Kyffin Williams: Digital Analysis of Paintings

Final Report for CS39440 Major Project

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Acknowledgements

Abstract

CONTENTS

1 Background & Objectives **1**
- 1.1 Sir John "Kyffin" Williams . . . 1
- 1.2 Interdisciplinary work with the National Library of Wales . . . 1
  - 1.2.1 Continuation of the Kyffin Project . . . 2
- 1.3 Existing Work . . . 3
  - 1.3.1 Edge-Orientated Gradients . . . 3
  - 1.3.2 Brush-stroke Analysis . . . 4
- 1.4 Analysis Objectives . . . 5
  - 1.4.1 Colour-space Analysis . . . 5
  - 1.4.2 Texture Analysis . . . 6
  - 1.4.3 Brush-stroke Analysis . . . 6
  - 1.4.4 Ensemble Techniques . . . 6
- 1.5 Classification Objectives . . . 6
  - 1.5.1 Classification . . . 7
  - 1.5.2 Exemplars . . . 8

2 Development Process **9**
- 2.1 Introduction . . . 9
- 2.2 Modifications . . . 9

3 Design **10**
- 3.1 Methodology . . . 10
- 3.2 Overall Architecture . . . 10

4 Implementation **13**
- 4.1 Basic Structure . . . 13
  - 4.1.1 Loading Data . . . 13
  - 4.1.2 Top-Level Classes . . . 13
  - 4.1.3 Command Line Interface . . . 14
- 4.2 Colour Space Analysis . . . 14
  - 4.2.1 Colour Models . . . 14
  - 4.2.2 Colour Histograms . . . 15
- 4.3 Texture Analysis . . . 15
  - 4.3.1 Edge Orientation . . . 15
- 4.4 Brush-Stroke Analysis . . . 16
- 4.5 Classification and Validation . . . 16
  - 4.5.1 k-Nearest Neighbour . . . 16
  - 4.5.2 Leave-One-Out Cross Validation . . . 16
  - 4.5.3 Weka 3 . . . 16
  - 4.5.4 Exemplars . . . 16
  - 4.5.5 Statistically Classified Exemplars . . . 17
- 4.6 3rd Party Libraries and Tools . . . 18
  - 4.6.1 Python . . . 18
  - 4.6.2 OpenCV . . . 18
  - 4.6.3 scipy & numpy . . . 18
  - 4.6.4 matplotlib . . . 18

4.6.5 Weka 3 . . . 18
4.6.6 git & github . . . 18

5 Testing **19**
5.1 Overall Approach to Testing . . . 19
5.2 Validation . . . 19
5.2.1 Leave-One-Out Cross Validation . . . 19
5.2.2 Validation using Weka . . . 19

6 Evaluation **20**
6.1 Evaluation of Requirements . . . 20
6.2 Evaluation of Design . . . 20
6.3 Evaluation of Tools . . . 20
6.3.1 Programming Language . . . 20
6.3.2 Image Processing/Computer Vision Libraries . . . 20
6.3.3 Machine Learning Libraries . . . 20
6.3.4 Scientific and Numeric Libraries . . . 20

Appendices **21**

A 3rd Party Libraries and Tools **22**
1.1 Python 2.7 . . . 22
1.1.1 setuptools . . . 22
1.1.2 scipy . . . 22
1.1.3 numpy . . . 22
1.1.4 matplotlib . . . 22
1.1.5 liac-arff . . . 22
1.2 OpenCV . . . 22
1.2.1 OpenCV Python . . . 22
1.3 Weka 3 . . . 22
1.4 git . . . 23
1.4.1 github . . . 23

B Equations **24**
2.1 Statistical Equations . . . 24
2.1.1 Mean . . . 24
2.1.2 Standard Deviation . . . 24
2.1.3 Pearson's product-moment coefficient . . . 24
2.2 Distance Equations . . . 24
2.2.1 Manhattan Distance . . . 24
2.2.2 Euclidean Distance . . . 24
2.3 Filter Equations . . . 24
2.3.1 Gradient Direction . . . 24
2.3.2 Discrete Derivative Masks . . . 25
2.3.3 Gabor Filter . . . 25

C Code Samples **26**
3.1 Example CSV Parsing Code . . . 26
3.2 argparse Example Code . . . 26

3.3 Gabor Filter Example Implementation 26
3.4 OpenCV Histogram Example Code 27

D Spreadsheet Data **29**

Annotated Bibliography **48**

LIST OF FIGURES

1.1 Example of a 1 by 2 Discrete Derivative Mask 3
1.2 Example of a 1 by 3 Discrete Derivative Mask 3
1.3 Pseudocode for Leave-One-Out Cross Validation 7
1.4 Pseudocode for k-Nearest Neighbour 7

3.1 Overview of the Classification Methodology 11
3.2 Basic Overall Architecture 11
3.3 Overall Architecture with Factory Methods 12
3.4 Overall architecture with Interfaces for Analysers and Classifiers 12

4.1 Painting Data in CSV Format 13
4.2 Steerable Filter ($\theta = 0$) 16
4.3 Steerable Filter ($\theta = \frac{\pi}{4}$) 16
4.4 Steerable Filter ($\theta = \frac{\pi}{2}$) 16
4.5 Steerable Filter ($\theta = \frac{3\pi}{4}$) 17
4.6 Nearest Exemplar Classification Psuedocode 17
4.7 Psuedocode for generating a Statistically Classified Exemplar 18

LIST OF TABLES

4.1 Layout of the Painting Data Spreadsheet 13
4.2 Command Line Arguments 14
4.3 Layout of the Exemplar Spreadsheet 17

D.1 Painting Spreadsheet Data 46
D.2 Exemplar Spreadsheet Data 47

LIST OF LISTINGS

C.1 Example CSV Parsing Code from http://docs.python.org/2/library/csv.html 26
C.2 Example argparse Code from http://docs.python.org/2/library/argparse.html . . . 26
C.3 Example implementation of a Gabor Filter in MATLAB from wikipedia [5] . . . 27
C.4 Example Histogram calculation and displaying code from OpenCV [3]. 27

Chapter 1

Background & Objectives

1.1 Sir John "Kyffin" Williams

Sir John "Kyffin" Williams (1918-2006) was a Welsh painter and printmaker, widely regarded as the defining artist of Wales during the 20th century [7]. He was advised to take up art by a doctor after failing a British Army medical examination because of an 'abnormality' (epilepsy) as something which would not tax his brain.

He studied at the Slade School of Fine Art and taught art in Highgate School, after which he retired to Anglesey until he died in 2006 after a long battle with cancer.

His most characteristic pictures are of Welsh landscapes, painted with thick layers of oil paint applied with a palette knife [4]. Most of his paintings are highly textural; to the point of being 3-dimensional.

As his life progressed Kyffin's 'abnormality' grew steadily worse, especially when exposed to bright light. As a result most of his paintings are of overcast Welsh landscapes and tend to become visibly darker over time [10]. By eye it is generally quite easy to approximate the time period in which a painting was created.

In 1969 he won a scholarship to study and paint in Y Wladfa; the Welsh settlement in Patagonia. This period of his life is very obvious from his paintings as there is a complete contrast in colour between Patagonian and Welsh landscapes.

1.2 Interdisciplinary work with the National Library of Wales

This project was initially suggested through a conversation between Hannah Dee and Gareth "Llyod" Roderick about image processing and art. Llyod is a PhD student at the National Library of Wales (NLW). Their initial idea was to try to geolocate a Kyffin painting on a map to build up a geographical representation of Kyffin's work.

Hannah started to create a prototype for performing geographical analysis, this proved to be a difficult task and one which is still being researched.

However, the nature of Kyffin's illness and painting style allows for a second form of analysis: temporal. As previously stated it is fairly easy to judge by eye a good approximation of the period in which a Kyffin painting was created. It should, therefore, follow that this process can be performed digitally.

When I started this project I was given a "database" (in reality this was just a spreadsheet) Llyod had produced, containing information of Kyffin Williams' paintings, including: title, year,

category (landscape, portrait, etc.), canvas size and a few additional details which aren't so relevant to the project.

The first meeting held was between Llyod, Hannah and I, in which we discussed the current state of the project, what our aims for the project were and what form of help Llyod could provide to us. As one of the objectives of this project is to, eventually, get a paper published, the relevant details of the process we would need to go through if we wanted to do so.

The second meeting was between Hannah, Llyod, Lorna M. Hughes (Llyod's supervisor) and I. Again we discussed the state of the project. Llyod had also produced a better version of his "database" to be more machine readable and succinct. A lot of information came from this meeting;

- The "cut-off" point between early and late is around 1973.
- The size of the canvas might be a useful data point to use in classification, as Kyffin sold more paintings he would have had the money available for larger canvases and the paint for said canvas.
- It is a little dubious as to whether some dates can be trusted. One painting owned by the NLW was stated to be his last painting, but Lorna believes it was painted much earlier and claimed to be his last to improve the sale price.
- Llyod may have found date markings on some paintings. These again may not be accurate, but may prove to increase the sample size.
- It should be easy to provide a "no later than" estimate for each painting from the art historians.
- Paul (?) should be able to produce some exemplars for us as a ground truth.
- Llyod may be able to find more paintings in the hands of private collectors to increase the sample size.
- Llyod had been playing around with ImageJ to do some basic graph plotting. This might be useful to look at further to expand my own work.

There were also more detailed discussions about publications, particularly in a digital humanities journal.

1.2.1 Continuation of the Kyffin Project

There are several projects that could continue on from the Kyffin Project.

One was to use the Learning/Teaching development fund to produce a web-based front-end for of some of my analysis.

Another venture was to look into PhD funding to build up a 3D map of some of Kyffin's paintings and being able to display it (perhaps via HTML5 and WebGL) so they can explore the painting digitally how it is meant to be in real life.

1.3 Existing Work

1.3.1 Edge-Orientated Gradients

As Kyffin Williams' work is highly texturally, looking at the edge orientation of the image is likely to be a valuable technique to use.

One technique recommended by Hannah was to look at Histogram of Orientated Gradients (HOG). The suggested paper outlined the use of grids of HOG descriptors to improve the feature set for robust visual object recognition [6]. As it significantly improves the feature set it seems sensible to try and implement it as a technique without the Kyffin project to experiment with a non colour-based approach.

The approach involves quite a few separate steps, only some of which are relevant to the project:

1. Gamma and colour normalization. Grayscale, Red, Green, Blue (RGB) and L, a, b Colour Space (LAB) spaces were used. RGB and LAB give similar results. Grayscale reduced performance less that square root gamma compression, but not as much as log compression.
2. Compute gradients. Often the simplest are the better here; Gaussian smoothing followed by discrete derivative masks (e.g.: figure 1.1, figure 1.2), etc. For colour this was done for each channel, and take the one with the largest norm.
3. Spatial and Orientation binning:
   - Spatial binning is done by splitting the images into cells which can be rectangle or radial.
   - Orientation binning are spaced equally between either 0-180 "unsigned" or 0-360 "signed" bins.
4. Normalisation and Descriptor Blocks. Gradients vary over foreground/background, etc. Typically the blocks were overlapped so that each scalar response contains several components.
5. Pass a detector window across the image.
6. Run through a Linear Support Vector Machine (SVM) to classify the image.

$$\begin{bmatrix} -1 \\ 1 \end{bmatrix}$$

Figure 1.1: Example of a 1 by 2 Discrete Derivative Mask

$$\begin{bmatrix} -1 \\ 0 \\ 1 \end{bmatrix}$$

Figure 1.2: Example of a 1 by 3 Discrete Derivative Mask

Obviously, when applying this as an analysis technique to paintings, there are some points which are completely irrelevant. Passing a detector window and running through a Linear SVM

are the obvious two. Normalisation is another unneeded step; computing performance isn't likely to be a large issue for this project; so long as the techniques complete within a semi-reasonable amount of time.

The leaves the act of computing the gradients (again, this can be done without Gaussian smoothing as that reduces accuracy) which should a simple matter implemented by earlier techniques. Binning by Rectangular Histogram of Orientated Gradients (R-HOG) or Circular Histogram of Orientated Gradients (C-HOG) descriptors, which may prove to the one of the more difficult parts of implementing this technique.

R-HOG descriptors have similarities to Scale-Invariant Feature Transform (SIFT) descriptors, but are used quite differently; SIFT descriptors are optimised for sparse baseline matching whilst R-HOG descriptors are optimised for the dense and robust coding of a spatial form. The size of the descriptor affects performance when using R-HOG, for paintings it may turn out that a size relating to the original size of the painting is a good way of getting around this problem.

