

Automatic Test Grader Using Image Processing And Machine Learning Techniques



Andries Petrus Smit
18183085

Department of Electrical and Electronic Engineering
University of Stellenbosch

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Study leader: JA du Preez
B.Eng Electrical and Electronic

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Acknowledgements

I would like to acknowledge my skripsie leader, JA du Preez, parents and the engineering class of 2017 for their kind contributing to this thesis.

Declaration

I, the undersigned, hereby declare that the work contained in this final year project is my own original work and that I have not previously in its entirety or in part submitted it at any university for a degree.

.....

Signature

.....

Date

ECSA Exit Level Outcomes Reference

Outcome	Reference	
	Sections	Pages
1. Problem solving: Demonstrate competence to identify, assess, formulate and solve convergent and divergent engineering problems creatively and innovatively.	<i>All</i>	<i>All</i>
5. Engineering methods, skills and tools, including information technology: Demonstrate competence to use appropriate engineering methods, skills and tools, including those based on information technology.	<i>2, 3, 4, 5, 6 & 7</i>	<i>10 – 62</i>
6. Professional and technical communication: Demonstrate competence to communicate effectively, both orally and in writing, with engineering audiences and the community at large.	<i>All</i>	<i>All</i>
9. Independent learning ability: Demonstrate competence to engage in independent learning through well developed learning skills.	<i>2, 3, 4 & 5</i>	<i>10 – 37</i>
10. Engineering professionalism: Demonstrate critical awareness of the need to act professionally and ethically and to exercise judgment and take responsibility within own limits of competence.	<i>8.3 & 8.4</i>	<i>66 – 67</i>

Is die ecsa outcome reg en EE sin?

For a more detailed review on how the respective outcomes were met in this thesis, please refer to [Appendix D](#).

Abstract

English abstract here.

Opsomming

Afrikaanse opsomming hier. Alle dokumente moet beide Afrikaans en Engelse opsommings bevat.

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Nomenclature

<i>ANN</i>	Artificial neural network
<i>DCNN</i>	Deep convolutional neural network
<i>OCR</i>	Optical character recognition
<i>OMR</i>	Optical mark recognition
<i>PGM</i>	Probabilistic graphical model

Chapter 1

Introduction

As modern technology and machine learning techniques advances, it is important for the educational sector to also continuously advance their learning environment. This allows for an ever improving learning experience in and outside the classroom.

1.1 Problem background

In the recent years the Applied Mathematics Department of Stellenbosch Engineering, started observing a decrease of accuracy in grading of tutorial tests, done by a teaching assistants or demi. Students complain on a regular basis about correct answers being marked wrong or even that their answers were totally ignored. To address this problem the Applied Mathematics department proposes to automate the process of grading these tutorial tests.

The head of the department wants a system that can analyse and grade tests written on a specific template. These answer sheets are handed out for the students to fill in their respective answers. The answer sheets are then scanned-in to create a digital copy. The system is tasked with automatically grading all these digital copies and transferring the graded results to a database.

The department will send weekly scanned in sheets, which needs to be graded and the results then sent back to them. This is done in parallel with the development and expansion of the test grading software. For these reasons an agile development methodology is used with a weekly validation test, as the system gets used.

1.2 Problem statement

Given the problem background and stakeholders discussed in the previous section the problem to be solved can be formulated as

Develop and **implement** a *automatic test grading system* that will *reduce marking time* and *increasing accuracy* on the *grading* of Applied Mathematics tutorial tests, written by students.

1.3 Project scope and assumptions

Initial discussions with the department head revealed that a specific answer sheet template can be used. This allows the custom image processing software to more accurately determine what the student filled in. The template will consist of bubbles that can be coloured in as well as blocks for handwritten digits, as can be seen in Figure 1.1. This template is constructed by the Applied Mathematics Department. Thus the focus of this project is on processing that scanned in document written on the specific template. To use the template the student must fill in his/her student number and answers in the blocks above each category. They are also required to fill in the bubble underneath each digit, corresponding to that specific digit. Additionally a bubble next to each question is provided if a negative sign is required.

Any additional assumptions are specified at the appropriate times throughout this project. Two more templates will also be implemented in later chapters, which will allow for multiple choice questions.

1.3 Project scope and assumptions

Stellenbosch University: Applied Mathematics B154

Tutorial Test 1

24 July 2017

Surname : US Number →

dsy afuysda fuiyoysdauoldfj hlfjijdh fljfdkghld-
flsj hlfkdj hgslijkfg hsdjfg jkfdsg hlfjksdh gls-
fjkd h glijksfhd glijkh d sljkgh lsfjkd hglkj d hglkj h
sfdglijksfhd glkfhd glijkhfd slgjk h fdslikg h lfdjkh
gify osuida fyosuidayf osudiy fousiday fouisyda

.....
Student's signature

1	<input type="text"/>	<input type="text"/>	<input type="text"/>	<input type="text"/>	<input type="text"/>	<input type="text"/>	<input type="text"/>	1
2	<input type="text"/>	<input type="text"/>	<input type="text"/>	<input type="text"/>	<input type="text"/>	<input type="text"/>	<input type="text"/>	2
3	<input type="text"/>	<input type="text"/>	<input type="text"/>	<input type="text"/>	<input type="text"/>	<input type="text"/>	<input type="text"/>	3
4	<input type="text"/>	<input type="text"/>	<input type="text"/>	<input type="text"/>	<input type="text"/>	<input type="text"/>	<input type="text"/>	4
5	<input type="text"/>	<input type="text"/>	<input type="text"/>	<input type="text"/>	<input type="text"/>	<input type="text"/>	<input type="text"/>	5
6	<input type="text"/>	<input type="text"/>	<input type="text"/>	<input type="text"/>	<input type="text"/>	<input type="text"/>	<input type="text"/>	6
7	<input type="text"/>	<input type="text"/>	<input type="text"/>	<input type="text"/>	<input type="text"/>	<input type="text"/>	<input type="text"/>	7
8	<input type="text"/>	<input type="text"/>	<input type="text"/>	<input type="text"/>	<input type="text"/>	<input type="text"/>	<input type="text"/>	8
9	<input type="text"/>	<input type="text"/>	<input type="text"/>	<input type="text"/>	<input type="text"/>	<input type="text"/>	<input type="text"/>	9
0	<input type="text"/>	<input type="text"/>	<input type="text"/>	<input type="text"/>	<input type="text"/>	<input type="text"/>	<input type="text"/>	0

Question 1:

(a) .

(b) .

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1	<input type="text"/>	<input type="text"/>	<input type="text"/>	<input type="text"/>	<input type="text"/>	<input type="text"/>	1
2	<input type="text"/>	<input type="text"/>	<input type="text"/>	<input type="text"/>	<input type="text"/>	<input type="text"/>	2
3	<input type="text"/>	<input type="text"/>	<input type="text"/>	<input type="text"/>	<input type="text"/>	<input type="text"/>	3
4	<input type="text"/>	<input type="text"/>	<input type="text"/>	<input type="text"/>	<input type="text"/>	<input type="text"/>	4
5	<input type="text"/>	<input type="text"/>	<input type="text"/>	<input type="text"/>	<input type="text"/>	<input type="text"/>	5
6	<input type="text"/>	<input type="text"/>	<input type="text"/>	<input type="text"/>	<input type="text"/>	<input type="text"/>	6
7	<input type="text"/>	<input type="text"/>	<input type="text"/>	<input type="text"/>	<input type="text"/>	<input type="text"/>	7
8	<input type="text"/>	<input type="text"/>	<input type="text"/>	<input type="text"/>	<input type="text"/>	<input type="text"/>	8
9	<input type="text"/>	<input type="text"/>	<input type="text"/>	<input type="text"/>	<input type="text"/>	<input type="text"/>	9
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4	<input type="text"/>	<input type="text"/>	<input type="text"/>	<input type="text"/>	<input type="text"/>	<input type="text"/>	4
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6	<input type="text"/>	<input type="text"/>	<input type="text"/>	<input type="text"/>	<input type="text"/>	<input type="text"/>	6
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9	<input type="text"/>	<input type="text"/>	<input type="text"/>	<input type="text"/>	<input type="text"/>	<input type="text"/>	9
0	<input type="text"/>	<input type="text"/>	<input type="text"/>	<input type="text"/>	<input type="text"/>	<input type="text"/>	0

Question 2:

(a) .

