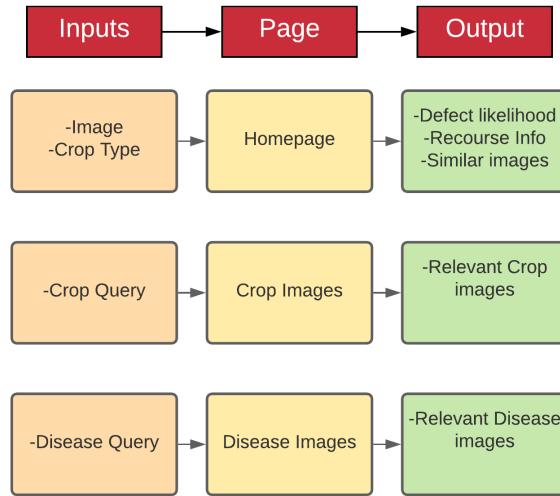


Figure 18: Input/Output overview

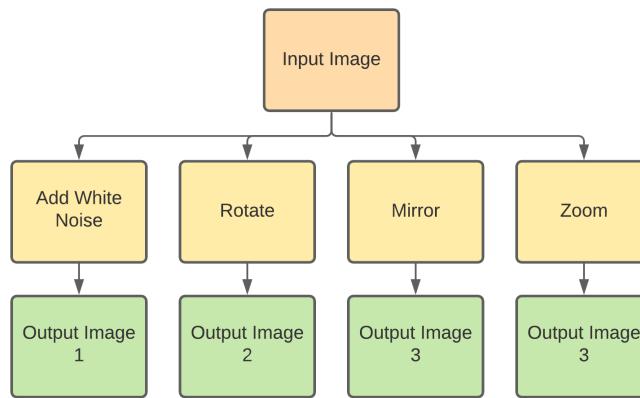


Figure 19: Input/Data Augmentation Methods

3.5 Employed Technologies & Justifications

3.5.1 Software Structure

Back-End

The design aims to separate the functionality of the CNN and the User Interface (UI) through use of a Representational State Transfer (RESTful) Application Interface (API). The central idea of this approach is to allow a separation of distinct components which allows for flexibility in managing updates and changes to each component. The 'backend' which in this context refers to the CNN and its related functionality, such as processing its input's and outputs; will both receive input and serve its output through the interface of the RESTful API. Each 'endpoint' or in other words internal class of the API will all inherit from the Resource interface which means it will get the main four HTTP protocol functions. POST, GET, PUT, DELETE. All interrogations of the CNN will be conducted through these requests.

A key feature of a RESTful interface is the fact that no client information is stored between requests, this aids in making the interface more scalable and interoperable. Scalable in the sense that increasing clients does not increase the amount of information the backend will have to store and interoperable in the sense that any client, be it mobile application, CLI program or webpage can use the interface.

To increase orthogonality of the system, defect images are stored standalone on an image server. With the API serving the name of the defect which gives the information necessary for the webpage to retrieve the correct images. This is because the directory structure of the image server is set up such that directory names are defect classes and all image names are numbers. Having the

images stored on a separate server rather than bundled with the front-end makes the service more useful. As it means any other interface can also choose to obtain the defect images (although image server endpoint information is not currently served by the API).