C-HOG descriptors become more complex still. They are similar to Shape Context [**?**], but differ in one key aspect: in C-HOG descriptors each spatial cell holds a stack of gradient-weighted orientation cells over an orientation-independent edge-presence count which Shape Contexts use.

According to the author it is better to think of C-HOG descriptors as an advanced form of centre-surround coding as small descriptors with very few radial bins gave the best results.

Local contrast normalisation can be performed to help against local variations in the illumination of foreground and background.

It would seem that both R-HOG and C-HOG descriptors are designed more for the detection window rather than analysis technique. This may make them less useful and result in an implemented technique being just a simple histogram of edge orientations.

1.3.2 Brush-stroke Analysis

Stroke analysis is one of the main goals for this project. It is quite apparent from looking at Kyffin Williams' paintings that his brush-strokes change over time, his early work having lots of smaller strokes over the canvas to large bold strokes in his later work.

The first paper I found relating to the analysis of brush-strokes involved moving a circular filter across the whole painting to find the ridges of strokes, then filling any unbroken areas. They then shrunk these areas to a single pixel line and fitted a n^{th} order polynomial to this line [2]. This method seems fairly simplistic, but could be an interesting first step, but as it is more focused on authenticating paintings it may be of limited use.

Another method for stroke analysis has been published in the IEEE Transactions on Pattern Analysis and Machine Learning journal. This method is far more complex, but is able to extract and label individual brush-strokes. An interesting part of their findings was the ability to date some of Van Gogh's paintings to a known period in his career [12].

This method involves performing edge detection of the painting followed by an edge linking algorithm which aims to remove small, noisy edges and to trace every edge. With this they then perform enclosing, as strokes may not be complete this stage also aims to fill in missing gaps of strokes and to fill these in within a certain tolerance.

The algorithm then decides if a stroke really is a painted stroke, if the stroke is completely enclosed, isolated from other non-edge pixels and forms a connected component then it is likely that it is a proper brush-stroke and is extracted. The edge pixels are used as the background and the non-edge pixels as the foreground, this is the process of labelling the brush-stroke.

For each of these labelled candidates, a heuristic function is used to threshold any brush-strokes that are either too long or too short, these strokes are discarded. These strokes are then

considered to be candidates if they are not significantly branched, the stroke is not too wide (this may change for Kyffin Williams as he used a pallet knife rather than a brush) and the brush-stroke is not too big or small.

Separately, the image is then segmented using k-means clustering by RGB values. This clustering algorithm is applied several times, lowering the tolerances for distance within a cluster. Connected components as a result of this clustering and have noise reduction performed upon them. Finally, the two types of brush-strokes are combined.

This technique may need some changing to account for Kyffin Williams' use of a pallet knife, but the overall principals of this technique should work with Kyffin's paintings.

1.4 Analysis Objectives

Analysis is one of the biggest sections of this project and involves creating techniques which will allow comparison of paintings in a way which will allow some form of classification to be performed on them.

Typically I would expect this to produce some form of high-dimension state space in which each painting is a point in the state space. From this state space the distance between one painting and another can be easily resolved using a distance measure like Manhattan distance (1.1), euclidean distance (1.2) or a distance measure more specific to the state space should it be needed (e.g.: chi-squared for histograms).

$$d_1(\mathbf{p}, \mathbf{q}) = \|\mathbf{p} - \mathbf{q}\|_1 = \sum_{i=0}^{n} |p_i - q_i| \tag{1.1}$$

$$d_1(\mathbf{p}, \mathbf{q}) = \sqrt{\sum_{i=0}^{n} (q_i - p_i)^2} \tag{1.2}$$

1.4.1 Colour-space Analysis

The simplest way of analysing a digital image is to look at the colours which it consists of. Doing this is relatively simple; each pixel has a set of values defining the colour of that point, getting something meaningful from this is less simple.

The simplest strategy is to perform some form of statistical analysis on each painting then use this for classification. Several good and computationally cheap options exist for this; mean (1.3) and standard deviation (1.4), are some good examples which often come predefined in image processing and computer vision libraries.

$$\mu = \frac{1}{N} \sum_{i=1}^{N} x_i \tag{1.3}$$

$$\sigma = \sqrt{\frac{1}{N} \sum_{i=1}^{N} (x_i - \mu)^2} \tag{1.4}$$

The representation of colour is another important factor, an RGB representation will have all three values change if there are many changes in brightness of the colours whilst a Hue, Saturation, Value (HSV) representation will only have a single value change.

Therefore, an object of this section should be to explore different colour models and statistical methods which can be applied to them.

Another useful technique which should be investigated early into the project are image histograms. These histograms plot the distribution of colour across an image and are therefore a very powerful method of analysing an image, especially for comparison. As with statistical analysis, histograms will be largely effective by colour model.

1.4.2 Texture Analysis

As Kyffin Williams' work is very textural, it follows that a main part of the analysis should focus around the texture of his paintings. Unfortunately for this section, it seems unlikely that I will be able to get any 3-dimensional models of Kyffin's paintings. This would have been a nice, if rather large, section of the project.

Instead it is more sensible to look at the orientation of edges in Kyffin's work. Some useful pre-existing techniques have already been discussed in section 1.3.1. Histograms of edge orientation [6] seem like a promising concept which may prove relatively simple to implement.

This section may also help with any work into brush-stroke analysis (see section 1.4.3).

1.4.3 Brush-stroke Analysis

With Kyffin's distinctive style and how obviously this style changes over time, the ultimate aim of this project is to be able to analyse the brush-strokes[1] in a painting.

From looking at the paintings it is very apparent that in his earlier work he made a lot more strokes than in his later works[2]. The strokes in his later work tend to have larger areas and span more of the canvas.

If it is possible to calculate a rough amount and size of strokes made in a given painting it should be a reasonable piece of data to classify on. As previously discussed in section 1.3.2 there has already been a decent amount of research into determining brush-strokes in a painting.

It would be preferable to try and take one of the techniques discussed in that research and change it to suit the needs of the project rather than attempting to create a whole new method of brush-stroke recognition.

1.4.4 Ensemble Techniques

With some of the aforementioned analysis techniques it makes sense to combine two or more techniques together; a good example would be colour histograms and histograms of edge orientation.

This form of analysis is inspired by the concept of the same name in statistics and machine learning which tend to obtain better predictive performance. It may also be worth while trying to weight different techniques so that the techniques which give the best performance affect the result of the ensemble technique more.

1.5 Classification Objectives

The overall objective of classification is to be able to label a painting by Kyffin Williams as being painted in a given year based on analysis performed on all other paintings with known years.

[1] A slight misnomer as Kyffin used a palette knife to paint with rather than a traditional brush

[2] Although this isn't quite true as the canvases he worked on in his later life tended to be larger

This ties in with the main aim of this project of being able to classify any Kyffin Williams painting, whether it has a known or unknown year, as being from a given year. Evidently for paintings with an unknown year it is difficult to know how accurately the system has been, so, for the most part, these paintings have been ignored and those paintings with a known year have made up the training and validation set.

Because of the small size of paintings with known years it should be computationally viable to perform leave-one-out cross validation (figure 1.3).

function LOOCV($data$) ▷ $data$ is a set of all data points
  for all $item \in data$ **do**
    $classified_{item} \leftarrow$ CLASSIFY($item, data \setminus \{item\}$)
  end for
return $classified$
end function

Figure 1.3: Pseudocode for Leave-One-Out Cross Validation

This can be used to evaluate the performance of the analysis technique and classification algorithm. Pearson's product-moment correlation coefficient (1.5) between actual year and classified year has been suggested to be a good performance measure for this project.

$$\rho_{X,Y} = \frac{\operatorname{cov}(X,Y)}{\sigma_X \sigma_Y} = \frac{E[(X - \mu_X)(Y - \mu_Y)]}{\sigma_X \sigma_Y} \tag{1.5}$$

1.5.1 Classification

One of the simplest methods of classification is k-Nearest Neighbour (figure 1.4) from this one can take a poll of the years for each neighbour and assign the year of the painting to classify to be the average of these years.

Depending which form of average you take (mathematical mean (1.3), median or mode) will alter the result; although it should be noted that median is very unlikely to give a result on its own due to the sparseness of the data.

Require: $0 < k \leq |data|$ ▷ $data$ is a set of all data points
  function KNEARESTNEIGHBOUR($k, data$)
    for $i = 1 \rightarrow k$ **do**
      $nn_i \leftarrow$ NEAREST($data$)
      $data \leftarrow data \setminus \{nn_i\}$
      $i = i + 1$
    end for
  return nn
  end function

Figure 1.4: Pseudocode for k-Nearest Neighbour

There are other techniques which could be applied to this problem, but the rewards for implementing them is not likely to be outweighed by the time it would take to implement such techniques. There is a workaround for this; there are several machine learning tool-kits which provide pre-implemented version of these techniques.

One of the most popular tool-kits available for general use is Weka [9], which is discussed in more detail in section 1.5.1.1.

Another technique suggested by Julie Greensmith is to use Learning Classifier Systems (LCS) [1], which has an implementation for Weka. This may prove to give very good results for the kind of analysis being performed on Kyffin's work.

1.5.1.1 Use of Weka

1.5.2 Exemplars

The use of exemplar images would be another way of performing classification. The idea of an exemplar is that a painting is the most representative of a given time period. With the help of Llyod, Lorna and the NLW a list of exemplars which can be used as a ground truth to classify against has been produced.

The initial idea for digitally producing exemplars is to take the middle painting for a time period, as would be expected. These can then be compared to the ground truths to see how correct the analysis technique performed.

However, there is also the potentially to generate a theoretical exemplar from the analysis. This might be hard to perform validation against the ground truth upon, but will give some useful data on Kyffin Williams' style and how it changed.

These theoretical exemplars would likely be produced using some form of Gaussian mixture model.

Chapter 2

Development Process

2.1 Introduction

2.2 Modifications

Chapter 3

Design

3.1 Methodology

Within our database of 325 paintings, we know the actual year of painting for 102 artworks. In order to determine the accuracy of our results, rather than work with the full dataset (and work with images with uncertain metadata in the form of date ranges), we have used a leave-one-out cross validation methodology. This involves us taking a painting for which we know the year, and then using our classifier to guess that year; thus we are able to tell whether we are right. We are also able, if we are wrong, to determine exactly how wrong we are.

To simplify the classification stage we use a K-Nearest Neighbour (KNN) classifier with the other 101 paintings for which we know the date. KNN is a fast, non-parametric classifier which makes no assumptions about the underlying patterns in the data, merely that paintings from around the same time will be similarly located in our feature space(s). Whilst we suspect that there may be some broader underlying trend in the change of style, for this work have concentrated on features for classification rather than the question of classification or regression itself. See figure 3.1.

3.2 Overall Architecture

The basic architecture for any system like this is to load the data in from a source of some form, apply an analysis technique to each data point then pass this data into the classification system.

From the classification system you should then be able to get the classified and actual year for each data point which can then have validation performed on it. This architecture is summed up in figure 3.2.

Building up from this it is apparent that to implement the analysis and classification steps that there is a need to implement the factory method design pattern [8, p. 93-100]. Reading from a data source should be a simple matter of reading from a file, and cross validation has already been decided to use leave-one-out cross validation.

Figure 3.3 shows the design after adding in the factory methods.

From this we then need the two top-level interfaces `Analyser` and `Classifier`. The `Analyser` interface should have a single method which runs analysis on a painting and return some form of object which represents the analysed data.

The `Classifier` class should have a method which takes a single painting and a set of paintings, returning a year which is the classified year of the single painting based on the set of paintings.

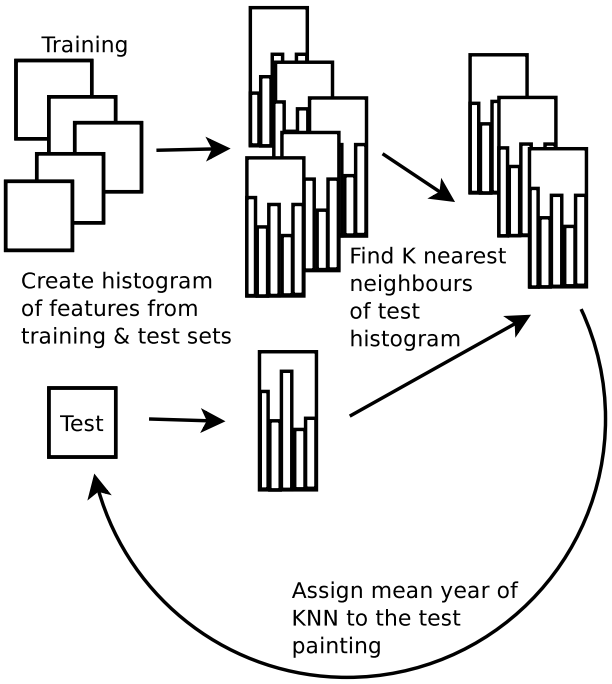

Figure 3.1: Overview of the Classification Methodology

Figure 3.2: Basic Overall Architecture

At this point it is also required that there is a class to store meta-data of a painting. Figure 3.4 depicts the design after adding in these parts.