(b) .

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2	<input type="text"/>	<input type="text"/>	<input type="text"/>	<input type="text"/>	<input type="text"/>	<input type="text"/>	2
3	<input type="text"/>	<input type="text"/>	<input type="text"/>	<input type="text"/>	<input type="text"/>	<input type="text"/>	3
4	<input type="text"/>	<input type="text"/>	<input type="text"/>	<input type="text"/>	<input type="text"/>	<input type="text"/>	4
5	<input type="text"/>	<input type="text"/>	<input type="text"/>	<input type="text"/>	<input type="text"/>	<input type="text"/>	5
6	<input type="text"/>	<input type="text"/>	<input type="text"/>	<input type="text"/>	<input type="text"/>	<input type="text"/>	6
7	<input type="text"/>	<input type="text"/>	<input type="text"/>	<input type="text"/>	<input type="text"/>	<input type="text"/>	7
8	<input type="text"/>	<input type="text"/>	<input type="text"/>	<input type="text"/>	<input type="text"/>	<input type="text"/>	8
9	<input type="text"/>	<input type="text"/>	<input type="text"/>	<input type="text"/>	<input type="text"/>	<input type="text"/>	9
0	<input type="text"/>	<input type="text"/>	<input type="text"/>	<input type="text"/>	<input type="text"/>	<input type="text"/>	0

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1	<input type="text"/>	<input type="text"/>	<input type="text"/>	<input type="text"/>	<input type="text"/>	<input type="text"/>	1
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3	<input type="text"/>	<input type="text"/>	<input type="text"/>	<input type="text"/>	<input type="text"/>	<input type="text"/>	3
4	<input type="text"/>	<input type="text"/>	<input type="text"/>	<input type="text"/>	<input type="text"/>	<input type="text"/>	4
5	<input type="text"/>	<input type="text"/>	<input type="text"/>	<input type="text"/>	<input type="text"/>	<input type="text"/>	5
6	<input type="text"/>	<input type="text"/>	<input type="text"/>	<input type="text"/>	<input type="text"/>	<input type="text"/>	6
7	<input type="text"/>	<input type="text"/>	<input type="text"/>	<input type="text"/>	<input type="text"/>	<input type="text"/>	7
8	<input type="text"/>	<input type="text"/>	<input type="text"/>	<input type="text"/>	<input type="text"/>	<input type="text"/>	8
9	<input type="text"/>	<input type="text"/>	<input type="text"/>	<input type="text"/>	<input type="text"/>	<input type="text"/>	9
0	<input type="text"/>	<input type="text"/>	<input type="text"/>	<input type="text"/>	<input type="text"/>	<input type="text"/>	0

Figure 1.1: Automatic grading template 1.

1.4 Project objectives

The problem as stated in section 1.2, is addressed by pursuing the following objectives:

1. Do a *literature study* on the topics of *Image Processing*, *Computer Vision* and *Character Recognition*.
2. Develop a *software application* to enable a *user* to grade a large number (approximately 1000) scanned in student tests automatically.
3. Do a weekly *validation experiment* with the software, by grading tutorial test for the department. The results are then used as the student's grade for that test.
4. Use an *agile development methodology* to improving the software in parallel with the grading of weekly tests.
5. Add additional software to allow grading of new *templates* and to increase the speed and accuracy of the software.

The objectives are covered in different chapters in the report. Note that each objective (1–5) build on the objective(s) previously listed.

The software must also ease the use of the template for students while also providing precise and useful feedback. To do this every graded result will also include feedback on what answers the student got wrong and what the correct answers were. To increase ease of use, software is developed that provides the luxury to students to only writing down their student numbers. Thus time does not get wasted filling in the student number bubbles. This result is achieved in Chapter 4.2.4.

1.5 Research methodology

To complete the objectives listed in Section 1.4, a agile development methodology is used. The methodology followed comprises of five different phases:

1. Identify a new feature or update that needs to be implemented into the software package.
2. Do a study on the existing methods to implement this new software.

3. Implement and integrate the new software with the current knowledge of the solution.
4. Test the software and observe if it is working as planned.
5. If the software is not working as planned, revisit steps 2-4 until the new software is working.
6. Use version control, for example Git, to save the latest version of the software.

The structure and graphical overview of the software, is presented next.

(Vra prof of my wiskunde reg is oor hoe die PGM stelsel werk.)

1.6 Graphical overview of system

1.6.1 System overview

When thinking about the system (for template 1), from a philosophical sense, it can fundamentally be represented with 6 information nodes. The student has certain information he/she wants to portray on the paper. This includes the 4 answers and student number he/she wants to write down. Thus those 5 nodes gives rise to the image, representing the last node. This has to be represented in a probabilistic way. This is, because the process of writing answers down and scanning the test sheet in is going to produce a different image every time a test is written, even though the same answers are intended. This graphical model is illustrated in Figure [A.1](#). The unnamed blocks indicate that information processing happens in these steps. For the complete visual overview of the system, again refer to Appendix [A](#).

For a more detailed mathematical derivation of the entire system, refer to Appendix [A](#).

1.6.2 Graphical representation

For this project a graphical approach is followed in representing the software developed. A graphical model in essence allows software to be represented as information (nodes or circles) and relationships (directed arrows). The directions of the arrows represents what information causes other information to be created, thus given a parent to offspring interpretation). An example of such a graph can again be seen in Figure [A.1](#).

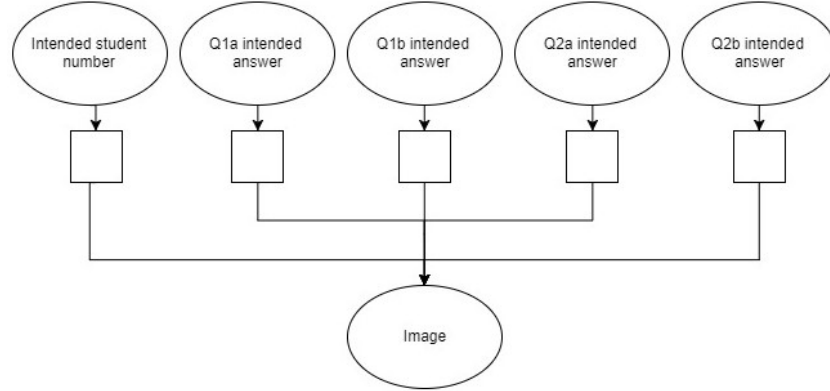


Figure 1.2: Graphical overview of the system as a whole.

This allows intuitive reasoning about how the system should operate. An observation is always made in the form of an image and then the system is tasked with predicting what the written answers are. Due to the probabilistic nature of the system a probabilistic component is also needed in this graphical models. Thus a probabilistic graphical model (PGM) is used.

A PGM is in essence the same as a general graphical model. The only difference is that now the information and relationships between information bubbles are probabilistic and not always certain as with general logic graphical models.

A literature study is presented next on methods currently used by existing automatic test grading systems. This will describe in the next chapter.

Chapter 2

Literature Study

In the previous chapter the problem statement and objectives of this project was laid out. Further a brief system overview was also provided. This chapter will provide information about already existing systems and the techniques they use in doing image processing and character recognition on images. Additionally, research on existing libraries, to aid in this project, will also be done.

2.1 Existing systems

A Optical Mark Recognition(OMR) system is a piece of software that is used to extracted hand written information from a filled in form. Each system normally has a specific template that it can extract information from. An template for one of these forms can be seen in Figure 2.1. These systems are generally used when fast and accurate grading of tests are needed. The biggest drawback of these systems are that information can only be portrayed in a very limited manner. On OMR templates there are a bubbles that allows a user to chose between different options to answer. OCR systems are thus excellent for the grading multiple choice type questions. At the moment most of these systems only grade colour-in bubbles and do not interpret characters on the page.