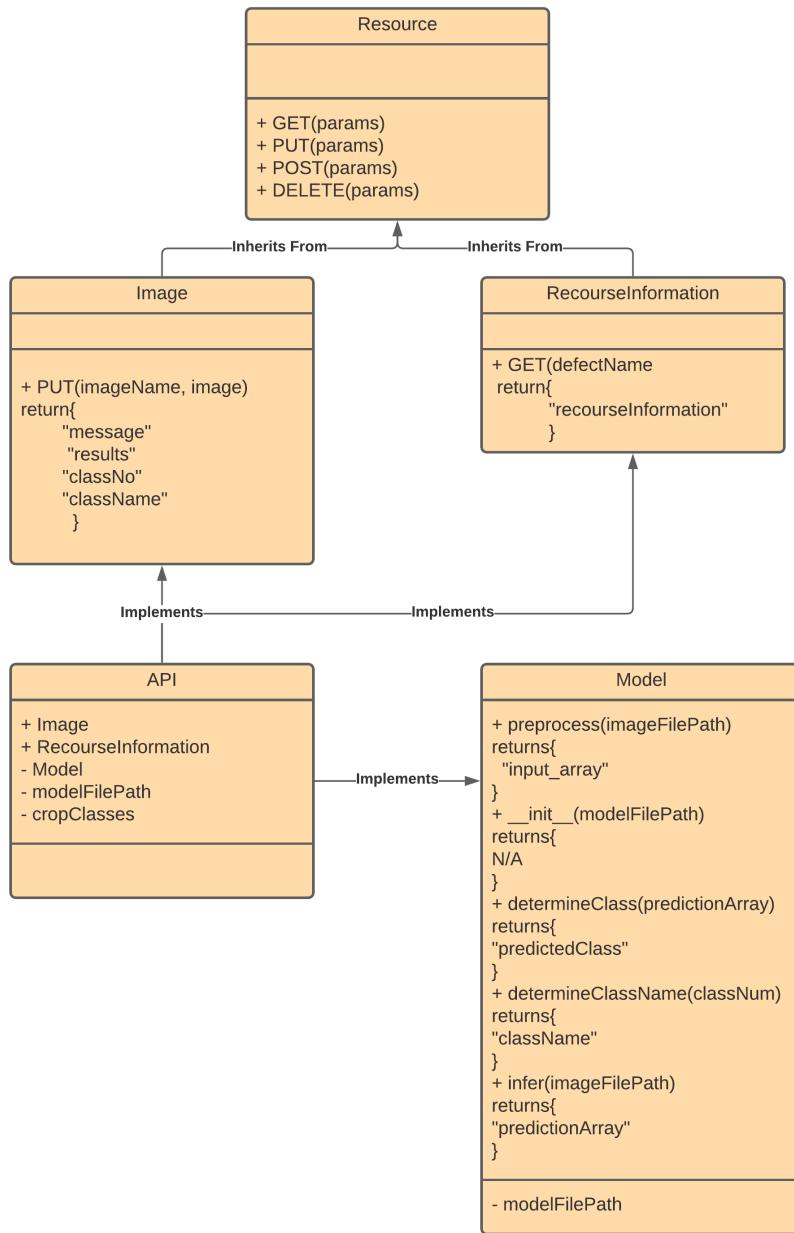


Figure 20: Backend Class Diagram

Front-End

Using the Vue.js webpack framework means the front-end will be split into components. A component acting much like an endpoint in an API. Each component will have its own set of functions and data, with the purpose of separating functionality of the UI into manageable subsets of functionality and styling with the objective being to decouple dependencies between components as

much as possible. This helps simplify the development process as it separates the problem into distinct parts and it helps with maintenance, allowing them to be tested and developed on in isolation.

UI components will be defined using Hypertext Markup language (HTML) and Cascading Style Sheets (CSS). Interactivity will be scripted in Javascript. All three extremely common in web development.

The main functionality of the web-app will be uploading an image to be analysed by the CNN and receiving a prediction of which defect is/isn't present. This will be conducted by a single component. Once a prediction has been made, the user can choose to see more information (consisting of images and recourse information) about the defect, which will be handled by a second component.

Responses from the API will come in JSON format. JSON is a structured data language and stores data hierarchically. This leads to dictionaries and lists of arbitrary depth in a tree structure. Much the same as XML or a filesystem. JSON is a very common language when dealing with webservices and is considered the norm to be the response of an API.

The application is made with the intention that as much data processing, such as determining which class is predicted, image preprocessing, and determining of defect image URL's, defect names etc. is handled on the back-end, meaning that any client wishing to interact with the API does not have to implement these features themselves. Therefore all functionality implemented in the web app will concern the consumption of user input and display of API response.