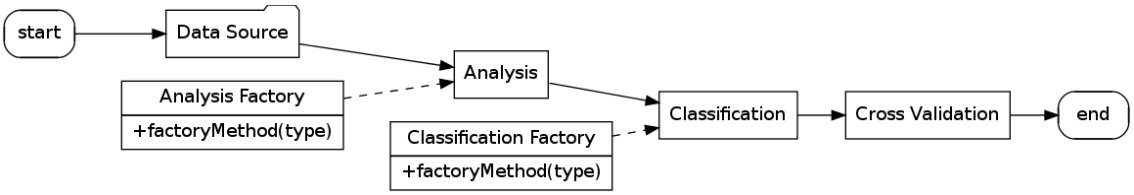

Figure 3.3: Overall Architecture with Factory Methods

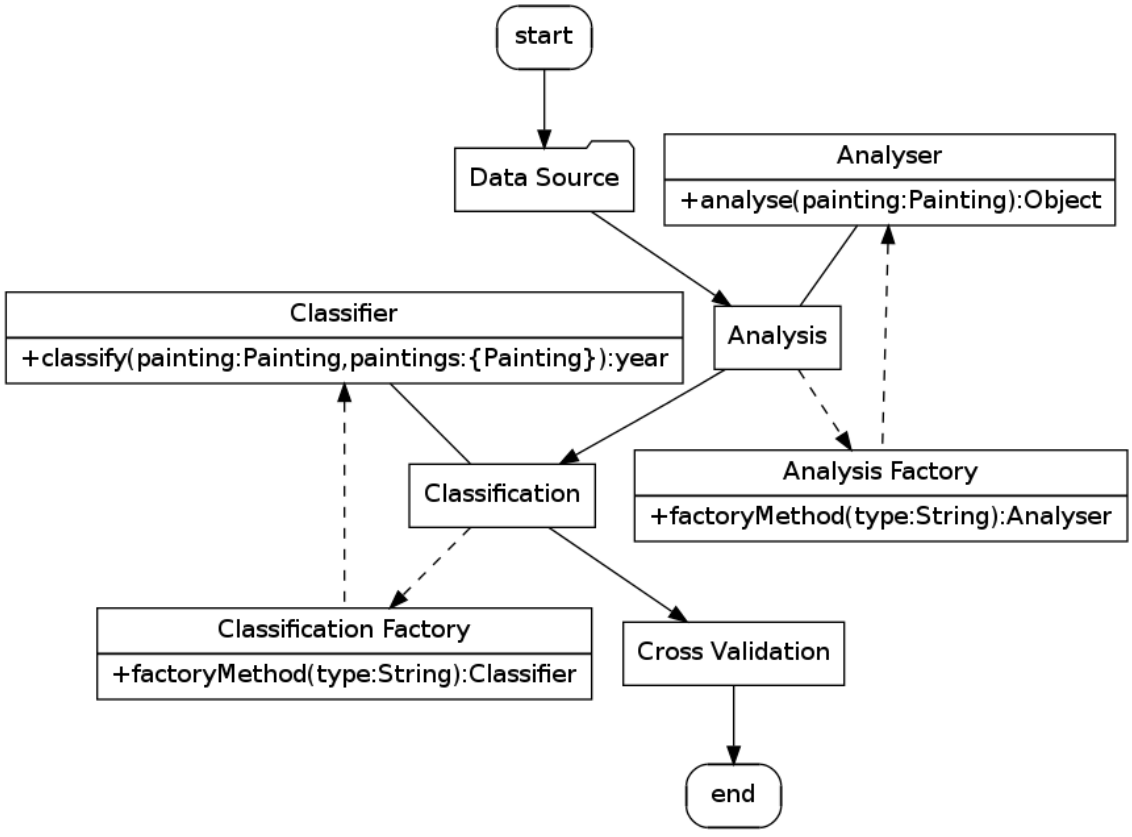

Figure 3.4: Overall architecture with Interfaces for Analysers and Classifiers

Chapter 4

Implementation

4.1 Basic Structure

4.1.1 Loading Data

One of the more key parts to implement before all others in this project is the ability to load in data from Llyods spreadsheet. The first step of this was to convert it to a Comma-Separated Values (CSV) file-type, which is easier to read programatically.

The initial spreadsheet was slightly different from the version depicted below, Llyod was kind enough to update it so it was easier to handle digitally. In this version of the spreadsheet the filenames were much longer and were in sub-folders depending on their collection. Extra logic was needed to locate the file (a simple matter of concatenating the collection to the filename as a directory). The image files in the second version were just flat files which I decided would be better placed in a data directory.

The move to the newer version was a good excuse to clean up some of the initial code to use better Python programming practises; replacing messy loops with list comprehension where possible, using Key Word Arguments (`**kwargs`) and dictionaries instead of having utility methods, etc.

From the original format show in table 4.1 (see table D.1 for the full document) the data was converted to the CSV format show in figure 4.1.

Filename	ID	Title	Catalogue entry BBC YP	Genre	Height	Width	Area	Materials	Collection	image width	image height	image height/image width
001.jpg	1	A Chapel in the Tyrol	1950-1960	Landscape	40.7	29.8	1212.86	oil on hardboard	NLW	687	944	1.3741

Table 4.1: Layout of the Painting Data Spreadsheet

```
001.jpg,1,A Chapel in the Tyrol,1950-1960,Landscape,40.7,29.8,1212.86,oil on hardboard, NLW,687,944,1.3741
```

Figure 4.1: Painting Data in CSV Format

This CSV was then parsed using the Python 2.7 in-built `csv` module with relative ease. The example code (see listing C.1) helped with correct resource management as, at this point, my Python knowledge was fairly low.

4.1.2 Top-Level Classes

Being used to Java, an initial instinct of mine was to set up interfaces for the majority of top-level classes (namely the `Analyser` and `Classifier` classes). However, because of Python's

duck typing, there wasn't possibly to create these classes as interfaces. I decided to create them as abstract stub classes which just held placeholder method definitions which needed to be overridden in the concrete sub-classes. This was a slightly pointless exercise due to the weak typing, but useful for me to get my head around the architecture.

I also implemented the `Painting` class and had a method to take an array (from the CSV file) and create a new instance of it from this. Later this was changed to use Python `**kwargs` instead as it made more sense for the job. This change was done during the change to the second version of Llyods database.

4.1.3 Command Line Interface

As a research program with lots of different analysis and classification techniques the next step in setting up the basic architecture was to create a set of command-line arguments which would switch the functionality of the program. These arguments are depicted in table 4.2.

Name	Short Flag	Long Flag	Description
Analyser	`-a`	`--analyser`	Switch the analysis technique
Machine Learning	`-m`	`--ml`	Switch the machine learning technique
Data	`-d`	`--csv`	The data file to use
GUI	`-g`	`--gui`	Switch the GUI visualisation
Binning	`-5`	`--bin-years`	Put paintings in 5 year bins
Export	`-e`	`--export`	Export analysed data

Table 4.2: Command Line Arguments

The `argparse` library handles this nicely, the example code shown in listing C.2 shows the usage of this library.

These flags then hook into the factory methods to actually create the instances.

4.2 Colour Space Analysis

Colour space analysis involves performing statistical analysis on different colour models (RGB, HSV, etc.). This gives a very simplistic view of the entire image.

OpenCV offers the `Avg` method to perform the average across the image, however with a further look into the documentation there is also the `AvgStd` method which performs both mean and standard deviation on an image.

The analysed data was just the tuple returned by the `AvgStd` method. The distance measure was defined to be the sum of all elements in the tuple (in the case of an RGB colour model the mean red, green and blue and the standard deviation of red, green and blue).

4.2.1 Colour Models

There are many colour models to consider with digital image processing. RGB is one of the better know colour spaces as it is often how images are captured. It does have a problem in that all three values can change when the brightness changes.

As one of the main principals of this project is that Kyffin Williams' work darkened over time, it should follow that RGB may not be the best colour model to use.

To account for this it was decided to also use a HSV colour model to compare and contrast to RGB.

OpenCV handles colour spaces slightly oddly. Initially it uses `LoadImageM` to load the image, which uses an integer argument as a flag to define whether the image should be loaded in colour or grayscale.

From this image you then can use `CvtColor` to convert the colour model of an image, which uses an integer argument as a flag to define a number of different colour spaces.

Once converted, all methods act exactly the same as they would on a RGB image.

4.2.2 Colour Histograms

Colour Histograms are a representation of the distribution of colour across an image; this makes them very powerful for analysing the colour space of an image.

OpenCV provides a number of methods for both calculating and operating upon colour histograms. Here the example code (figure C.4) from the OpenCV documentation was a useful reference as some of the details of creating histograms in OpenCV are not noted implicitly in the python documentation.

The distance measure between colour histograms is also handled by OpenCV using a compare histogram method. Under the covers this uses a Chi Squared (equation 4.1) method to compare to histograms of equal dimensions.

$$d(H_1, H_2) = \sum_I \frac{(H_1(I) - H_2(I))^2}{H_1(I) + H_2(I)} \tag{4.1}$$

4.3 Texture Analysis

4.3.1 Edge Orientation

Edge orientation involves passing a filter over an image which is used to find the orientation of that gradient. There are many forms of filter which can be used to do this. The simplest of which discrete derivative masks (figure 1.1, figure 1.2, etc.), steerable filters are a more adjustable implementation of this. There are also more complex filters, like Gabor filters, which provide better flexibility and matching.

Using discrete derivative masks it is fairly simple to work out to orientation of a gradient mathematically. First pass a mask of the form $\begin{bmatrix} -1 \\ 0 \\ 1 \end{bmatrix}$, followed by one in the form $\begin{bmatrix} -1 & 0 & 1 \end{bmatrix}$. These give you $\frac{\delta f}{\delta x}$ and $\frac{\delta f}{\delta y}$ respectively.

From these values you can then use a gradient direction function, shown in equation 4.2, to work out the actual direction of the gradient.

$$\theta = \operatorname{atan2}\left(\frac{\delta f}{\delta x}, \frac{\delta f}{\delta y}\right) \tag{4.2}$$

Another way of doing this is to change the orientation of the filter and bin the direction into certain cardinal directions; typically 0, $\frac{\pi}{4}$, $\frac{\pi}{2}$ and $\frac{3\pi}{4}$ (from π to 2π becomes a repeat of any of those directions, only in reverse and are, therefore, covered already).

To do this we can use steerable filters (shown in figures 4.2, 4.3, 4.4 and 4.5). With these we adjust the angle they are designed to match (θ), which will then give the degree to which a gradient

matches that angle. To complete the binning by orientation, this value will then have a threshold applied, then added to the bin if the value is above the threshold.

$$\begin{bmatrix} 0 & 1 & 0 \\ 0 & 1 & 0 \\ 0 & 1 & 0 \end{bmatrix}$$

Figure 4.2: Steerable Filter ($\theta = 0$)

$$\begin{bmatrix} 0 & 0 & 1 \\ 0 & 1 & 0 \\ 1 & 0 & 0 \end{bmatrix}$$

Figure 4.3: Steerable Filter ($\theta = \frac{\pi}{4}$)

$$\begin{bmatrix} 0 & 0 & 0 \\ 1 & 1 & 1 \\ 0 & 0 & 0 \end{bmatrix}$$

Figure 4.4: Steerable Filter ($\theta = \frac{\pi}{2}$)

4.3.1.1 Histogram of Edge Orientation

4.4 Brush-Stroke Analysis

4.5 Classification and Validation

4.5.1 k-Nearest Neighbour

4.5.2 Leave-One-Out Cross Validation

4.5.3 Weka 3

4.5.3.1 Attribute-Relation File Format (ARFF)

4.5.4 Exemplars

4.5.4.1 Nearest Exemplar Classification

To implement Nearest Exemplar Classification was a fairly easy task: Llyod (with help from members of the NLW) provided a secondary spreadsheet which contained all the necessary information of exemplar by year (see table D.2 for the full document).