2.1.1 Standard OMR techniques

As can be seen in Figure 2.1, there is normally specific reference blocks on a OMR template. These blocks are included to allow the computer vision and image processing

algorithms find the orientation of the image more easily.

In an OMR system there are normally two phases to marking an test, as stated in [Ivetic & Dragan \(2003\)](#). The first step is to determine the region within where the answers are located in the image. In this process the system finds the orientation of the template in the image and thus can approximate the location of the bubbles. Normally some preprocessing on a blank template is done beforehand too aid in locating the bubbles. Once the bubbles are found their locations gets stored and processed. The final step is then to calculate the average pixel concentration in the bubbles and estimate whether they have been filled in.

MCQ ANSWER SHEET

REGISTER NUMBER

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(0) (0) (0) (0) (0) (0) (0) (0)
 (1) (1) (1) (1) (1) (1) (1) (1)
 (2) (2) (2) (2) (2) (2) (2) (2)
 (3) (3) (3) (3) (3) (3) (3) (3)
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 (6) (6) (6) (6) (6) (6) (6) (6)
 (7) (7) (7) (7) (7) (7) (7) (7)
 (8) (8) (8) (8) (8) (8) (8) (8)
 (9) (9) (9) (9) (9) (9) (9) (9)

Course : _____
Subject : _____

Date of Examination

Date: Month: Year:

INSTRUCTIONS TO CANDIDATE

1. Use HB Pencil only for shading inside the Bubbles.
2. Use Ball Point Pen only to write in the Rectangle Boxes Provided
3. Write and shade your Register Number in the space provided.

Correct Method: (A) (B) (C) (D) Wrong Method: ✗ ✗ ✗ ✗

ANSWERS

1	(A)	(B)	(C)	(D)		16	(A)	(B)	(C)	(D)	
2	(A)	(B)	(C)	(D)		17	(A)	(B)	(C)	(D)	
3	(A)	(B)	(C)	(D)		18	(A)	(B)	(C)	(D)	
4	(A)	(B)	(C)	(D)		19	(A)	(B)	(C)	(D)	
5	(A)	(B)	(C)	(D)		20	(A)	(B)	(C)	(D)	
6	(A)	(B)	(C)	(D)		21	(A)	(B)	(C)	(D)	
7	(A)	(B)	(C)	(D)		22	(A)	(B)	(C)	(D)	
8	(A)	(B)	(C)	(D)		23	(A)	(B)	(C)	(D)	
9	(A)	(B)	(C)	(D)		24	(A)	(B)	(C)	(D)	
10	(A)	(B)	(C)	(D)		25	(A)	(B)	(C)	(D)	
11	(A)	(B)	(C)	(D)		26	(A)	(B)	(C)	(D)	
12	(A)	(B)	(C)	(D)		27	(A)	(B)	(C)	(D)	
13	(A)	(B)	(C)	(D)		28	(A)	(B)	(C)	(D)	
14	(A)	(B)	(C)	(D)		29	(A)	(B)	(C)	(D)	
15	(A)	(B)	(C)	(D)		30	(A)	(B)	(C)	(D)	

Signature of the Candidate

Signature of the Invigilator

Figure 2.1: Standard OMR template, from [VijayaForm \(2017\)](#)

2.2 Additional techniques

The above method allows for grading of tests using a simple OMR system. For the test grader used for the Applied Mathematics tests, there is a need to go beyond such a basic system. In standard OCR, when a student makes a mistake, he/she needs to erase the existing answer and write a new answer in. This can be time consuming for a template with 8 bubble row choices per answer. This also increases the probability that the student will make a mistake in the process. Addressing this problem it is determined that two additional options need to be made available. Firstly the student is allowed to cross out answers instead of totally erasing them. An example of this can be seen in Figure 2.2. Then secondly the system needs to be accurate enough to determine the student's student number only by filling in the character blocks above the bubbles. This requirement is addressed by using a PGM in Section 4.2.4. Using optical character recognition (OCR), the bubble information and character information can thus be cross-referenced in an intelligence way, as seen in Section 4.2.

2.2.1 Contour detection

To determine if an answer in a bubble is truly coloured in and not just crossed out, contour detection is needed. This means that the contour around the bubble needs to be detected and used in analysis. In python this can be implemented using the freely available OpenCV library, as referenced in Rosebrock (2016). OpenCV is an image processing library has has highly optimized techniques to find contours in a given image. Given this new contour information the bubbles is can now be assessed by the pixels inside it, as well as its shape. (Verander die image dalk na een wat 'n contour om het)

2.2.2 Character recognition

To further increase the accuracy of the system, Optical Character Recognition (OCR) software will also be need and applied on the characters blocks, present on the templates. Research shows that one preferred way of doing OCR is using TensorFlow. This method is described in Google (2017). TensorFlow is also a python library, but allows the build of instructions to be implemented in efficient c++ code. For this test grader,

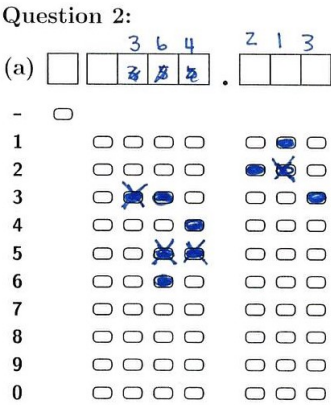


Figure 2.2: Corrected answer by crossing out bubbles.

TensorFlow is used to construct a convolutional neural network. This network will read an image, containing the digit, and predict the probability of each digit.

2.3 Conclusion: System requirements

In conclusion it can be seen that the system will need to incorporate a combination of image processing(OMR) on the bubbles and character recognition on the digits, handwritten by the students. When these different evidence is the considered in combination, a more accurate student answer can be estimated. This will also allow for more convenience for students writing these test, hoekom?. Kyk na oom Johan se raad. Die litriture study moet oor huidige metodes gaan en hul resultate.

Chapter 3

Image Processing

The previous chapter focused on existing methods of grading tests automatically. It was found that most systems only use image processing, without a machine learning component, to grade these test. In this chapter the core techniques behind processing these answer sheets, using image processing, is described. By using only these image processing techniques a reasonably accurate system can already be constructed.

For further improvements in accuracy we will investigate and implement two machine learning approaches. These approaches are discussed in [Chapter 4](#).

3.1 Orientation Detection

As mentioned in [Section 2.1.1](#) there are two main steps in OMR grading. The first challenge with grading a scanned in answer sheet, is finding the orientation of the template in the image. To do this there 2 or more references points must be found on the page. These reference points then allows for the calculation of the template's rotation, offset and size inside the image. In [Chapter 2](#) it was determined that the traditional way to find this reference points was to include them on the page, in forms of black blocks. This is an effective method of finding the template, but might look a bit less attractive, due to the black blocks on the page. For this project the markers, reference points, that the software uses are already present on the template paper. These are the two longest horizontal lines as well as the two vertical lines on the comment box, as can be seen in [Figure 3.1](#). Together these lines have enough information to determine 4 reference points, shown in red in the figure. The reason

these lines are chosen as references, are due to the fact that a Radon transform can easily be applied to find them, as seen in Section 3.1.2. Thus the software can successfully find the template even though one of the 4 lines are identified incorrectly. Using the reference points the rotation, offset and size of the template is calculated. But before the orientation of the image can be determined it is a good idea to quickly check if the image might be upside down. This is done to make it easier to find the orientation afterwards. To do this some initial image filtering is firstly required and is discussed in the next section.

3.1.1 Initial filtering and orientation detection

To check if an image is upside down the software first needs to find relevant contours on the page. The contours are then filtered out if it does not loosely match the characteristics of a bubble or character block. This is done in 5 steps:

1. Threshold the image by making all the pixel values either white (lower than the mean) or black (higher than the mean)
2. Do contour analysis on the image to find all the contours, using the python library OpenCV.
3. Filter through the contour array to filter out all contours that are not approximately the size and aspect ratios desired.
4. Save these contours for later use.
5. Determine if more contours lie above the middle of the image. This is true if the image is the right way around. Rotate the image by 180° otherwise.