This means the navigation drop-downs, defect images and recourse/prevention information are all served dynamically through the API and can be scaled more easily than if the information was stored on the frontend. Because the content is dynamic, any client consuming the information won't have to manually update their defect list or defect names if the CNN model changes. This is in-line with the don't repeat yourself (DRY) principle. Having two places where what is supposed to be the same information is stored is an immediate 'code smell' and can easily lead to bugs. This also stands true for methods which enact some kind of business logic. For instance it would not be best practice to implement the algorithm which re-scales the image both on the front and back end, as the size the algorithm needs to re-scale to may change, or a better method for re-scaling the image may become apparent, this would cascade to changing two parts of the system.

3.5.2 Hosting

To make the application accessible on the internet one will utilize virtual machines (VM's) running linux, hosted in the cloud. There will be three VM's, one to host the front-end, back-end and the other to host the defect images. In all cases nginx will be used to create HTTP servers that will handle all functionality regarding the HTTP protocol and the socket layer.

Aside from creating backups of work, version control allows production environments (in this case the VM's) to be easily updated with new features, simply by pulling the latest changes from the repo, installing any new dependencies and re-building the application.

3.5.3 Choosing The CNN Architecture

The initial architecture one experimented with was the InceptionNetV3, the reason being that one already had a familiarity with the architecture and therefore could rationalise about what may need to change in order to get better performance on the target dataset if initial experiments were not satisfactory. One opted to use a model pre-trained on the ILSSVRC dataset and fine-tune it to suit the crop dataset. This resulted in the model taking around six hours to train over an epoch (using Google Colab GPU runtime) and also drastically overfitting the training data. One reasoned that the vast number of weights could be to blame for both problems, firstly the more weights the greater the training time, secondly, more filters leads to the network making less generalisations and being able to store many bespoke feature maps to target subsets or perhaps even individual images. Hence when it comes to an unseen example it's feature maps are not generic enough to aid in identifying the unseen image. Therefore one decided to use a smaller network, 'EfficientNetB0', a network available as a pre-trained¹[1] CNN through the Keras library. For comparison the InceptionV3 architecture is 92mb and contains 23,851,784 parameters (weights) whereas the EfficientNetB1 is 29mb and contains 5,330,571 parameters (approx 1/3 the parameters). Fine-tuning this network proved very successful, achieving a 98.6% accuracy. For this dataset, due to the fact all classes the network is classifying for are relatively similar, less feature maps are needed to generalise about the forms present. To contrast, a network that must classify 100 different classes ranging from a baseball to a shark, with all objects present in different contexts, for instance a closeup of the baseball sat on a table, and a long range shot of it mid flight across the stadium. And it becomes easy to see why so many filters would be necessary. If we take the crop-example we see all images are closeups of leaves with a neutral background. Therefore it is possible to generalise about this smaller subset of possible images with fewer filters. In fact few parameters becomes a desirable quality of the network as it forces the network to generalise

¹on the ILSSVRC dataset

as it does not have the ability to 'memorise' all the individual training images.

CNN Data and Training

One of the most important parts when creating a CNN is the data it is trained on (Halevy *et al.* 2009). The more properly labeled data the network sees, the better. The most comprehensive dataset available (and the one which will mostly be used) is the Plant Village dataset. It contains 54303 images of healthy and unhealthy leaf images, in 38 categories divided by species and disease. This dataset also contains pre-segmented²[1] versions of all the images. This dataset was used in two separate studies cited in the literature review.

Other datasets that may be used to pre-train the network before are the CIFAR10, CIFAR100 & ILSVRC datasets. These datasets are not specifically plant based, but may benefit the network to build initial feature maps. In (Choi) the authors used networks pre-trained on generic data such as the datasets mentioned. Experiments will be conducted to determine if this benefits classification accuracy [comment](not yet...)

One unfortunate aspect was the fact that one was unable to obtain a dataset that reflected plant defects other than diseases, such as nitrogen/water/heat deficiencies.