The spreadsheet was arranged in the format described in table 4.3, from there it was a simple matter of saving the spreadsheet as a CSV file and taking some of the existing code for parsing CSV files. This caused a slight problem in that the parsed data didn't have enough information to create a full `Painting` object, yet all the analysis techniques worked from these objects.

This was solved easily thanks to Python's dynamic typing. A simple class which implemented all the necessary elements of `Painting` could be passed to the analysis techniques without any

$$\begin{bmatrix} 1 & 0 & 0 \\ 0 & 1 & 0 \\ 0 & 0 & 1 \end{bmatrix}$$

Figure 4.5: Steerable Filter ($\theta = \frac{3\pi}{4}$)

Filename	ID	Title	Catalogue Entry	Year
154.jpg	154	Landscape at Llanaelhaearn	1947	1947
etc.				

Table 4.3: Layout of the Exemplar Spreadsheet

complaints. With a statically typed language this would have been harder to complete, but there would have been ways around using sub-classes and so on.

With the exemplars loaded and analysed, the program could continue as normal, until the classification step.

The idea of Nearest Exemplar Classification is to classify the unknown example using the nearest exemplar to that example in the feature space. This acts as a k-Nearest Neighbour with $k = 1$ and the space of neighbours only including the exemplars, rather than every other example. The psuedocode for this is shown in figure 4.6.

Initially this was implemented so that the examples that were exemplars were also classified, but this is a pointless exercise which only skews the results. Additional logic was added to skip any example which was an exemplar itself.

function NEAREST EXEMPLAR CLASSIFICATION($example$, $exemplars$)
  if $example \in exemplars$ **then**
    return $\varnothing$
  end if
  return NEAREST($example, exemplars$)
end function

Figure 4.6: Nearest Exemplar Classification Psuedocode

This proved to give slightly worse correlation per technique than k-Nearest Neighbour. This result is to be expected; for a start an artistically classified exemplar is unlikely to be the same as a statistically classified exemplar (see section 4.5.5). Also, with fewer examples to classify against, any variance in the data set (of which there is a lot) will likely be magnified.

Lastly, a painting may be picked as an exemplar by an expert for different reasons than any analysis technique that currently exists can give; emotional connections and knowledge of the artists history can be very subjective and may not relate to anything put down in paint.

4.5.5 Statistically Classified Exemplars

Another approach to exemplars is to work out a theoretical exemplar for a given period; the centroid of paintings within the given feature space for a single year, for example.

The simplest way of working this out is showing in figure 4.7, this works by taking the mean (equation 1.3) of each feature in the set of paintings for a single year, this will give the point in feature space that is most central. This is the same technique used to generate centroids in a

clustering algorithm (k-Means Clustering, for example).

function STATISTICALCLASSIFYEXEMPLAR($examples$)
  for all $example \in examples$ **do**
    for all $feature \in example_{features}$ **do**
      $average_{feature} \leftarrow average_{feature} + example_{feature}$
    end for
  end for
  for all $feature \in average$ **do**
    $average_{feature} \leftarrow \frac{average_{feature}}{\text{LENGTH}(examples)}$
  end for
  return $average$
end function

Figure 4.7: Psuedocode for generating a Statistically Classified Exemplar

This may become a long operation depending on how many dimensions the feature space has. A technique like Principal Component Analysis (PCA) may be useful to help cut down the number of dimensions needed that this algorithm uses.

4.6 3rd Party Libraries and Tools

4.6.1 Python

4.6.1.1 Python setuptools

4.6.2 OpenCV

4.6.3 scipy & numpy

4.6.4 matplotlib

4.6.5 Weka 3

4.6.5.1 liac-arff

4.6.6 git & github

Chapter 5

Testing

5.1 Overall Approach to Testing

As this is a research-based project, it is difficult to perform any for of unit, functional or requirements testing. Most testing is based on validating the results of analysis and classification techniques.

5.2 Validation

5.2.1 Leave-One-Out Cross Validation

5.2.2 Validation using Weka

Chapter 6

Evaluation

6.1 Evaluation of Requirements

6.2 Evaluation of Design

6.3 Evaluation of Tools

6.3.1 Programming Language

6.3.1.1 Dependency Management

6.3.2 Image Processing/Computer Vision Libraries

6.3.3 Machine Learning Libraries

6.3.3.1 File Formats

6.3.4 Scientific and Numeric Libraries

Appendices

Appendix A

3rd Party Libraries and Tools

1.1 Python 2.7

1.1.1 setuptools

`http://pypi.python.org/pypi/setuptools`

1.1.2 scipy

`http://www.scipy.org/` [11]

1.1.3 numpy

`http://www.numpy.org/` [11]

1.1.4 matplotlib

`http://matplotlib.org/`

1.1.5 liac-arff

`https://github.com/renatopp/liac-arff`

1.2 OpenCV

`http://opencv.org/` [3]

1.2.1 OpenCV Python

`http://opencv.willowgarage.com/wiki/PythonInterface` [3]

1.3 Weka 3

`http://www.cs.waikato.ac.nz/ml/weka/` [9]

1.4 git

1.4.1 github

Appendix B

Equations

2.1 Statistical Equations

2.1.1 Mean

$$\mu = \frac{1}{N}\sum_{i=1}^{N} x_i$$

2.1.2 Standard Deviation

$$\sigma = \sqrt{\frac{1}{N}\sum_{i=1}^{N}(x_i - \mu)^2}$$

2.1.3 Pearson's product-moment coefficient

$$\rho_{X,Y} = \frac{\operatorname{cov}(X,Y)}{\sigma_X \sigma_Y} = \frac{E[(X - \mu_X)(Y - \mu_Y)]}{\sigma_X \sigma_Y}$$

2.2 Distance Equations

2.2.1 Manhattan Distance

$$d_1(\mathbf{p}, \mathbf{q}) = \|\mathbf{p} - \mathbf{q}\|_1 = \sum_{i=0}^{n} |p_i - q_i|$$

2.2.2 Euclidean Distance

$$d_1(\mathbf{p}, \mathbf{q}) = \sqrt{\sum_{i=0}^{n}(q_i - p_i)^2}$$

2.3 Filter Equations

2.3.1 Gradient Direction

$$\theta = \operatorname{atan2}\left(\frac{\delta f}{\delta x}, \frac{\delta f}{\delta y}\right)$$

2.3.2 Discrete Derivative Masks

$$\begin{bmatrix} -1 & 0 & 1 \end{bmatrix} \begin{bmatrix} -1 \\ 0 \\ 1 \end{bmatrix}$$

2.3.3 Gabor Filter

$$g(x, y; \lambda, \theta, \psi, \sigma, \gamma) = \exp\left(-\frac{x'^2 + \gamma^2 y'^2}{2\sigma^2}\right) \cos\left(2\pi \frac{x'}{\lambda} + \psi\right) \tag{B.1}$$

where:

$$x' = x\cos\theta + y\sin\theta$$
$$y' = x\sin\theta + y\cos\theta$$

Appendix C

Code Samples

3.1 Example CSV Parsing Code

Listing C.1: Example CSV Parsing Code from http://docs.python.org/2/library/csv.html

```
>>> import csv
>>> with open('eggs.csv', 'rb') as csvfile:
...     spamreader = csv.reader(csvfile, delimiter=' ',
    quotechar='|')
...     for row in spamreader:
...         print ', '.join(row)
Spam, Spam, Spam, Spam, Spam, Baked Beans
Spam, Lovely Spam, Wonderful Spam
```

3.2 argparse Example Code

Listing C.2: Example argparse Code from http://docs.python.org/2/library/argparse.html

```
import argparse

parser = argparse.ArgumentParser(description='Process some integers.')
parser.add_argument('integers',
                    metavar='N',
                    type=int,
                    nargs='+',
                    help='an integer for the accumulator')
parser.add_argument('--sum',
                    dest='accumulate',
                    action='store_const',
                    const=sum, default=max,
                    help='sum the integers (default: find the max)')

args = parser.parse_args()
print args.accumulate(args.integers)
```

3.3 Gabor Filter Example Implementation

Listing C.3: Example implementation of a Gabor Filter in MATLAB from wikipedia [5]

```
function gb=gabor_fn(sigma,theta,lambda,psi,gamma)

sigma_x = sigma;
sigma_y = sigma/gamma;

% Bounding box
nstds = 3;
xmax = max(abs(nstds*sigma_x*cos(theta)),abs(nstds*sigma_y*sin(
    theta)));
xmax = ceil(max(1,xmax));
ymax = max(abs(nstds*sigma_x*sin(theta)),abs(nstds*sigma_y*cos(
    theta)));
ymax = ceil(max(1,ymax));
xmin = -xmax; ymin = -ymax;
[x,y] = meshgrid(xmin:xmax,ymin:ymax);

% Rotation
x_theta=x*cos(theta)+y*sin(theta);
y_theta=-x*sin(theta)+y*cos(theta);

gb= exp(-.5*(x_theta.^2/sigma_x^2+y_theta.^2/sigma_y^2)).*cos(2*
    pi/lambda*x_theta+psi);
```

3.4 OpenCV Histogram Example Code

Listing C.4: Example Histogram calculation and displaying code from OpenCV [3].

```
# Taken from: http://opencv.willowgarage.com/documentation/
    python/imgproc_histograms.html#calchist
# Calculating and displaying 2D Hue-Saturation histogram of a
    color image

import sys
import cv

def hs_histogram(src):
    # Convert to HSV
    hsv = cv.CreateImage(cv.GetSize(src), 8, 3)
    cv.CvtColor(src, hsv, cv.CV_BGR2HSV)

    # Extract the H and S planes
    h_plane = cv.CreateMat(src.rows, src.cols, cv.CV_8UC1)
    s_plane = cv.CreateMat(src.rows, src.cols, cv.CV_8UC1)
    cv.Split(hsv, h_plane, s_plane, None, None)
    planes = [h_plane, s_plane]

    h_bins = 30
```

```
    s_bins = 32
    hist_size = [h_bins, s_bins]
    # hue varies from 0 (~0 deg red) to 180 (~360 deg red again
       */
    h_ranges = [0, 180]
    # saturation varies from 0 (black-gray-white) to
    # 255 (pure spectrum color)
    s_ranges = [0, 255]
    ranges = [h_ranges, s_ranges]
    scale = 10
    hist = cv.CreateHist([h_bins, s_bins], cv.CV_HIST_ARRAY,
       ranges, 1)
    cv.CalcHist([cv.GetImage(i) for i in planes], hist)
    (_, max_value, _, _) = cv.GetMinMaxHistValue(hist)

    hist_img = cv.CreateImage((h_bins*scale, s_bins*scale), 8,
       3)

    for h in range(h_bins):
        for s in range(s_bins):
            bin_val = cv.QueryHistValue_2D(hist, h, s)
            intensity = cv.Round(bin_val * 255 / max_value)
            cv.Rectangle(hist_img,
                         (h*scale, s*scale),
                         ((h+1)*scale - 1, (s+1)*scale - 1),
                         cv.RGB(intensity, intensity, intensity)
                            ,
                         cv.CV_FILLED)
    return hist_img

if __name__ == '__main__':
    src = cv.LoadImageM(sys.argv[1])
    cv.NamedWindow("Source", 1)
    cv.ShowImage("Source", src)

    cv.NamedWindow("H-S Histogram", 1)
    cv.ShowImage("H-S Histogram", hs_histogram(src))

    cv.WaitKey(0)]
```