It is important to note that there are still unwanted contours in the list, but for now this reduced list is sufficient. Once the list is found the software counts the number of contour centrepoints below and above the image center. Figure 3.2 shows the resulting contours found in the image. As can be seen in the figure more bubbles should be below the horizontal center line, for the image to be the right side up. The next step will now be to determine the coordinates of the answers the student wrote down. To do this the template is first located in the image. This process is described in Section 3.1.2.

3.1 Orientation Detection

Stellenbosch University: Applied Mathematics B154 Test ...3... 97.../99.../20 17

Surname : ...Steynham... I.A. US Number →

Enter your student number, both as numbers and by filling in the ovals below the student number.

Give your answer for each question, both as numbers and by filling in the corresponding oval below each box.

Use only pen to colour the ovals.

Steynham

Student's signature

<p>Question 1:</p> <p>(a) <input type="text" value=""/><input type="text" value=""/><input type="text" value="1"/><input type="text" value="4"/> , <input type="text" value="0"/><input type="text" value="5"/><input type="text" value="5"/></p> <p>- <input type="text" value=""/></p> <table border="0" style="width: 100%;"> <tr><td>1</td><td><input type="checkbox"/></td><td><input type="checkbox"/></td><td><input type="checkbox"/></td><td><input type="checkbox"/></td><td><input type="checkbox"/></td><td><input type="checkbox"/></td><td>1</td></tr> <tr><td>2</td><td><input type="checkbox"/></td><td><input type="checkbox"/></td><td><input type="checkbox"/></td><td><input type="checkbox"/></td><td><input type="checkbox"/></td><td><input type="checkbox"/></td><td>2</td></tr> <tr><td>3</td><td><input type="checkbox"/></td><td><input type="checkbox"/></td><td><input type="checkbox"/></td><td><input type="checkbox"/></td><td><input type="checkbox"/></td><td><input 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Figure 3.1: Four markers found from applying Radon transforms.

3.1 Orientation Detection

Stellenbosch University: Applied Mathematics B154 **T**utorial Test 1 24 July 2017

Surname : **Erisk** US Number → **1 3 4 2 1 1 0 8**

day afuysda fuysydaufedij hifjijeh hfjefkgld-
 hfj hfkdj hgdjkgf hgdjfg jkfdsgh hfksdgh gfs-
 fjdgh gfykstsd gjknd sfkggh hfjke hgfke hgfjgh
 sfuqfkehd gkfjhd gjenhd sfjgh hfdsfjgh hfjgh
 gily usuida fyosuidayfi usudiy fousiday fousyda



Student's signature

0	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	0
1	<input checked="" type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input checked="" type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	1
2	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input checked="" type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	2
3	<input type="checkbox"/>	<input checked="" type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	3
4	<input type="checkbox"/>	<input type="checkbox"/>	<input checked="" type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	4
5	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	5
6	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	6
7	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input checked="" type="checkbox"/>	<input checked="" type="checkbox"/>	7
8	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input checked="" type="checkbox"/>	8
9	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	9

Question 1:

(a) ☐ ☐ ☐ **0** , **0** **1** ☐

- ☒

0	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input checked="" type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	0
1	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input checked="" type="checkbox"/>	<input type="checkbox"/>	1
2	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	2
3	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	3
4	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	4
5	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	5
6	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	6
7	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	7
8	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	8
9	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	9

(b) ☐ **1** **2** **3** , **8** ☐

- ☒

0	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	0
1	<input checked="" type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	1
2	<input type="checkbox"/>	<input checked="" type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	2
3	<input type="checkbox"/>	<input type="checkbox"/>	<input checked="" type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	3
4	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	4
5	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	5
6	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	6
7	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	7
8	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input checked="" type="checkbox"/>	<input type="checkbox"/>	8
9	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	9

Question 2:

(a) ☐ ☐ ☐ **1** **5** , ☐ ☐

- ☐

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2	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	2
3	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	3
4	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	4
5	<input type="checkbox"/>	<input checked="" type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	5
6	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	6
7	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	7
8	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	8
9	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	9

(b) ☐ **7** **7** **1** **7** , ☐ ☐

- ☐

0	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input checked="" type="checkbox"/>	<input checked="" type="checkbox"/>	0
1	<input checked="" type="checkbox"/>	<input checked="" type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	1
2	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	2
3	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	3
4	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	4
5	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	5
6	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	6
7	<input checked="" type="checkbox"/>	<input checked="" type="checkbox"/>	<input checked="" type="checkbox"/>	<input checked="" type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	7
8	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	8
9	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	9

Figure 3.2: Reduced contours in image.

3.1.2 Radon Transform

(Maak 'n symbols page) The Radon transform is an integral transform that can be represented by a series of line integrals over a function $f(x, y)$. These transforms are commonly used in CT scans. Mathematically this transform is defined as

$$G(r, \theta) = \int_{-\infty}^{\infty} \int_{-\infty}^{\infty} f(x, y) \delta(x \cos(\theta) + y \sin(\theta) - r) dx dy.$$

Where r represents the perpendicular offset of the line and θ the angle of the line. x and y represents a 2D space within which the function $f(x, y)$ is defined. A visual interpretation of this transform can be seen in Figure 3.3. In this project a Radon transform is calculated at specific intervals of the gradient. Each gradient interval will thus generate a 1 dimensional array of values corresponding with the pixel intensities along the lines that are being summed, as seen in Figure 3.3. This method is used determine where the 2 horizontal and 2 vertical lines are located, as mentioned in Section 3.1. To find the first two horizontal lines the Radon transform is applied at a angle of 90° and then incremented by a small amounts for the next transform. Black lines will cause a spike to appear on the Radon transform when it is summing parallel with that black line. Thus by finding the transform angle value that present this maximum value. The rotation of the template can be found. The two maximum values that is recorded at this angle is can then be interpreted as the locations of the two horizontal lines. After the correct angle is found the two vertical lines can be found by applying a Radon transform at a angle 90° clockwise from the previously calculated angle. Those two values then provides the relative locations of the two vertical lines. Now the four reference point shown in Figure 3.1 can be calculated.

3.1.3 Finding the template

Once the image is rotate correctly the two maximum values of the radon transform will indicate the two horizontal lines in the template. Using those two lines the relative size of the template in the image and y-offset value can be determined . The last step is thus to determine the x-offset value of the template. To do this a vertical Radon transform is applied to detect the two vertical lines of the comment box. This will provide the last x-offset value needed to find the template inside the image as well as additional size evidence to confirm the previously calculated size estimate. Once the