3.5.4 Technologies & Libraries

Vue.js

Vue.js allows for rapid creation of usable websites thanks to its webpack framework, which handles most of the boilerplate needed to handle URL routing and overall structure. It is also considered easy to learn when compared to React and Angular (im Studiengang Bachelor *et al.*) which for this project is optimal. Although Vue is currently less popular than React and Angular its popularity is rising, which means it's not entirely redundant to learn from an employability standpoint. Vue is a component based framework, meaning it creates a structure to allow the programmer to utilize component technologies to build the website. The component technologies are; custom elements, which allow the programmer to embed javascript code in to either existing HTML elements by inheriting from them, or creating entirely new ones. HTML templates, which allows for sections of HTML to be re-used throughout the application, for instance navigation bars. And Shadow DOM's, which allows for DOM elements to contain sub-trees of elements, this is to aid in encapsulating the scope of the contained scripting and styling, meaning individual elements can have their own layers of encapsulation.

²meaning the background has been blacked out

Bootstrap

Bootstrap is a CSS framework that has predefined classes for styling HTML elements, this helps with the aesthetics of the webpage. For a solo developer this can allow for more time to be spent on making the functionality more robust and cut down time spent on appearance.

Jupyter Notebook / Google Colab

The Jupyter Python environment allows for easy prototyping of code, it allows the programmer to write code in cells that can be run independently and not necessarily in the same order each time. In the case of Colab, it allows for the usage of google servers and Graphics Processing Units (GPUS) which can be used to train neural networks. With the benefit of being able to then save the trained weights for usage elsewhere.

Tensorflow & Keras

These Python libraries allow for the creation of complex CNN architectures by abstracting away the underlying matrix/tensor multiplication of deep learning. Allowing for the programmer to declare relationships between CNN features such as convolutional layers, batch normalisation, dropout etc. Without having to construct their inner workings. It also allows for the creation of user defined layers, so adding in ones own bespoke functionality for a layer of the CNN is possible. These libraries are ubiquitous in the machine vision sector, with cutting edge models being created

Nginx

NginX is a web server. This software, installed on the virtual machines (VM's) hosting, front/back end and files. Handles incoming HTTP protocol requests on ports it is configured to listen to, and serves content accordingly. Additionally, if the need arises, NginX can be used as a load balancer. Taking incoming requests and distributing them amongst the back-end servers via a reverse-proxy. With the reverse-proxy approach it is also possible to cache response data. Reducing load on the back-end. It can also be used to create IP address white/black lists, set file upload limits, keep access logs and more.

Gunicorn

Gunicorn is another technology used to host the application. This time it is used to interface with the Flask API. It is a Web Server Gateway Interface (WSGI) HTTP server. This gives an interface to the API to allow it to send data back and forth between the web server, NginX.

Flask/FLask-Restful

These libraries provide a framework for creating RESTful API's in Python and gives the Resource class to inherit from for each endpoint. Flask also provides a built in development server for testing the application on your local machine.

Numpy

This Python library is essential when performing mathematical operations with Python, especially matrix multiplication, as in this case it is over 10,000 times faster than vanilla python. Other mathematical operations are also often orders of magnitude faster than vanilla. Additionally it adds the ability to use 'proper' arrays and not lists which are extensible, this means less memory is needed.(Wickramarachchi 2020)

Node & Node Package Manager

Node creates an environment for JavaScript to be run outside of the browser environment. This is especially useful during development as it allows the developer to create a local Node server to test the code. Node's package manager checks for any dependencies the code may have and automatically installs appropriate versions, ensuring that the project does not have incompatible versions of dependencies installed simultaneously. As this can easily be a source of frustration when trying to handle multiple dependencies. This also means that whenever a new dependency is added in development, the package manager will automatically add and install it in production during the build process.

3.6 Requirements

For assessing requirement priority one will employ the MOSCOW method (Clegg and Barker 1994). This creates subcategory of requirements with the headings Must/Should/Could/Won't - have. The contents of the categories can change during development in light of development progress. Items placed in the Won't-have category prevent the process of 'scope-creep'.

- Must Have
 - CNN that is capable of classifying at least 2 different defects across 2 different plant species.
 - An API that allows communication from the UI to the CNN
 - API must be able to receive images.