Appendix D

Spreadsheet Data

Filename	ID	Title	Catalogue entry BBC YP	Genre	Height	Width	Area	Materials	Collection
001.jpg	1	A Chapel in the Tyrol	1950-1960	Landscape	40.7	29.8	1212.86	oil on hardboard	NLW
002.jpg	2	A Ruined Classical Building	1940-1960	Landscape	30.4	40.7	1237.28	oil on hardboard	NLW
003.jpg	3	Above Carneddi, No.2	1985	Landscape	50	75	3750	oil on canvas	NLW
004.jpg	4	Across the Water	1990-2006	Landscape	50.3	76	3822.8	oil on canvas	NLW
005.jpg	5	Allt Corn Yd, Llanddona	n.d.	Landscape	61	91.4	5575.4	oil on canvas	OYM
006.jpg	6	Alpine Mountain Landscape	1950-1960	Landscape	60.8	50.5	3070.4	oil on canvas	NLW
007.jpg	7	Alpine Mountains/ Y Grib Goch	1990-2006	Landscape	50.5	60.8	3070.4	oil on canvas	NLW
008.jpg	8	Alun Oldfield-Davis, Controller (1945-1967)	n.d.	Portrait	174	98	17052	oil on canvas	BBC
009.jpg	9	An Officer of the Royal Welch Fusiliers	1940-1950	Portrait	60.7	40.5	2458.35	oil on canvas	NLW
010.jpg	10	Anglesey Cottages with Cattle	1970	Landscape	59.8	76	4544.8	oil on canvas	NMGW
011.jpg	11	Anglesey Landscape	1960	Landscape	90	121	10890	oil on canvas	OYM
012.jpg	12	Ann Griffiths (b.1935)	1970	Portrait	54.3	49.7	2698.71	oil on canvas	NLW
013.jpg	13	Ar Hyd Y Ffos	1969	Landscape	121	91	11011	oil on canvas	NLW
014.jpg	14	Autumn Road	1950-1960	Landscape	61	76.3	4654.3	oil on canvas	NLW
015.jpg	15	Autumn Sunset	1960-1980	Landscape	60.5	76.2	4610.1	oil on canvas	NLW
016.jpg	16	Barn in a Patagonian Landscape	1969	Landscape	50.7	61	3092.7	oil on canvas	NLW
017.jpg	17	Blaen Ffrancon No.1	1978	Landscape	92.1	121.9	11226.99	oil on canvas	NMGW
018.jpg	18	Blaen Nant	1976	Landscape	76.7	127	9740.9	oil on canvas	RAA
019.jpg	19	Blue Sky with Brown Hill	1970-1990	Landscape	55.5	91.2	5061.6	oil on canvas	NLW
020.jpg	20	Bryn Cader Faner	2000	Landscape	120.3	120.3	14472.09	oil on canvas	NLW
021.jpg	21	Bryn yr Hen Bobl	1970-1990	Landscape	61	61	3721	oil on canvas	NLW
022.jpg	22	Buildings, Patagonia	1969	Landscape	51	68.7	3503.7	oil on canvas	NLW

Filename	ID	Title	Catalogue entry BBC YP	Genre	Height	Width	Area	Materials	Collection
023.jpg	23	Capel Carmel	1958	Landscape	51.5	62	3193	oil on canvas	OYM
024.jpg	24	Carreg Cennen No.1	1982	Landscape	75.5	75.5	5700.25	oil on canvas	NLW
025.jpg	25	Cattle in the Field	1940-1950	Landscape	30.5	40.6	1238.3	oil on board	NLW
026.jpg	26	Ceg y Ffos	1969	Landscape	17.5	25	437.5	oil on canvas	NLW
027.jpg	27	Ceserea	1960-1980	Landscape	47.1	99.5	4686.45	oil on canvas	NLW
028.jpg	28	Chapel at Dinorwic	2000	Landscape	111	111	12321	oil on canvas	NLW
029.jpg	29	Chapel with a Mountain Behind	1960-1970	Landscape	71.2	91.6	6521.92	oil on canvas	NLW
030.jpg	30	Charles Evans	1967	Portrait	61.1	51.5	3146.65	oil on canvas	NLW
031.jpg	31	Church and Cottage, North Wales	1950-1960	Landscape	76	127	9652	oil on canvas	NLW
032.jpg	32	Cloud and Hills above the Traeth	n.d.	Landscape	90.5	120.4	10896.2	oil on canvas	BU
033.jpg	33	Cloud and Mist, Eryri	1950-1960	Landscape	61	51	3111	oil on canvas	NLW
034.jpg	34	Cloud on Foel Goch	1960-1961	Landscape	91.3	112.8	10298.64	oil on canvas	NLW
035.jpg	35	Cloud on the Mountains	1970-1990	Landscape	71	91.5	6496.5	oil on canvas	NLW
036.jpg	36	Cloud on the Mountains	1950-1970	Landscape	51	61	3111	oil on canvas	NLW
037.jpg	37	Cloud over Crib Goch	1970-1990	Landscape	60.5	60.5	3660.25	oil on canvas	NLW
038.jpg	38	Clouds above Crib Goch	n.d.	Landscape	89.58	93.7	8393.646	oil on canvas	BU
039.jpg	39	Cloudy Day in Snowdonia	1940-1950	Landscape	22.9	30.9	707.61	oil on hardboard	NLW
040.jpg	40	Cnicht	1960-1970	Landscape	50.5	60.8	3070.4	oil on canvas	NLW
041.jpg	41	Coastal Sunset	1970-1990	Landscape	76.2	76.2	5806.44	oil on canvas	NLW
042.jpg	42	Coastal Sunset	1990-2006	Landscape	50.5	75.7	3822.85	oil on canvas	NLW
043.jpg	43	Col des Aravis, Haute Savoie	1960-1980	Landscape	45.7	60.7	2773.99	oil on canvas	NLW
044.jpg	44	Conservatory, Highgate	1950	Landscape	60	49.5	2970	oil on canvas	NLW

Filename	ID	Title	Catalogue entry BBC YP	Genre	Height	Width	Area	Materials	Collection
045.jpg	45	Corporal Norman Pritchard, Goat Major, 3rd Battalion	1983	Portrait	112	110	12320	oil on canvas	RWFRM
046.jpg	46	Cottage in the Fields	1990-2006	Landscape	50.5	60.7	3065.35	oil on canvas	NLW
047.jpg	47	Cottages, Carmel, No.1	1985	Landscape	49.7	117	5814.9	oil on canvas	NLW
048.jpg	48	Cottages, Cilgwyn	n.d.	Landscape	52.2	62	3236.4	oil on canvas	MOMA
049.jpg	49	Cottages, Eryri	1960-1980	Landscape	45.7	75.8	3464.06	oil on canvas	NLW
050.jpg	50	Cottages, Eryri	1960-1980	Landscape	50.5	60.5	3055.25	oil on canvas	NLW
051.jpg	51	Cottages, Llanddona	1955	Landscape	50.8	76.5	3886.2	oil on canvas	NMGW
052.jpg	52	Cottages, Llanrhuddlad	1955	Landscape	51.8	62	3211.6	oil on canvas	OYM
053.jpg	53	Cottages, Mynydd Bodafon	1962	Landscape	57	77.5	4417.5	oil on canvas	OYM
054.jpg	54	Cottages, North Wales	1960-1970	Landscape	61.3	50.5	3095.65	oil on canvas	NLW
055.jpg	55	Cottages, Snowdonia	1960-1970	Landscape	51	61	3111	oil on canvas	NLW
056.jpg	56	Councillor Dora Phyllis Oxenham (19101996), CBE, Chair of Northamptonshire County Council (19691972)	1960s	Portrait	60.5	65	3932.5	oil on canvas	Northamptonshire Council
057.jpg	57	Craggs and Trees	1970-1990	Landscape	75.6	76	5745.6	oil on canvas	NLW
058.jpg	58	Crib Coch and Llanberis Pass	n.d.	Landscape	122	152.4	18592.8	oil on canvas	Newport Museum and Art Gallery
059.jpg	59	Crib Goch	n.d.	Landscape	51	122	6222	oil on canvas	Gwynedd Council Collection
060.jpg	60	Crib Goch with a Blue Sky	1970-1990	Landscape	50.8	61	3098.8	oil on canvas	NLW
061.jpg	61	Crows and Storm Coming	1960-1970	Landscape	61	76.2	4648.2	oil on canvas	NLW

Filename	ID	Title	Catalogue entry BBC YP	Genre	Height	Width	Area	Materials	Collection
062.jpg	62	Crucifixion	1950-1960	Genre	61	76	4636	oil on canvas	NLW
063.jpg	63	Cwm Hetiau	1970-1990	Landscape	121.2	182.9	22167.48	oil on canvas	NLW
064.jpg	64	Cwm Pennant	n.d.	Landscape	50	67.2	3360	oil on canvas	Newport Museum and Art Gallery
065.jpg	65	Dafydd Williams on the Mountain	1969	Landscape	91.5	121.8	11144.7	oil on canvas	RAA
066.jpg	66	Dame Eileen Louise Younghusband	1965	Portrait	91.5	71.1	6505.65	oil on canvas	NPG
067.jpg	67	Dark Hills across the Water	1950-1970	Landscape	50.5	91.5	4620.75	oil on canvas	NLW
068.jpg	68	Dark Mountains, Blue Sky	1950-1970	Landscape	76	152.5	11590	oil on canvas	NLW
069.jpg	69	Dark Mountains, Eryri	1970-1990	Landscape	70.7	91.2	6447.84	oil on canvas	NLW
070.jpg	70	Dead Hare in Brown Paper	1940-1950	Still life	50.7	68.3	3462.81	oil on canvas	NLW
071.jpg	71	Deposition	1960-1970	Genre	76	152.6	11597.6	oil on canvas	NLW
072.jpg	72	Deposition	n.d.	Genre	22	32.5	715	oil on board	Glynn Vivian Art Gallery
073.jpg	73	Deserted Farm, Llanrhuddlad	1970	Landscape	51	61	3111	oil on canvas	Southend Museum Collection
074.jpg	74	Dolwyddelan Castle	1985	Landscape	75	75	5625	oil on canvas	NLW
075.jpg	75	Dr Alun Oldfield Davies	1970	Portrait	121.5	91.5	11117.25	oil on canvas	NLW
076.jpg	76	Dr Llywellyn Wyn Griffith (1890-1977)	1960-1979	Portrait	90	70	6300	oil on canvas	NLW
077.jpg	77	Drwsycoed	n.d.	Landscape	49.7	59.8	2972.06	oil on canvas	Merthyr Tydfil Museum Service

Filename	ID	Title	Catalogue entry BBC YP	Genre	Height	Width	Area	Materials	Collection
078.jpg	78	Duffryncamwy, Patagonia	1969	Landscape	121.3	121.3	14713.69	oil on canvas	NMGW
079.jpg	79	Dusk in the Mountains	1940-1960	Landscape	22	42.5	935	oil on hardboard	NLW
080.jpg	80	Dyfryn, Cesarea	n.d.	Landscape	74	126	9324	oil on canvas	BU
081.jpg	81	Eryri	1960-1970	Landscape	40.8	50.8	2072.64	oil on canvas	NLW
082.jpg	82	Eryri (Snowdon)	n.d.	Landscape	38.8	76.4	2964.32	oil on canvas	Glynn Vivian Art Gallery
083.jpg	83	Euros Hughes Irrigating his Fields	1969	Landscape	50	50	2500	oil on canvas	NLW
084.jpg	84	Evan Roberts (1909-1991)	1990	Portrait	72	72	5184	oil on canvas	OYM
085.jpg	85	Farm at Cesarae	n.d.	Landscape	65	93	6045	oil on canvas	BBC
086.jpg	86	Farm behind Harlech	n.d.	Landscape	29	75	2175	oil on canvas	Amgueddfa Ceredigion Museum
087.jpg	87	Farm below Crib Goch	1967	Landscape	122	183	22326	oil on canvas	GAC
088.jpg	88	Farm Building, Eryri	1970-1990	Landscape	50.5	75.7	3822.85	oil on canvas	NLW
089.jpg	89	Farm Buildings	1960-1970	Landscape	40.5	51	2065.5	oil on canvas	NLW
090.jpg	90	Farm Ceserea	n.d.	Landscape	50	111.5	5575	oil on canvas	OYM
091.jpg	91	Farm Eryri	1970-1990	Landscape	61.3	50.8	3114.04	oil on canvas	NLW
092.jpg	92	Farm, Llanddona	1958	Landscape	51.8	62	3211.6	oil on canvas	OYM
093.jpg	93	Farm, Llanfairyn-ghornwy	1975	Landscape	39.5	49.9	1971.05	oil on canvas	NLW
094.jpg	94	Farm near Nanhoron	1970-1990	Landscape	60.7	76.3	4631.41	oil on canvas	NLW
095..jpg	95	Farmer Amongst the Rocks	1990-2006	Landscape	60.7	91	5523.7	oil on canvas	NLW
096.jpg	96	Farmer and Cattle	1957	Landscape	58.5	128.7	7528.95	oil on canvas	OYM
097.jpg	97	Farmer and Cottages	1940-1950	Landscape	61	50.7	3092.7	oil on canvas	NLW