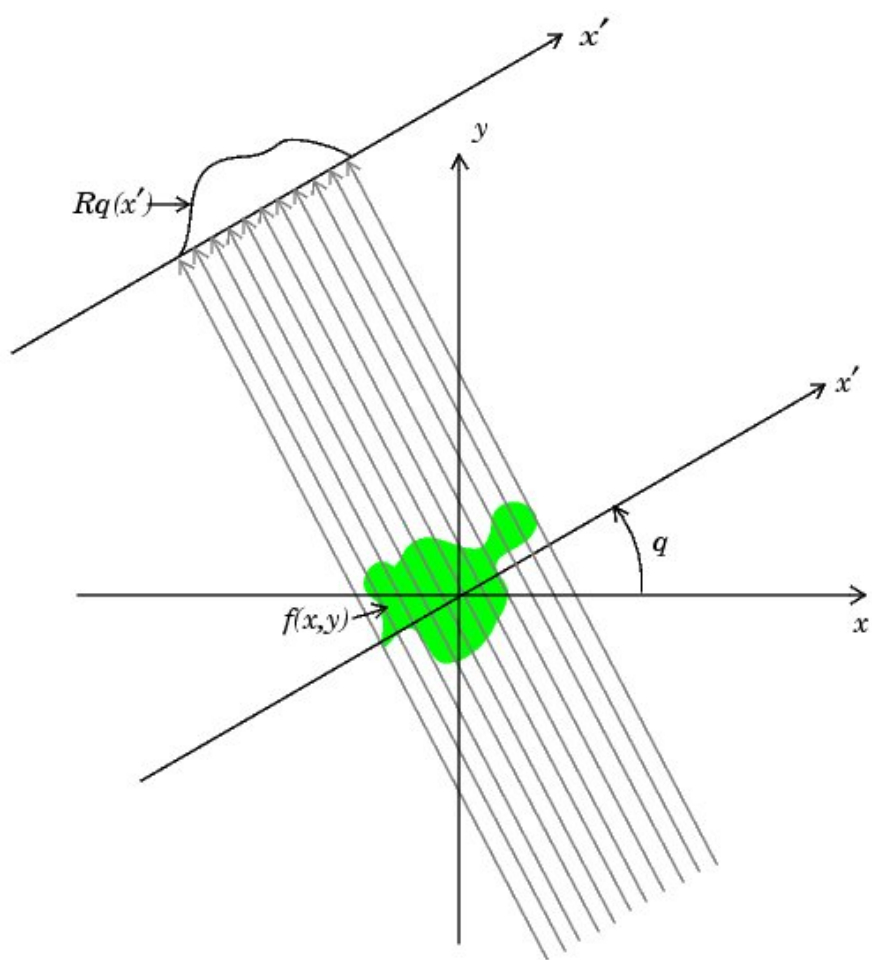


Figure 3.3: Radon transform applied on a 2 dimensional area, from [Edoras \(2017\)](#)

template is found the bubble values and digit blocks can be determined, using reference location. These reference locations were calculated in preprocessing done on an empty template. Figure 3.4 illustrates the final estimation of all the bubbles in the template. The estimated bubble centres are coloured red, while the green points represent the centres of all the remaining contours. (Stel dalk beter en duideliker)

In Figure 3.5 The final rotation after applying consecutive Radon transforms can be seen.


Now that all a list of possible bubble contours are found, the next challenge is to find one contour for each bubble. This is discussed in the next section.

3.1 Orientation Detection

Stellenbosch University: Applied Mathematics B154 Tutorial Test 1 24 July 2017

Surname : Brink US Number → 1 3 4 2 1 1 0 8

day afuysda fuizysdaulefj hfjjch hfjekghid-
 hfj hfkdj hgdjkg hddfg jkfksgh lfksdh gk-
 fkdh gjkslhd gjend stkgk hfjke hgkjd hgkjh
 sfkgjkslhd gkfjhd gjenhd stgikh hfjdjkg hfjdjh
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Student's signature

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Question 1:

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0						0
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3						3
4						4
5						5
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7						7
8						8
9						9

(b) 1 2 3 , 8 1

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0						0
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7						7
8						8
9						9

Question 2:

(a) 1 5 , 1 5

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0						0
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7						7
8						8
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(b) 7 7 1 7 , 1 5

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0						0
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7						7
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Figure 3.4: Detection of template in image and estimation of bubble locations.

3.2 Bubble detection and processing

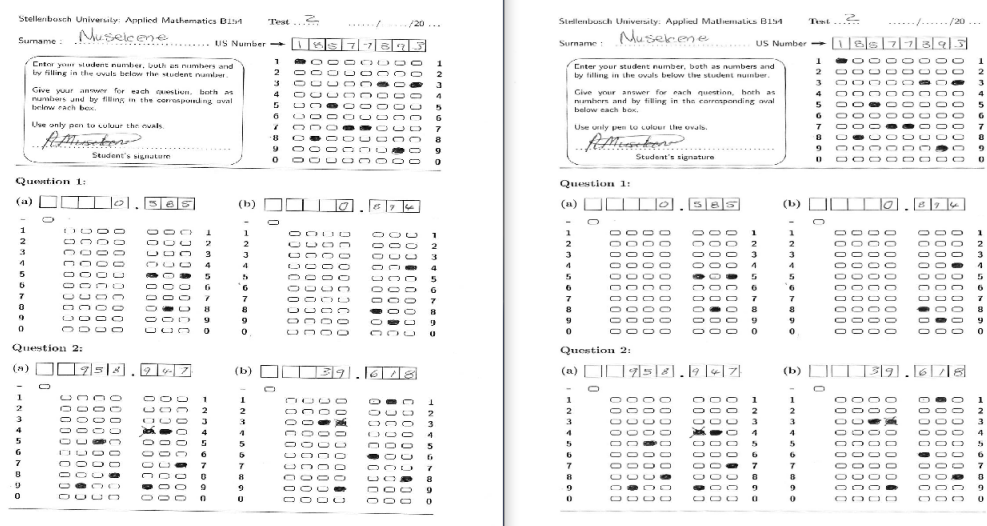


Figure 3.5: Result in rotation after applying radon transform.

3.2 Bubble detection and processing

To find the location of each bubble in the image, the system simply takes the contour closest to the estimated bubble location. This can be done in an efficient manner by sorting the contours by their locations. Searching through the contours now becomes linear and of complexity $O(n)$, where n is the number of bubbles. This means that the processing time to find these bubbles is linearly related to the number of bubbles in the template image. Next the data in each contour needs to be processed and stored. The first type of evidence is calculating the average pixel intensity inside the contours. If this value is high the bubble is most likely coloured in or crossed out. The advantage of using the closest contour as the bubble's estimated location, over conventional methods now becomes apparent. In conventional methods an estimated area is calculated where the bubble is most likely to be located. This becomes problematic if the system needs to know if the bubble has been crossed out, as only data about pixel intensities are present. Using contour analysis, information about the shape of the bubble entry is also provided. Thus by drawing the smallest possible block around the contour, that still covers every value inside the contour, an area can be calculated. This area becomes large when an answer is crossed out, due to the lines stretching outside the initial bubble. By inspecting the area value, the system can successfully determine if the bubble is filled in and crossed out.

3.3 Data processing and grading

The previous section now allows each bubble to be classified into 3 categories namely, empty, completely filled in and crossed out. An additional category of partially filled in will also be introduced, as it aids grading of tests where students write lightly. An algorithm to determine what bubble was chosen can now be described as follows:

1. Count the number of completely filled in answers in each column. Store the position of that entry for later use.
2. If there are no completely filled in answers, count the amount of partially filled in answers and override the previous values.
3. If the previous result is 0, set the output value for that column to 0.
4. If step 2 or 3 presents a value greater than 1, save the answer sheet to a clashlist to be evaluated manually once the automatic grading of the test are completed.

3.4 Conclusion

This chapter provided an overview of a basic automatic test grading system using image processing and computer vision. The system can achieve acceptable results using only these techniques.

The following chapter will focus on applying additional machine learning techniques to further improve the accuracy of grading these test. Two new test templates will also be introduced. (maak zeker jy het daaroor gepraat).

Chapter 4

Machine learning approach

The previous chapter briefly described the basic workings of the optical mark recognition (OCR) system inside the automatic test grader. There is still one critical piece of information that has not been observed in the system. This information is the characters that the student writes into the designated boxes.

This next chapter will provide two machine learning approaches to significantly improve the accuracy of the system over the previous standalone basic system. Firstly an approach to locate and classify hand written characters, provided by the students, using a deep convolutional neural network (DCNN), will be described. A more accurate method in determining the true digit represented by the bubble and character evidence, using a probabilistic graphical model (PGM), will also be implemented. This PGM method will then allow for an integrated probabilistic approach to determine the true student number using the bubble as well as character evidence. It will be determined that the PGM is accurate enough to determine the student number by only using the character recognition information provided.