- * Accepted formats being .jpg & .png
- API must return defect information, which will be an array of probability values for each defect class
- API must return recourse information.
- Application must display images that show the predicted defect.
 - * These images may be stored either on a separate server to the front-end. Perhaps in the API servers 'static folder'. Alternatively they will be bundled with the front end.
- The API will be robust enough to handle the receipt of erroneous requests.
- A python backend that will handle image classification using a CNN.
- A UI that will allow the user to upload an image to be analysed.
 - * The user will be able to choose an image file from their local storage using a file explorer popup.
- The UI will display information regarding the likelihood of each kind of possible defect.
- To display the relevant images that fit the description of the most likely defects.
- To display recourse information to rectify the defect.
- Collecting, cleaning and pre-processing the image data.
- Artificially grow the dataset by performing translations/rotations/adding noise to the images to make the training data more comprehensive.
- CNN model should be straightforward to replace when better performance is realised.
- Should Have
 - A page to allow users to see a gallery of images sorted by defect type.
 - The CNN should be able to classify at least 7 different defects across at least two different plant species.
 - The CNN should achieve at least 80% accuracy at classifying all different classes of defect in a held out test set that contains an equal number of each class.
 - Regularisation techniques to prevent the NN overfitting.
- Could Have

- Mobile device support.
- Ability for users to add additional information about the crop to determine the defect.
- Won't Have

Chapter 4 - Results and Discussion

4.1 Main Results

4.1.1 CNN

The Performance of the CNN given the available hardware (Google Colab GPU Runtime) is good. With a 98.6% classification accuracy on a held out validation set. With current cutting edge being 99.74% on the same dataset (as covered in the literature review). The CNN is capable of identifying 38 unique classes of crop images. Unfortunately due to the lack of data, one was unable to include additional defects such as lack of water/nitrogen/sunlight etc. However the design of the system allows for the CNN model to be changed very easily. As simply as changing two files on the API server. This means that as model performance improves and classification range broadens, the system is able accomodate for this.

Separation of the software components allows for the easy interchange of CNN models. This means once the model is trained, changing the model is as simple as changing a single filepath on the API server. Although if one wishes to extend the number of defects (classes) the model is able to predict; three steps must take place. Firstly, the filepath to the JSON file defining all classes must be updated on the API to reflect the new set of classes, the model .h5 file needs updating. And lastly the images for the new defect must be added to the image server. Making the process straightforward as updating two file paths and uploading images using secure file transfer protocol (SFTP).

4.1.2 Architecture

The separation of responsibility between the API and front-end has created two orthogonal systems that can be upgraded and interchanged easily. The front end need not know any details about the CNN(model) it is interacting with. The classes the model is able to identify are dynamically updated on the front-end and prediction data also remains consistent between model implementations. Recourse and prevention information are similarly easy to update and can be changed dynamically, simply by updating a JSON file on the back-end. Images the front-end display are also easily changed and are hosted on a separate image server, further separating the systems interdependence. A call for modularity and separation of responsibility was a key theme occurring

in many works cited in the literature review.

4.1.3 Development

A major change made to the design of the application was the choice to drop the relational database in favor of using hierarchical storage as it was noted that the application did not need to handle complex relational data. Initially the purpose was to have the database handle filepaths to images and recourse/defect information but this was easily handled with consistent directory naming on the image server and JSON files.

A feature that has the code in place to deliver but no information to display is the recourse and prevention section. At this stage one was unable to obtain the information necessary to populate these values. However, once the relevant information is obtained, only JSON files on the API side need be updated to properly fulfill this requirement.

Some of the main issues that arose during development were during the move to production. This involved learning new technologies such as NginX and Gunicorn to deploy the project as the configuration can be obtuse upon first interaction. Some API code also did not work the same way as on the development server and so had to be modified to work in the production environment.

Through the use of version control it has been straightforward to update the code on the production servers as it is simple as pulling the latest changes from the git repository. Version control has been helpful throughout the lifecycle thanks to the ability to branch the codebase (see version control).