Filename	ID	Title	Catalogue entry BBC YP	Genre	Height	Width	Area	Materials	Collection
098.jpg	98	Farmer and Dog Climbing a Rocky Path	1950-1960	Landscape	50.6	65.7	3324.42	oil on canvas	NLW
099.jpg	99	Faarmer and Dog in the Moutnains	1950-1970	Landscape	61.2	77.7	4755.24	oil on canvas	NLW
100.jpg	100	Farmer at Dusk	1970-1990	Landscape	68.3	50.7	3462.81	oil on canvas	NLW
101.jpg	101	Farmer in Eryri	1970-1990	Landscape	50.7	60.7	3077.49	oil on canvas	NLW
102.jpg	102	Farmer on the Mountain	1984-1990	Landscape	91.4	121.7	11123.38	oil on canvas	NLW
103.jpg	103	Farmer on the Mountains	n.d.	Landscape	90.1	119.8	10793.98	oil on canvas	BU
104.jpg	104	Farmer with Following Dog	1990-2006	Landscape	60.8	61	3708.8	oil on canvas	NLW
105.jpg	105	Farmer below the Ridge	1983	Landscape	122.5	92.8	11368	oil on canvas	OYM
106.jpg	106	Farmers, Cwm Nantlle	1947	Landscape	51.2	61.2	3133.44	oil on canvas	NMGW
107.jpg	107	Farmers on the Carneddau	1980	Landscape	121.7	183	22271.1	oil on canvas	NLW
108.jpg	108	Farmers on the Moelwyns; Llwybr Iddew Mawr	1970	Landscape	121	182	22022	oil on canvas	NLW
109.jpg	109	Farmhouse on the Horizon in Rugged Land	1960-1970	Landscape	61	91.8	5599.8	oil on canvas	NLW
110.jpg	110	Farms, Porth Dafarch No.1	1977	Landscape	91	91	8281	oil on canvas	GAC
111.jpg	111	Fedw, Penrhosllugwy	1948	Landscape	58.5	88.5	5177.25	oil on canvas	OYM
112.jpg	112	Fferm Fynydd Hill Farm (recto)	n.d.	Landscape	75.5	151.5	11438.25	oil on canvas	Gwynedd Council Collection
113.jpg	113	Fferm Fynydd Hill Farm (verso)	n.d.	Landscape	75.5	151.5	11438.25	oil on canvas	Gwynedd Council Collection
114.jpg	114	Ffridd Llwyn Gorful	1970	Landscape	62	88	5456	oil on canvas	NLW

Filename	ID	Title	Catalogue entry BBC YP	Genre	Height	Width	Area	Materials	Collection
115.jpg	115	Figure and Mountains (verso)	n.d.	Landscape	57.3	126	7219.8	oil on canvas	NMGW
116.jpg	116	Fred Uhlman (1901-1985)	1960	Portrait	61	51	3111	oil on canvas	NLW
117.jpg	117	Fresians in a Field with the Coast Beyond	1940-1950	Landscape	51	68.5	3493.5	oil on canvas	NLW
118.jpg	118	Fusilier Dean (The Depot, Wrexham, 1948)	1948	Portrait	88	75	6600	oil on canvas	RWFRM
119.jpg	119	Gardener at work, near a Church	1940-1950	Landscape	40	32.9	1316	oil on canvas	NLW
120.jpg	120	German Girl	1963	Portrait	61	51	3111	oil on canvas	RAA
121.jpg	121	Girl Guide 1	1990-2006	Portrait	76.1	76.2	5798.82	oil on canvas	NLW
122.jpg	122	Girl Guide 2	1990-2006	Portrait	76.5	76.5	5852.25	oil on canvas	NLW
123.jpg	123	Giudecca, Venice	1950-1970	Landscape	76	63.1	4795.6	oil on canvas	NLW
124.jpg	124	Golfer Resting	1940-1950	Genre	20.3	26.7	542.01	oil on board	NLW
125.jpg	125	Green Fields and Grey Mountains, Snowdonia	1970-1990	Landscape	76.3	76.3	5821.69	oil on canvas	NLW
126.jpg	126	Green Mountain Landscape	1950-1970	Landscape	40.8	51	2080.8	oil on canvas	NLW
127.jpg	127	Green Trees and Fields Beneath a Dark Mountain	1950-1970	Landscape	51	61	3111	oil on canvas	NLW
128.jpg	128	Grey Cloud and Sun over the Mountains	1970-1990	Landscape	50.8	68.5	3479.8	oil on canvas	NLW
129.jpg	129	Grey Sky and Dark Moutnains	1960-1970	Landscape	50.5	60.7	3065.35	oil on canvas	NLW
130.jpg	130	Gyrn Las	1990-2006	Landscape	50.3	76.2	3832.86	oil on canvas	NLW
131.jpg	131	Hamlet in the Trees	1970-1990	Landscape	61.2	77	4712.4	oil on canvas	NLW
132.jpg	132	Hamlet on the Horizon	1970-1980	Landscape	40.5	50.7	2053.35	oil on canvas	NLW
133.jpg	133	Hampstead Heath	1940-1950	Landscape	18.2	34.1	620.62	oil on cardboard	NLW

Filename	ID	Title	Catalogue entry BBC YP	Genre	Height	Width	Area	Materials	Collection
134.jpg	134	Henry Roberts, Bryngwyn, Patagonia	1969	Landscape	120.5	120.5	14520.25	oil on canvas	NLW
135.jpg	135	Henry Roberts o Hafotty (1888-1960)	n.d.	Portrait	68.5	50.5	3459.25	oil on canvas	NLW
136.jpg	136	Hermon	n.d.	Landscape	91	91	8281	oil on canvas	OYM
137.jpg	137	Highgate Schoolboy	1953	Portrait	92	50.6	4655.2	oil on canvas	Glynn Vivian Art Gallery
138.jpg	138	Highgate West Hill	n.d.	Landscape	45	55	2475	oil on canvas	Highgate Literary, Scientific Institute
139.jpg	139	Hill Farm in Merioneth	during or before 1958	Landscape	51	112	5712	oil on canvas	Herbert Art Gallery and Museum
140.jpg	140	Hill Farmers	n.d.	Landscape	91.5	137	12535.5	oil on canvas	Bodelwyddan Castle Trust
141.jpg	141	Hills above nant Peris	n.d.	Landscape	94.4	125	11800	oil on canvas	BU
142.jpg	142	Hillside Cottages	1960-1970	Landscape	50.5	50.6	2555.3	oil on canvas	NLW
143.jpg	143	Hillside with Sheep Farmer and Dog	n.d.	Landscape	74.5	125.2	9327.4	oil on canvas	BU
144.jpg	144	Hillside with Trees on the Horizon	1960-1970	Landscape	71.2	91.2	6493.44	oil on canvas	NLW
145.jpg	145	Horses and Riders	1940-1950	Genre	21.6	45.6	984.96	oil on hardboard	NLW
146.jpg	146	Hugh Rowalnds	1990-2006	Portrait	50.7	61	3092.7	oil on canvas	NLW
147.jpg	147	Hugh Thomas, Portrait of a Farmer	1950	Portrait	59.5	49.5	2945.25	oil on canvas	BU
148.jpg	148	Huw T. Edwrds	1960	Portrait	91.5	71	6496.5	oil on canvas	NMGW
149.jpg	149	Italian Ruins	1950	Landscape	26.3	40.8	1073.04	oil on canvas	NLW
150.jpg	150	Jack Jones	1959	Portrait	58.2	45.7	2659.74	oil on canvas	Glynn Vivian Art Gallery
151.jpg	151	Jack Raymond Jones	1969	Portrait	90.5	55	4977.5	oil on canvas	NLW

Filename	ID	Title	Catalogue entry BBC YP	Genre	Height	Width	Area	Materials	Collection
152.jpg	152	John Dafydd Evans (1900-1984)	1945	Portrait	25.5	36.5	930.75	oil on board	NLW
153.jpg	153	Keith Andrew (b.1947)	1980s	Portrait	74.5	74.5	5550.25	oil on canvas	NLW
154.jpg	154	Landscape at Llanael-haearn	1947	Landscape	51.1	61	3117.1	oil on canvas	Arts Council Collection
155.jpg	155	Landscape with Cattle	1950	Landscape	29	40	1160	oil on canvas	NLW
156.jpg	156	Llandonna	n.d.	Landscape	89	119.5	10635.5	oil on canvas	BBC
157.jpg	157	Llanerchymedd Mill	1955	Landscape	52	69.5	3614	oil on canvas	OYM
158.jpg	158	Lle Cul, Patagonia	1969	Landscape	89.5	89.5	8010.25	oil on canvas	NLW
159.jpg	159	Lle Cul, Patagonia	1969	Landscape	92	122	11224	oil on canvas	NLW
160.jpg	160	Lle Cul, Patagonia	1969	Landscape	49.5	60	2970	oil on canvas	NLW
161.jpg	161	Lle Cul, Patagonia	1969	Landscape	49.9	60	2994	oil on canvas	NLW
162.jpg	162	Lliwedd	1978	Landscape	91	91	8281	oil on canvas	OYM
163.jpg	163	Llyn Conwy	1996	Landscape	54	131	7074	oil on canvas	NLW
164.jpg	164	Llyn-y-Cau, Cader Idris	1950 or be-fore	Landscape	37.3	75.3	2808.69	oil on canvas	NLW
165.jpg	165	Llyn-y-Cau, Cader Idris	1990	Landscape	120	120	14400	oil on canvas	NLW
166.jpg	166	Lone Cottage	1990-2006	Landscape	50.7	76.2	3863.34	oil on canvas	NLW
167.jpg	167	Lowlight Eryri	1970-1990	Landscape	76	76	5776	oil on canvas	NLW
168.jpg	168	Mackerel	1988	Still life	104	68.5	7124	oil on canvas	NLW
169.jpg	169	Male Nude	1940-1950	Study	35.5	25.3	898.15	oil on board	NLW
170.jpg	170	Man and Horse in the Desert	1970	Landscape	90.2	98	8839.6	oil on canvas	NLW
171.jpg	171	Marie Levy, nee Wooler	1960	Portrait	60	50	3000	oil on canvas	NLW
172.jpg	172	Mary	1950s	Portrait	61	51	3111	oil on canvas	NMGW
173.jpg	173	Meadows, Mist and Mountains	1970-1990	Landscape	45.6	55.5	2530.8	oil on canvas	NLW
174.jpg	174	Michelle	1950-1970	Portrait	60.5	50.5	3055.25	oil on canvas	NLW
175.jpg	175	Miss Josling	1960	Portrait	30.5	20.5	625.25	oil on board	OYM

Filename	ID	Title	Catalogue entry BBC YP	Genre	Height	Width	Area	Materials	Collection
176.jpg	176	Miss Parry	1979	Portrait	110	49.2	5412	oil on canvas	NLW
177.jpg	177	Mist on the Mountains	1960-1970	Landscape	55.5	76	4218	oil on canvas	NLW
178.jpg	178	Moel Hebog	1952	Landscape	25.4	35.5	901.7	oil on board	NLW
179.jpg	179	Moelfre	n.d.	Landscape	50.5	68	3434	oil on canvas	OYM
180.jpg	180	Moelwyn Bach	1960	Landscape	92.2	122.5	11294.5	oil on canvas	OYM
181.jpg	181	Moelwyn Back from Tanygrisiau	1960-1970	Landscape	50.5	68	3434	oil on canvas	NLW
182.jpg	182	Mont Blanc	1950-1960	Landscape	21.4	37.6	804.64	oil on hardboard	NLW
183.jpg	183	Moonlight above Gwynant	1990-2006	Landscape	121.9	121.9	14859.61	oil on canvas	NLW
184.jpg	184	Mountain Landscape	1987 or before	Landscape	12	12.5	150	oil on canvas	NLW
185.jpg	185	Mountain Landscape	1957	Landscape	44.5	55	2447.5	oil on canvas	Merthyr Tydfil Museum Service
186.jpg	186	Mountain Landscape with High Sun	1970-1980	Landscape	76.3	76.2	5814.06	oil on canvas	NLW
187.jpg	187	Mountain Landscape with Trees and a Field in the Foreground	1960-1980	Landscape	50.5	76.5	3863.25	oil on canvas	NLW
188.jpg	188	Mountain Stream with Trees	1970-1990	Landscape	55.5	68	3774	oil on canvas	NLW
189.jpg	189	Mountain Summit with Low Cloud	1960-1970	Landscape	71	91.5	6496.5	oil on canvas	NLW
190.jpg	190	Mountain Summits, Snowdonia	1960-1970	Landscape	50.2	91.3	4583.26	oil on canvas	NLW
191.jpg	191	Mountain Torrent	1940-1950	Landscape	40.7	51	2075.7	oil on canvas	NLW
192.jpg	192	Mountain Valley	1940-1950	Landscape	12	33.6	403.2	oil on board	NLW
193.jpg	193	Mountain Valley	1940-1950	Landscape	51	68.7	3503.7	oil on canvas	NLW
194.jpg	194	Mountain Valley Cottages	1990-2006	Landscape	71.2	91.5	6514.8	oil on canvas	NLW