4.1 Character recognition using a neural network

4.1.1 Introduction

An neural network is a powerful machine learning tool for approximating complex functions. The basic architecture of a neural network can be seen in Figure 4.1. The structure of an feed-forward neural network consist of an input, hidden and output layer, as described in [Nielsen \(2015\)](#). A artificial neural network (ANN) is a simplified

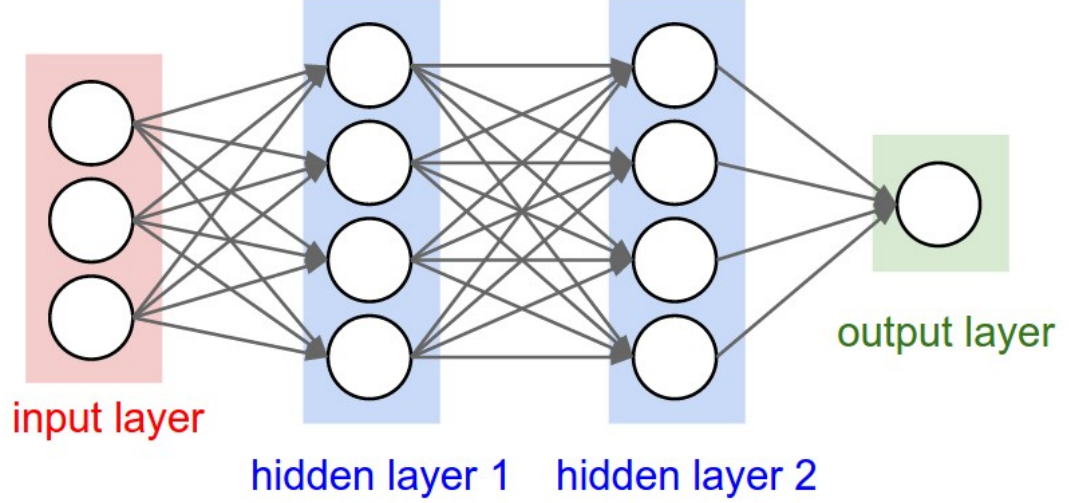


Figure 4.1: Basic structure of a neural network, from [Karpathy \(2017\)](#)

approximation of how neurons in the brain works. Each neuron in the network acts as a small processing unit. The final output can thus be collected by reading the value at the output layer after it has been passed each layer of the network.

For this project, a neural network will be trained to predict what digit, from 0 to 9, is most likely present in a image. Figure 4.2 illustrates the input of of the neural network using and 14 by 14 example image. For this project a 28 by 28 greyscaled image will be used as input. Thus if each pixel represents one value, ranging from 0.0 to 1.0, there is total of 748 input values.

4.1.2 Neural Network Basics

4.1.2.1 The artificial neuron

The neuron unit takes in decimal values as input. The first step is then to calculate the weighted sum of these inputs, as shown in, Equation 4.1. Where c is the number of inputs. x_i and w_i respectively are the input and weight values at index i .

$$z = \sum_{i=0}^c x_i * w_i \quad (4.1)$$

The summed value then gets normalize using an sigmoid function, seen in Equation 4.2.

4.1 Character recognition using a neural network

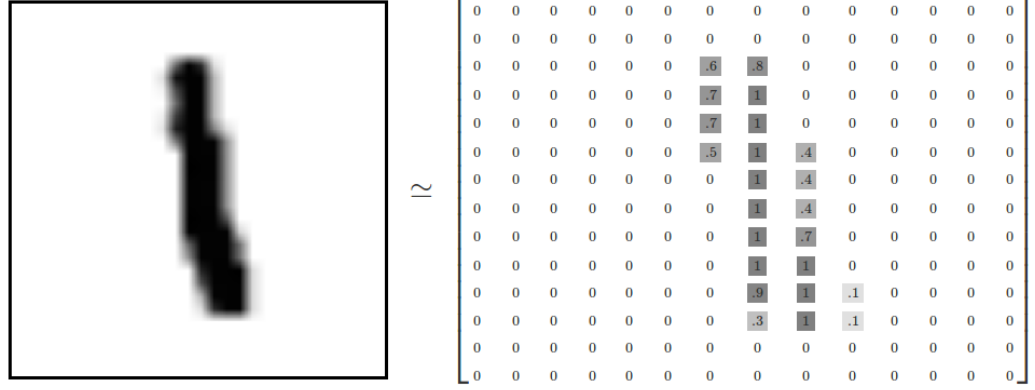


Figure 4.2: Example image used as input to the neural network, [Tensorflow \(2017\)](#)

$$Out(z) = \frac{1}{1 + e^{-z}} \quad (4.2)$$

This artificial neuron thus basically takes in a weighted input and produces a normalized out. By adjusting the weights, certain inputs will excite and others inhibit the output of the neuron more. This process thus allows different functions to be approximated by changing these weights. If a network of these neurons gets place together, shown in Figure 4.1, complex functions can be trained onto the network. These weights variables thus needs to be tuned to specific values, to allow the network to best categorize digits given an image. The process of calculating values for these weights will be covered in Section sec:trainNN.

4.1.2.2 Getting a output from the network

After the 748 input values have been assigned to the network inputs, each of the network's coulombs can be calculated one at a time. The first coulomb in the hidden layer will thus use the 748 input values and produce a normalize output for each of the neurons in that coulomb. This is done using using the previously mentioned equations 4.1 and 4.2. Once the first column's outputs are calculated the next column can be calculated. This process is repeated until all the columns are calculated in the hidden layer. The output layer is then calculated using the same method. For the character recognition in the test grader, 10 output neurons will be used, corresponding to the

4.1 Character recognition using a neural network

probability of the 10 digits being present. The values observed on the output neurons, gets normalized and used as the probability of each digit being present, using Equation 4.3. Where $prob(i)$ is the probability of digit i being the character in the image. The value $Out(z_i)$ is the output of the output neuron at index i .

$$prob(i) = \frac{Out(z_i)}{\sum_{k=0}^{10} Out(z_k)} \quad (4.3)$$

For a more detailed explanation on the DCNN used in this project, refer to Appendix B.1. (Maak dit dalk dat die neural network in overview hier beskryf word. Soos hoe dit werk as a black box. En dan Verder word die wiskunde agter NN and DCNN agter in die appedix beskryf)

Bv: For a mathematical description on neural networks and DCNN, refere to Appendix B.1.

4.1.2.3 Training of neural network

To train a neural network the MNIST dataset will be used. This is a database that has a labeled training set of 60,000 images, and a labeled test set of 10,000 images. The neural network will be trained using the training set. The basic idea behind the training method used in a neural network will be described in the following steps. For a more detailed description refer to Appendix B.

1. Calculate the network's output for each of the training images used in this training round.
2. Get the error margin of the network, using a formula that compares the true label of the training image, with the estimated label of the network.
3. Calculate the value with which each weight should be changed to reduce the error margin. One method of doing this is using the gradient decent with back propagation algorithms.
4. Repeat steps 1-3 until a time or accuracy criteria is met.

4.1 Character recognition using a neural network

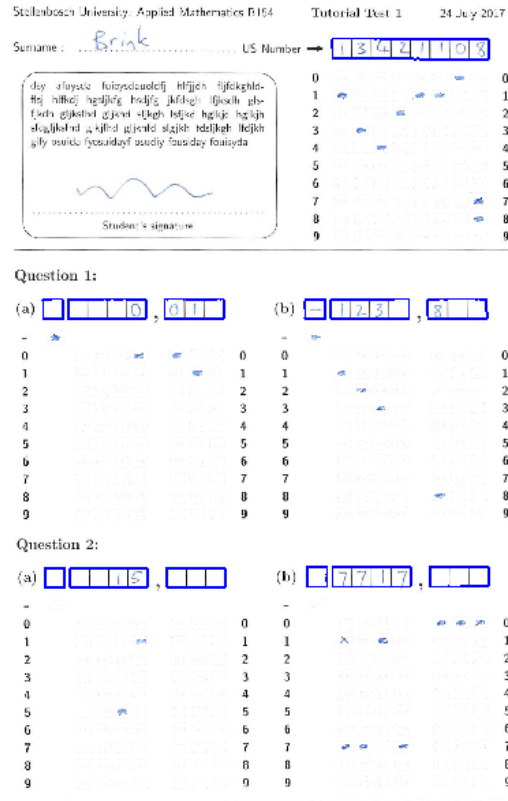


Figure 4.3: Image scanned for character areas.

4.1.3 Preprocessing on image

For the neural network to be able to classify digits from a 28 by 28 image, those subimages must first be found inside the test image. To do this Image processing is required. This is done in 6 steps as seen below: (Kry images by items om beter te lyk)

1. Find the contour closest to the expected location of the block, calculated in Section 3.1.3. This is illustrated in Figure 4.3. The bubbles have already been filter out of the image in a previous process.
2. Transform the image to become fully rectangle using OpenCv's *four_point_transform* method. This method applies a four point perspective transform on the image to reshape it into a rectangular form. An example of the final product can be seen in Figure 4.4.