Upon reflection, using the Vue.js framework standalone may not have been the best choice for the sole reason that one did not find a way of caching page states. Which has led to the inability to go back to the results display state of the Upload *Image* page after navigating away from it. It is possible that using the

4.1.4 System Usability

Strongly agree = 5, Strongly disagree = 1. In the case of odd questions, agreeing is positive sentiment. For even questions agreeing is negative sentiment. The calculations are as follows. X is the sum of odd-numbered questions -5. Y is 25-sum of all even-numbered questions. The SUS score is $(X + Y) * 2.5$. The mean average of all SUS scores is then calculated. With the best possible score being 100.

1. I think	2. I fou	3. I tho	4. I th	5. I fc	6. I th	7. I wc	8. I fc	9. I fe	10. I n	X	Y	SUS Score
5	1	5	1	4	1	5	1	5	1	19	20	97.5
3	2	4	2	4	2	5	1	4	3	15	15	75
4	2	2	3	4	2	4	2	4	1	13	15	70
3	1	5	1	5	1	4	1	4	1	16	20	90
4	2	4	1	4	1	5	2	4	1	16	18	85
3	1	4	2	4	3	5	2	4	1	15	16	77.5
4	2	4	1	4	3	4	2	4	2	15	15	75
5	1	4	2	4	2	5	1	4	2	17	17	85
											81.875	

Figure 21: SUS scores table

In this case the system scored 81.875 which is above the average of 68 (Jeff Sauro 2011). However with the limited number of questionnaire respondents (8) the evidence is not wholly conclusive.

4.1.5 Requirements Checklist

- Must Have
 - CNN that is capable of classifying at least 2 different defects ✓ The CNN is capable of classifying 38 crop classes. across 2 different plant species.
 - An API that allows communication from the UI to the CNN ✓
 - API must be able to receive images.
 - * Accepted formats being .jpg & .png
 - API must return defect information, which will be an array of probability values for each defect class ✓
 - API must return recourse information. ✓
 - Application must display images that show the predicted defect. ✓
 - * These images may be stored either on a separate server to the front-end. Perhaps in the API servers 'static folder'. Alternatively they will be bundled with the front end.
 - The API will be robust enough to handle the receipt of erroneous requests. ✓
 - A python backend that will handle image classification using a CNN. ✓
 - A UI that will allow the user to upload an image to be analysed. ✓
 - * The user will be able to choose an image file from their local storage using a file explorer popup.

- The UI will display information regarding the likelihood of each kind of possible defect.
 - ✓
 - To display the relevant images that fit the description of the most likely defects.✓
 - To display recourse information to rectify the defect.✓
 - Collecting, cleaning and pre-processing the image data. ✓
 - Artificially grow the dataset by performing translations/rotations/adding noise to the images to make the training data more comprehensive.✓
- Should Have
 - A page to allow users to see a gallery of images sorted by defect type. ✓
 - The CNN should be able to classify at least 7 different defects across at least two different plant species. ✓
 - The CNN should achieve at least 80% accuracy at classifying all different classes of defect in a held out test set that contains an equal number of each class. ✓
 - Regularisation techniques to prevent the NN overfitting. ✓
 - Could Have
 - Mobile device support. ✓
 - Ability for users to add additional information about the crop to determine the defect.
 - Won't Have

4.2 Evaluation Results

lorem ipsum

Chapter 5 - Conclusion

5.0.1 Further Work

The design of the API lends itself to easily being extended to include more endpoints. This can enable the API in the future to handle requests to different models for different classification problems. One possible usage of this extensibility is that of automated pest/weed control. Whereby the system would include using drones to destroy weeds in crop fields automatically. Additionally, a model may be trained to analyse aerial photographs of land, to determine if conservation/re-wilding targets are being met.

A way of integrating the model API with even further applications is using blockchain technology. Currently there exists a service known as Chainlink (<https://chain.link/>). Which aims to be a middleware to bring external API feeds to existing blockchains. This could stand as a way of monetizing the usage of image classification or other AI services, such as recurrent neural networks (RNN) for text sentiment analysis, music generation or image upscaling etc.

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Appendix A - Project Proposal

Appendix B - Ethics Checklist