Filename	ID	Title	Catalogue entry BBC YP	Genre	Height	Width	Area	Materials	Collection
195.jpg	195	Mountainous Landscape	n.d.	Landscape	21	37	777	oil on board	Glynn Vivian Art Gallery
196.jpg	196	Mountains and Rocks	1950-1960	Landscape	40.5	50.7	2053.35	oil on canvas	NLW
197.jpg	197	Mountains, Eryri, with Cloud	1970-1990	Landscape	90.7	91.5	8299.05	oil on canvas	NLW
198.jpg	198	Mountains, North Wales	1950-1970	Landscape	76	63.1	4795.6	oil on canvas	NLW
199.jpg	199	Mountains, Snowdonia	1960-1980	Landscape	60.7	76.1	4619.27	oil on canvas	NLW
200.jpg	200	Mountains, Snowdonia	1950-1960	Landscape	50.7	68.5	3472.95	oil on canvas	NLW
201.jpg	201	Mountains with Blue Sky	1970-1990	Landscape	56	76.2	4267.2	oil on canvas	NLW
202.jpg	202	Mrs Rowlands	1984	Portrait	126	76.5	9639	oil on canvas	OYM
203.jpg	203	Mynydd Bodafon, Anglesey	n.d.	Landscape	57	67	3819	oil on canvas	Hereford Museum and Art Gallery
204.jpg	204	Mynydd Mawr a'r Wyddfa	1970-1990	Landscape	61	91.5	5581.5	oil on canvas	NLW
205.jpg	205	Nant Ffrancon	1960-1970	Landscape	76	127.4	9682.4	oil on canvas	NLW
206.jpg	206	Nant Ffrancon from Llandegfan	1960	Landscape	30.8	76.4	2353.12	oil on canvas	GAC
207.jpg	207	Near Capel Curig	1960-1980	Landscape	50.5	60.8	3070.4	oil on canvas	NLW
208.jpg	208	Nun at a Crucifix	1950-1960	Portrait	76.8	61.5	4723.2	oil on canvas	NLW
209.jpg	209	Paith, Patagonia	1969	Landscape	51	68.7	3503.7	oil on canvas	NLW
210.jpg	210	Patagonian Landscape	1969	Landscape	65	65	4225	oil on canvas	NLW
211.jpg	211	Path below Crib Goch	1970-1980	Landscape	76	76	5776	oil on canvas	NLW
212.jpg	212	Pen Carmen, Ty Ddewi	n.d.	Landscape	57.3	126	7219.8	oil on canvas	NMGW
213.jpg	213	Pencamedd, Llansadwrn	n.d.	Landscape	58	79	4582	oil on canvas	NLW
214.jpg	214	Pengwyryd	1999	Landscape	120	120	14400	oil on canvas	NLW
215.jpg	215	Penmon Coast and Ynys Seriol	1960-1980	Landscape	55.3	91.5	5059.95	oil on canvas	NLW
216.jpg	216	Penmon Cross	n.d.	Landscape	77.5	39.5	3061.25	oil on canvas	OYM

Filename	ID	Title	Catalogue entry BBC YP	Genre	Height	Width	Area	Materials	Collection
217.jpg	217	Pentrepella	1970s	Landscape	76.6	178	13634.8	oil on canvas	NLW
218.jpg	218	Pilot Boat off Moelfre	1947	Landscape	38.5	74.5	2868.25	oil on canvas	OYM
219.jpg	219	Plucked Chicken	1950-1970	Still life	102	56.5	5763	oil on canvas	NLW
220.jpg	220	Ponies at Betws Garmon	n.d.	Landscape	89.5	119.6	10704.2	oil on canvas	BU
221.jpg	221	Ponies at Dusk	1960-1970	Landscape	55.8	91.3	5094.54	oil on canvas	NLW
222.jpg	222	Ponies on a Sea Cliff	1990-2006	Landscape	76.1	76	5783.6	oil on canvas	NLW
223.jpg	223	Pony on Llanddwyn Island	n.d.	Landscape	72.3	87.3	6311.79	oil on canvas	Derbyshire and Derby School Library Service
224.jpg	224	Porth Swtan, Sir Fon	1985	Landscape	49.8	89.8	4472.04	oil on canvas	NLW
225.jpg	225	Portrait of a Boy	1944	Portrait	27.9	21.6	602.64	oil on hardboard	UCL Art Museum
226.jpg	226	Portrait of Grey-Haired Woman	1943	Portrait	30.5	25.4	774.7	oil on canvas	UCL Art Museum
227.jpg	227	Portrait of a Young Woman looking Left	1950-1970	Portrait	61	51	3111	oil on canvas	NLW
228.jpg	228	Pwllderi	1970-1990	Landscape	51.3	61	3129.3	oil on canvas	NLW
229.jpg	229	R.S. Thomas (1913-2000)	1980	Portrait	91	91	8281	oil on canvas	NLW
230.jpg	230	Range of Mountains, Snowdonia	1950-1960	Landscape	50.3	76.1	3827.83	oil on canvas	NLW
231.jpg	231	Rhosybol	1960–1970	Landscape	91	121.7	11074.7	oil on canvas	NLW
232.jpg	232	Road to the Farm	1970-1990	Landscape	50.5	76.2	3848.1	oil on canvas	NLW
233.jpg	233	Roadside Cottage, Eryri	1940-1950	Landscape	50.5	61	3080.5	oil on canvas	NLW
234.jpg	234	Rocamdour	1960-1970	Landscape	51	61.2	3121.2	oil on canvas	NLW
235.jpg	235	Royal Welchman in Scarlet	1948	Portrait	75.3	59.6	4487.88	oil on canvas	RWFRM
236.jpg	236	Rugged Mountains with Low Cloud	1970-1990	Landscape	91.3	91.6	8363.08	oil on canvas	NLW

Filename	ID	Title	Catalogue entry BBC YP	Genre	Height	Width	Area	Materials	Collection
237.jpg	237	Sea at Trearddur	1976	Seascape	50	114	5700	oil on canvas	Southend Museum Collection
238.jpg	238	Self Portrait	1953	Portrait	32	13	416	oil on canvas	NLW
239.jpg	239	Self Portrait	1968	Portrait	89.5	60.5	5414.75	oil on canvas	NLW
240.jpg	240	Self Portrait	1997	Portrait	124.5	74.7	9300.15	oil on canvas	NLW
241.jpg	241	Self Portrait	1940-1950	Portrait	34.7	29.4	1020.18	oil on hardboard	NLW
242.jpg	242	Sir Charles Eans (1918-1995)	1965	Portrait	91	71	6461	oil on canvas	NMGW
243.jpg	243	Sir David Hughes Parry (1983-1973), President (1955-1964)	1964	Portrait	91	71	6461	oil on canvas	Aberystwyth School of Art Gallery and Museum
244.jpg	244	Sir Thomas Parry (1904-1985)	1970	Portrait	75.5	90.5	6832.75	oil on canvas	NLW
245.jpg	245	Skeleton	1940-1950	Still life	28	57.8	1618.4	oil on paper	NLW
246.jpg	246	Snow above Beddgelert	1959	Landscape	91.5	122	11163	oil on canvas	National Museums Liverpool
247.jpg	247	Snow and Cloud, Snow-donia	1950-1970	Landscape	61	76.5	4666.5	oil on canvas	NLW
248.jpg	248	Snow on Siabod	1968	Landscape	40.6	50.9	2066.54	oil on canvas	NMGW
249.jpg	249	Snow on the Mountains, Eryri	1960-1970	Landscape	61.2	76.3	4669.56	oil on canvas	NLW
250.jpg	250	Snowdon	Mid 20th Century (pre 1965, see note)	Landscape	55	80	4400	oil on canvas	Alun School
251.jpg	251	Snowdon from Drws y Coed	n.d.	Landscape	119.8	181.6	21755.68	oil on canvas	BU

Filename	ID	Title	Catalogue entry BBC YP	Genre	Height	Width	Area	Materials	Collection
252.jpg	252	Snowdon from Gelli Iago	1960-1970	Landscape	91.6	121.7	11147.72	oil on canvas	NLW
253.jpg	253	Snowdon from Llyn Nantlle	1945	Landscape	39.4	49.5	1950.3	oil on canvas	NMGW
254.jpg	254	Snowdon from near Harlech	n.d.	Landscape	21	35.7	749.7	oil on board	Glynn Vivian Art Gallery
255.jpg	255	Snowdon from Ty Obry	1960s	Landscape	120	240	28800	oil on canvas	NLW
256.jpg	256	Snowdon Range	1990-2006	Landscape	76.2	126.3	9624.06	oil on canvas	NLW
257.jpg	257	Snowdon Range	1950-1970	Landscape	51	68.6	3498.6	oil on canvas	NLW
258.jpg	258	Snowdon, the Traeth and the Frightened Horse	1948	Landscape	76.5	183	13999.5	oil on canvas	Aberystwyth School of Art Gallery and Museum
259.jpg	259	Snowdonian Summits	1970-1990	Landscape	50.5	76	3838	oil on canvas	NLW
260.jpg	260	Snowstorm off Penmon	1961	Landscape	91.5	122	11163	oil on canvas	OYM
261.jpg	261	Storm	1950-1960	Seascape	51	61.2	3121.2	oil on canvas	NLW
262.jpg	262	Storm Approaching	1990-2006	Seascape	90.9	90.9	8262.81	oil on canvas	NLW
263.jpg	263	Storm Approaching, Eryri	1990-2006	Seascape	50.5	76	3838	oil on canvas	NLW
264.jpg	264	Storm at Trearddur	1987	Seascape	95	126	11970	oil on canvas	OYM
265.jpg	265	Storm Clouds over the Mountains	1960-1970	Seascape	56	91.6	5129.6	oil on canvas	NLW
266.jpg	266	Storm from the Beach	1990-2006	Seascape	61	91.2	5563.2	oil on canvas	NLW
267.jpg	267	Storm, Porth Cwyfan	1995	Landscape	94.3	145.4	13711.22	oil on canvas	NMGW
268.jpg	268	Storm, Trearddur	1996	Landscape	60	90.5	5430	oil on canvas	NLW
269.jpg	269	Stormy Sea	1970-1990	Seascape	55.7	76.2	4244.34	oil on canvas	NLW
270.jpg	270	Stormy Sea	1990-2006	Seascape	50.5	75.5	3812.75	oil on canvas	NLW
271.jpg	271	Stormy Sea	1990-2006	Seascape	71	91.5	6496.5	oil on canvas	NLW
272.jpg	272	Stormy Sea under a Dark Sky	1990-2006	Seascape	50.5	76	3838	oil on canvas	NLW

Filename	ID	Title	Catalogue entry BBC YP	Genre	Height	Width	Area	Materials	Collection
273.jpg	273	Stormy Sky and Distant Mountain	1960-1980	Landscape	50.4	61	3074.4	oil on canvas	NLW
274.jpg	274	Summer, Snowdonia	1970-1990	Landscape	61	76	4636	oil on canvas	NLW
275.jpg	275	Sun and Cloud on Lliwedd	1973	Landscape	55.3	76.2	4213.86	oil on canvas	Aberystwyth School of Art Gallery and Museum
276.jpg	276	Sunflowers with Mountains Beyond	1940-1950	Landscape	40.8	29.8	1215.84	oil on canvas	NLW
277.jpg	277	Sunset	n.d.	Landscape	121.7	121.7	14810.89	oil on canvas	OYM
278.jpg	278	Sunset, Anglesey	2004	Landscape	91	91	8281	oil on canvas	NLW
279.jpg	279	Swtan	1947	Landscape	44.6	50.8	2265.68	oil on canvas	OYM
280.jpg	280	Talsarn	1981	Landscape	58.3	58.6	3416.38	oil on canvas	Hereford Museum and Art Gallery
281.jpg	281	Tan-y-Grisiau	n.d.	Landscape	90	70	6300	oil on canvas	OYM
282.jpg	282	The Chelsea Pensioner	1980	Portrait	95	64	6080	oil on canvas	OYM
283.jpg	283	The Church and Cottages, Aberffraw	1960s	Landscape	49.5	75	3712.5	oil on canvas	Merthyr Tydfil Museum Service
284.jpg	284	The Cleric	1940-1950	Portrait	91.3	61.2	5587.56	oil on canvas	NLW
285.jpg	285	The Crucifixion	n.d.	Genre	125.5	57	7153.5	oil on canvas	BU
286.jpg	286	The Dark Lake	1951	Landscape	44.5	54.5	2425.25	oil on canvas	Swindon Art Gallery
287.jpg	287	The Gathering (Farmers on Glyder Fawr)	1980s	Landscape	122	183	22326	oil on canvas	NLW
288.jpg	288	The Moelwyns from Aberglasyn	1952	Landscape	38.8	77	2987.6	oil on canvas	NLW