4.1 Character recognition using a neural network

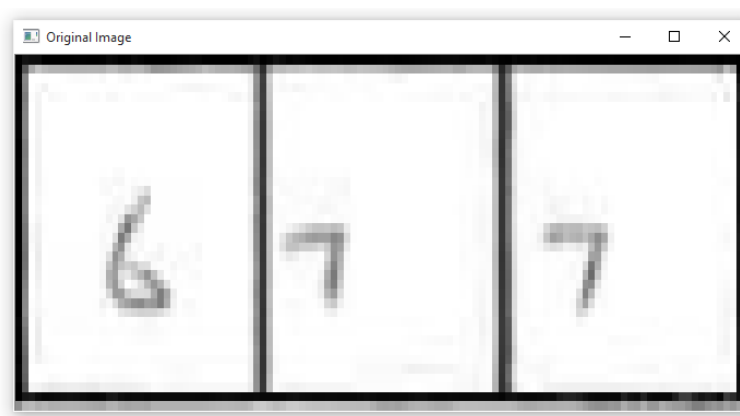


Figure 4.4: The found box is then normalized to rectangular shape.

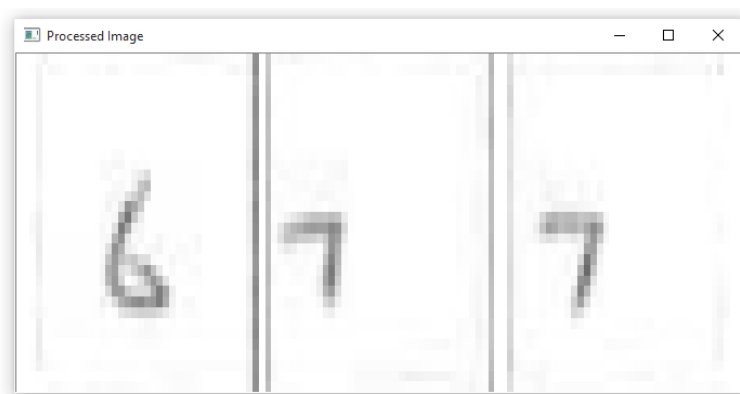


Figure 4.5: a Random transform then gets applied.

3. Do a horizontal and vertical Radon transform, Section 3.1.2, to find and remove the dark box lines on the image, as seen in Figure 4.5.
4. Use the values received from the Radon transform to segment the image into the different boxes.
5. Using a custom segmentation algorithm, find the pixels most likely to belong to the digit, as seen in Figure 4.6.
6. Locate the area the pixels are located in, as seen in Figure 4.7
7. Now calculate the center of the pixels, recenter and normalize the image area, as seen in Figure 4.8

4.1 Character recognition using a neural network

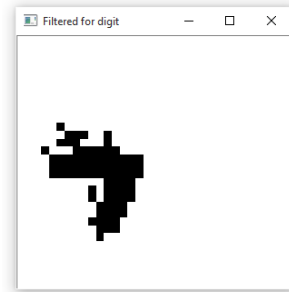


Figure 4.6: An clustering algorithm is used to find the main cluster in the remaining image.

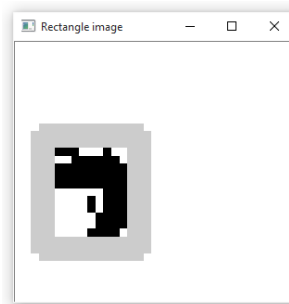


Figure 4.7: Area of found cluster.

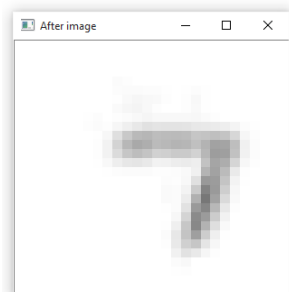


Figure 4.8: Final translation and normalization of image.

8. Finally reshape the image into an 28 by 28 greyscaled image to be processed by the neural network.

Each box on the image can now be classified by the neural network and saved. The new character recognition evidence can now be used in combination with the bubble evidence to make a significantly more accurate estimate for the intended answers from the student. The next step is thus to combine all these individual evidence, in an intelligence way, to make an accurate prediction. A method to achieve this result will be covered in the next section.

4.2 Probabilistic Graphical Models

The final step in determining the students answers is to probabilistically determine the most likely answers, given all the evidence presented. To do this a probabilistic graphical model (PGM) will be developed.

4.2.1 Structure of the graph

A Probabilistic graphical model (PGM) is a probabilistic graph containing random variables, where the graph expresses the conditional independence structure between these variables. The type of PGM used for this project is a Bayesian network. A Bayesian network models a set of random variables and their conditional dependencies via a directed acyclic graph (DAG). As seen in Figure A.4, arrows are used to indicate which variables are conditionally dependent on another.

The figure should be interpreted in the direction which information flows. Originally a student has a certain digit that he/she wants to portray on the page. This is given by the 'Digit user intended bubble'. There are 10 possible digits to consider and thus the bubble has 10 possible states. The intended digit gives rise to the intended bubbles and character that the student wants to write down. The student might sometimes mistakenly think that the first bubble represents 0 and thus even if the intended digit is 0 the intended bubble might be 1. Thus, this must also be done in a probabilistic manner to compensate for this uncertainty. The intended bubbles and character then produce evidence, as seen in Figure A.4.

When looking at Figure 4.10, it is observed that there are 11 evidence areas to consider. They are the 10 bubbles and the character block. The process of writing

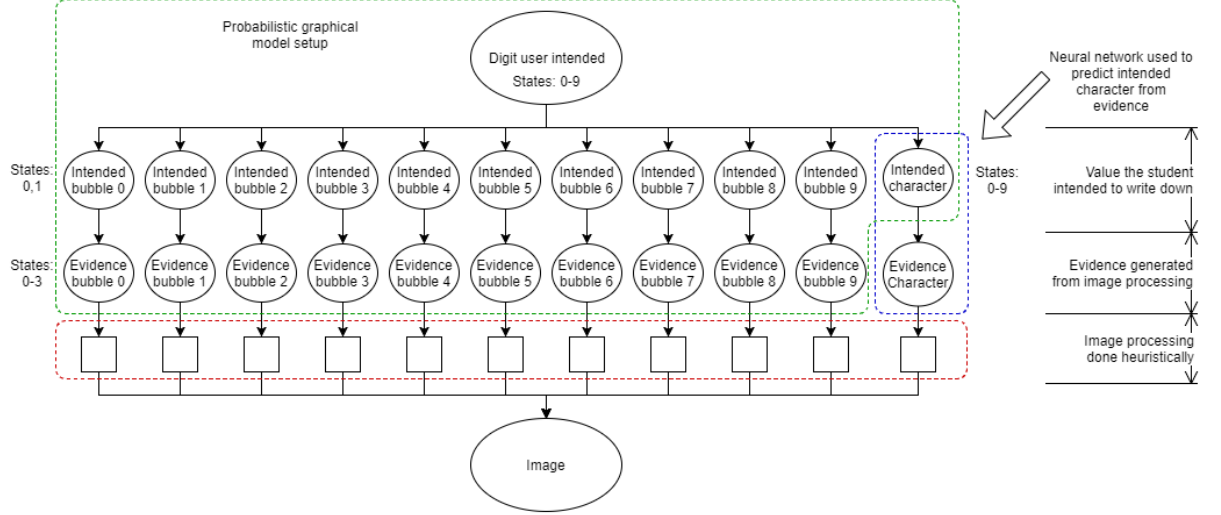


Figure 4.9: Graphical setup of determining intended digit.

down this digit introduces so noise into the system, due to the fact the student is not always going to write down the digit in exactly the same way. Thus the evidence is also probabilistically linked to the 'intended bubble' and 'intended character' parent distribution. This evidence then gets written down on the paper and is what ultimately influences how the image looks. Each of the bubbles can take one of 4 states as evidence. These states are blank, crossed-out, partially coloured in and fully coloured in. The character block evidence is an 28 by 28 greyscale image. Thus it can have $28 \times 28 \times 256$ possible states, where 256 is the possible pixel intensities of each pixel. This value with true range 0 to 256, gets converted into a normalized value between 0.0 and 1.0 when the neural network needs to process it.