Filename	ID	Title	Catalogue entry BBC YP	Genre	Height	Width	Area	Materials	Collection
289.jpg	289	The New Road to the Valley	1969	Landscape	91.5	91	8326.5	oil on canvas	NLW
290.jpg	290	The Old Soldier	1951	Portrait	91.4	70.5	6443.7	oil on canvas	Arts Council Collection
291.jpg	291	The Path from the Shore	1970-1990	Landscape	91.5	91.2	8344.8	oil on canvas	NLW
292.jpg	292	The Way to the Cottages	1990-2006	Landscape	60.7	91.2	5535.84	oil on canvas	NLW
293.jpg	293	Three Farmers on a mountain Path	1960-1970	Landscape	50.7	68.7	3483.09	oil on canvas	NLW
294.jpg	294	Tom Owen	1951	Portrait	83	74	6142	oil on canvas	Carmarthenshire County Council
295.jpg	295	Towards the Moutains	1960-1980	Landscape	51	61	3111	oil on canvas	NLW
296.jpg	296	Traeth Coch	1970-1980	Landscape	76.1	127.2	9679.92	oil on canvas	NLW
297.jpg	297	Tre'r Ceiri	n.d.	Landscape	35.5	45.5	1615.25	oil on canvas	Glynn Vivian Art Gallery
298.jpg	298	Tryfan	1960-1980	Landscape	91.2	122.2	11144.64	oil on canvas	NLW
299.jpg	299	Tryfan	1950-1960	Landscape	40.5	51	2065.5	oil on canvas	NLW
300.jpg	300	Tryfan No.2	n.d.	Landscape	50	110	5500	oil on canvas	Atkinson Art Gallery
301.jpg	301	View from Pwllfanogl	n.d.	Landscape	76	76	5776	oil on canvas	OYM
302.jpg	302	View of Snowdon in Winter	n.d.	Landscape	27.1	76.5	2073.15	oil on canvas	Glynn Vivian Art Gallery
303.jpg	303	Waterfall, Ogwen	n.d.	Landscape	127	77	9779	oil on canvas	MOMA
304.jpg	304	Wave Breaking on Rocks	1950-1970	Landscape	70.8	91.2	6456.96	oil on canvas	NLW
305.jpg	305	Wave on Stormy Sea	1990-2006	Seascape	50.5	91.2	4605.6	oil on canvas	NLW
306.jpg	306	Welsh Black Bull	1990-2006	Landscape	71.2	91.2	6493.44	oil on canvas	NLW
307.jpg	307	Welsh Black on Rocky Outcrop above the Coast	1940-1950	Landscape	51	68.5	3493.5	oil on canvas	NLW

Filename	ID	Title	Catalogue entry BBC YP	Genre	Height	Width	Area	Materials	Collection
308.jpg	308	Welsh Blacks Grazing on Snowdonia	1970-1990	Landscape	50.8	60.8	3088.64	oil on canvas	NLW
309.jpg	309	Welsh Blacks, Llanddona	1960-1970	Landscape	61	61	3721	oil on canvas	NLW
310.jpg	310	Welsh Landscape	1970	Landscape	50.5	68.5	3459.25	oil on canvas	NLW
311.jpg	311	Welsh Landscape	n.d.	Landscape	119.5	119.5	14280.25	oil on canvas	CU
312.jpg	312	Welsh Landscape with Farmers	n.d.	Landscape	49.5	113.5	5618.25	oil on canvas	CU
313.jpg	313	Welsh Pony Grazing at the Coast	1960-1970	Landscape	56	76.3	4272.8	oil on canvas	NW
314.jpg	314	Welsh Sheepdog	1980-1990	Genre	51	76	3876	oil on canvas	NW
315.jpg	315	William Lee	1979	Portrait	91	91	8281	oil on canvas	NMGW
316.jpg	316	William Moelwyn Merchant (1913-1997)	1970	Portrait	90	90	8100	oil on canvas	NLW
317.jpg	317	Winter at Fachwen	1967	Landscape	122	244	29768	oil on canvas	GAC
318.jpg	318	Winter Coast	1970-1990	Landscape	50.9	76.5	3893.85	oil on canvas	NLW
319.jpg	319	Woman with a Duster	1990	Portrait	121.5	91	11056.5	oil on canvas	NLW
320.jpg	320	Y Garn and Foel Goch	1950	Landscape	60.5	95.5	5777.75	oil on canvas	Scarborough Art Gallery
321.jpg	321	Yellow Fields under a Grey Sky	1950-1960	Landscape	60.8	91.5	5563.2	oil on canvas	NLW
322.jpg	322	Yolanta	1967	Portrait	60	91	5460	oil on canvas	OYM
323.jpg	323	Young Girl with a Black Dress, Standing	1950-1970	Portrait	76.5	50.5	3863.25	oil on canvas	NLW
324.jpg	324	Young Woman Looking Forward	1950	Portrait	60.9	40.7	2478.63	oil on canvas	NLW
325.jpg	325	Yr Wyddfa a Grib Goch	1950-1960	Landscape	60.7	76	4613.2	oil on canvas	NLW

Table D.1: Painting Spreadsheet Data

Filename	ID	Title	Catalogue entry BBC YP	exemplar year
154.jpg	154	Landscape at Llanaelhaearn	1947	1947
258.jpg	258	Snowdon, the Traeth and the Frightened Horse	1948	1948
155.jpg	155	Landscape with Cattle	c.1950	1950
286.jpg	286	The Dark Lake	1951	1951
288.jpg	288	The Moelwyns from Aberglasyn	c.1952	1952
238.jpg	238	Self Portrait	c.1953	1953
051.jpg	51	Cottages, Llanddona	c.1955	1955
185.jpg	185	Mountain Landscape	1957	1957
023.jpg	23	Capel Carmel	c.1958	1958
246.jpg	246	Snow above Beddgelert	c.1959	1959
206.jpg	206	Nant Ffrancon from Llandegfan	c.1960	1960
260.jpg	260	Snowstorm off Penmon	1961	1961
053.jpg	53	Cottages, Mynydd Bodafon	c.1962	1962
120.jpg	120	German Girl	c.1963	1963
243.jpg	243	Sir David Hughes Parry	1964	1964
242.jpg	242	Sir Charles Evans	c.1965	1965
087.jpg	87	Farm below Crib Goch	1967	1967
248.jpg	248	Snow on Siabod	c.1968	1968
158.jpg	158	Lle Cul, Patagonia	1969	1969
073.jpg	73	Deserted Farm, Llanrhuddlad	c.1970	1970
275.jpg	275	Sun and Cloud on Lliwedd	1973	1973
093.jpg	93	Farm, Llanfairynghornwy	c.1975	1975
018.jpg	18	Blaen Nant	1976	1976
237.jpg	237	Sea at Trearddur	c.1976	1976
017.jpg	17	Blaen Ffrancon No.1	c.1978	1978
107.jpg	107	Farmers on the Carneddau	c.1980	1980
105.jpg	105	Farmer below the Ridge	c.1983	1983
202.jpg	202	Mrs Rowlands	c.1984	1984
003.jpg	3	Above Carneddi, No.2	c.1985	1985
264.jpg	264	Storm at Trearddur	1987	1987
165.jpg	165	Llyn-y-Cau, Cader Idris	c.1990	1990
267.jpg	267	Storm, Porth Cwyfan	1995	1995
268.jpg	268	Storm, Trearddur	1996	1996
214.jpg	214	Pengwyryd	c.1999	1999
020.jpg	20	Bryn Cader Faner	2000	2000
278.jpg	278	Sunset, Anglesey	2004	2004

Table D.2: Exemplar Spreadsheet Data

Annotated Bibliography

[1] J. Bacardit and X. Llorà, "Large-scale data mining using genetics-based machine learning," *Wiley Interdisciplinary Reviews: Data Mining and Knowledge Discovery*, vol. 3, no. 1, pp. 37–61, Jan. 2013. [Online]. Available: http://dx.doi.org/10.1002/widm.1078

A paper recommended by Julie Greensmith for information on a Learning Classifier System (LCS) which Julie believes will yield good results with the Kyffin Williams project.

[2] I. E. Berezhnoy, E. O. Postma, and H. J. van den Herik, "Authentic: Computerized brushstroke analysis," in *Multimedia and Expo, 2005. ICME 2005. IEEE International Conference on*. IEEE, July 2005, pp. 1586–1588. [Online]. Available: http://dx.doi.org/10.1109/icme.2005.1521739

Defines a method of analysing brushstrokes by applying a circular filter across a digital image to pick up the ridges of a brushstroke. This can then be used to pick out individual brushstrokes in order to be able to fit a nth order polynomial to them. Though this paper focuses on authenticating Van Gogh's paintings, it could easily be applied to the work of Kyffin Williams and may allow for some interesting analysis.

[3] G. Bradski, "The OpenCV Library," *Dr. Dobb's Journal of Software Tools*, 2000.

Used Python (http://opencv.willowgarage.com/documentation/python) and C++ (http://opencv.willowgarage.com/documentation) documentation for library reference and some learning on image processing/computer vision. Used since 11 October 2012.

[4] I. Chilvers, J. Glaves-Smith, and I. Chilvers, *A dictionary of modern and contemporary art*. Oxford University Press, 2009. [Online]. Available: http://www.worldcat.org/isbn/0199239665 0199239665.

[5] W. Contributors, "Gabor filter," Online, Oct. 2012. [Online]. Available: http://en.wikipedia.org/w/index.php?title=Gabor_filter&oldid=517342109

[6] N. Dalal and B. Triggs, "Histograms of oriented gradients for human detection," in *Computer Vision and Pattern Recognition, 2005. CVPR 2005. IEEE Computer Society Conference on*, ser. CVPR '05, vol. 1. Washington, DC, USA: IEEE, June 2005, pp. 886–893 vol. 1. [Online]. Available: http://dx.doi.org/10.1109/cvpr.2005.177

Describes a method of producing histograms of edge orientations which may prove to be a useful analysis technique for Kyffin Williams' art. The most interesting part of this paper is the use of segmentation and binning of gradients

which seems like it could be useful to differentiate different parts of the image which may be painted in different styles.

[7] J. Davies and A. Gymreig, *The Welsh Academy encyclopaedia of Wales*. University of Wales Press, 2008, pp. 957–958. [Online]. Available: http://www.worldcat.org/isbn/9780708319536 9780708319536.

[8] E. Gamma, *Entwurfsmuster : Elemente wiederverwendbarer objektorientierter Software*, ser. Addison-Wesley professional computing series. Addison-Wesley, 1996. [Online]. Available: http://www.worldcat.org/isbn/9780201633610 9780201633610.

[9] M. Hall, E. Frank, G. Holmes, B. Pfahringer, P. Reutemann, and I. H. Witten, "The WEKA data mining software: an update," *SIGKDD Explor. Newsl.*, vol. 11, no. 1, pp. 10–18, Nov. 2009. [Online]. Available: http://dx.doi.org/10.1145/1656274.1656278

Citation for the Weka data mining software. Weka is a Java based tool which can be used to run a lot of classifiers to a dataset, making it a very useful tool to apply to the Kyffin Williams project. Weka allows the application of complex machine learning techniques without having to spend a lot of time learning, understand and implementing said techniques.

[10] R. Harris, "How rolf learnt to paint like sir kyffin williams," BBC Broadcast, Feb. 2011. [Online]. Available: http://www.bbc.co.uk/programmes/p00f6nyt

A video on the BBC by Rolf Harris about some of Kyffin Williams' life and about his interesting style of painting.

[11] E. Jones, T. Oliphant, P. Peterson, *et al.*, "SciPy: Open source scientific tools for python," 2001.

[12] J. Li, L. Yao, E. Hendriks, and J. Z. Wang, "Rhythmic brushstrokes distinguish van gogh from his contemporaries: Findings via automated brushstroke extraction," *Pattern Analysis and Machine Intelligence, IEEE Transactions on*, vol. 34, no. 6, pp. 1159–1176, June 2012. [Online]. Available: http://dx.doi.org/10.1109/tpami.2011.203

Defines a complex method for analysing individual brush strokes which has been used to classify the period of two paintings by Van Gogh. This technique could be very powerful when applied to Kyffin Williams' work. This could be one of the most important techniques for the whole of the Kyffin Williams project.