4.2.2 Determining the intended digit

After the model is constructed the intended digit needs to be estimated, given the image. This can be done by reasoning from the bottom (image evidence) upwards to the intended digit. The first step is to process the image that produces the evidence using of image processing. Producing the bubble evidence from the image is described in Chapter 3. In 4.1.3, the process to extract the character evidence from the image was also described. Using the neural network the probability of intended character can be determined. After these steps have been completed the intended digit can be

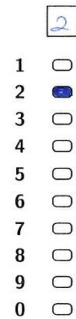


Figure 4.10: Column representing one digit.

determined using the PGM, shown in Figure Figure A.4. Thus is done by first setting the evidence node to the values calculated when image processing were done on them. The 'intended character' node then gets set to priors calculated through the use of the neural network. After this is done inference is done on the PGM and the resulting probability of each digit is calculated for the 'intended digit node'.

4.2.3 Training the model

This subsection still needs to be completed.

As seen in Figure A.4, the PGM will include the bubble evidence as well as a prior probability that the neural network provides as evidence. Once these values are assigned, the PGM model will infer the intended digit using the probability distribution specified. To do this the conditional probabilities of the PGM, must first be determined from data. This is done by simple.. to be continued.

4.2.4 Student number identification

To be continued..

4.3 Conclusion

This chapter looked at two machine learning techniques to improve the accuracy with which the system infers the answers written on each scanned test sheet. A method was shown, using a neural network, to estimate the probability of each digit given only the character box as input. Additionally a approach was discussed, using a PGM, to allow

the system to make a final prediction of what the student intended to write down given the bubble and character boxes as evidence.

The following chapter will cover the validation and results of the system from weekly grading done for the Applied mathematics department.

Chapter 5

Analysis of results

This still needs to be written up.

Document the accuracy of the system before and after the machine learning components have been added. Compare the results.

5.1 Future improvements

Increase speed of test. Use the Radon transform to locate circles. Then do image processing only on that areas. No need for contour finding on the whole image.

Chapter 6

Summary and conclusions

This section still needs to be written up.

6.1 Project summary

6.2 How this final year project benefits society

Must say something here. Also say something about ethics, how you realised that your work may have an impact on the environment (or not), *etc.*

6.3 What the student learned

During the execution of this project, the student learned that time management is important, because ... Also, using L^AT_EX is of cardinal importance to professionally typeset a report.

6.4 Conclusion: Summary and conclusions

This chapter provided a summary of the objectives, methodology and results of the final year project....

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Appendix A

Overview of system

In this chapter a graphical and mathematical derivation of the entire system is given.

A.1 System as a whole

As described in Chapter 1, the system can fundamentally be represented with 6 information nodes. These nodes are shown in Figure A.1. The student has certain information he/she wants to portray on the paper. This includes the 4 answers and student number the student wants to write down. Thus those 5 nodes gives rise to the image, representing the last node. Thus fundamentally the system is tasked with working out these 5 conditional probabilities: $P(\text{StudentNumber}/\text{Image})$, $P(\text{Answer1}/\text{Image})$, $P(\text{Answer2}/\text{Image})$, $P(\text{Answer3}/\text{Image})$ and $P(\text{Answer4}/\text{Image})$. The random variables StudentNumber and Answer(1 to 3) thus represent all the possible values that

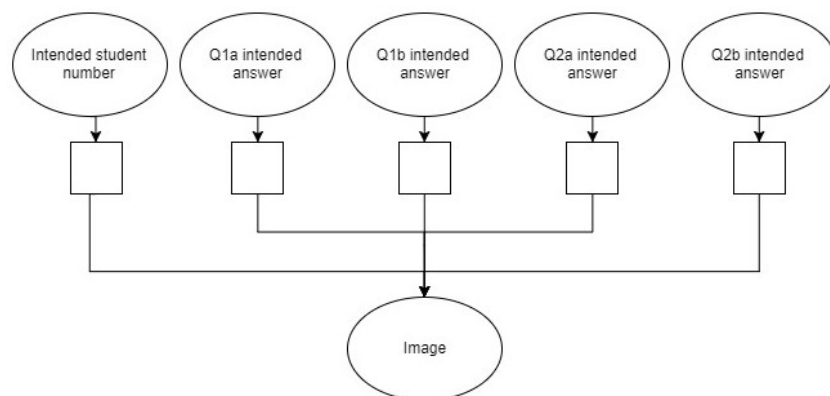


Figure A.1: System overview.

the student number and answers possibly can be. The Image is a random variable representing the total number of possible states the image can represent. This value is in the order of $1240 \times 1754 \times 256$ possible states. To practically represent this further assumptions are made in the following sections.

The aim of the software is to maximize the likelihood of those probability distributions indicating the correct answers. The reason the problem is represented in a probabilistic way is due to the fact that different images are going to be generated every time a test is written. This is true even when the same information is going to be portrayed. Everytime a student writes a test he/she is going to write in different ways. A probabilistic graphical model (PGM) is thus used to describe this system and its inner operations. For a more detailed explanation on PGM's, refer to Section 4.2. The blocks in Figure A.1 represent additional processing that is described in the following sections.

To calculate those 5 probabilities, some more detailed derivations are necessary. These derivations are described in the next section.

A.2 Deriving the intended student entry

A.2.1 Student answer

To determine a answer for one of the students questions, $P(\text{Answer2}/\text{Image})$, so further derivations and assumptions are necessary. There are 8 possible columns to use for an answer. The first column defecates the sign of an answer. Thus two signs are possible. For each of the remaining 7 columns a number from 0 - 9 can be represented. Thus there are ten possible values for each column. This gives a possible number of values to search through to be $2 \times 10^7 = 20000000$. Each of these states needs to be calculated and thus is computationally intractable. Thus a assumption is needed to reduce the number of possible states. A fair assumption to made, all 20000000 possible numbers are equally likely to be written down. Thus each column digit becomes independent of the another columns. Thus if a value in one column is known, it does not influence the probabilities of the other columns being a certain value. Thus the number of states no becomes $2 + 10 \times 7 = 72$, which is significantly less. and An illustration of this graph can be seen in Figure A.2. In Equation A.1 this independence property can now be seen. To find the most probable answer only $P(\text{sign}/\text{Image})$ and $P(\text{digit}(1-7)/\text{Image})$ still

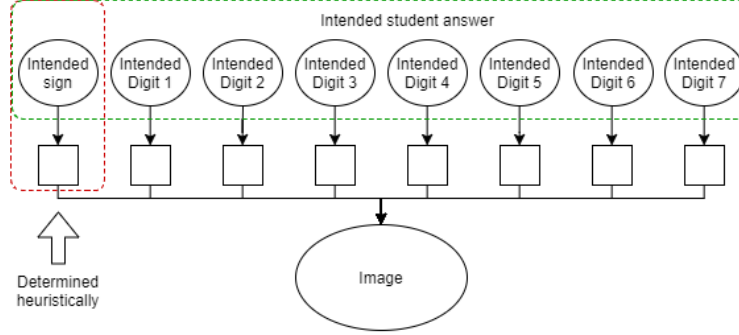


Figure A.2: Graphical setup of determining student answer.

needs to be calculated. Using the image processing techniques described in Section 3 the $P(sign/Image)$ can simply be determined heuristically by determining the probability of the bubble being coloured in, underneath the sign. Thus the only values yet to calculate is $P(digit/Image)$. This is described in Section A.3.

$$P(Answer/Image) = P(sign/Image) * P(digit1/Image) * ... * P(digit7/Image) \quad (A.1)$$

A.2.2 Student number

The previous assumption does not hold in the case of student numbers. Knowing the digit value of one column changes the probability of each other column taking a certain value. The reason for this is, because there is only a limit number of student numbers to consider. Thus if the first digit is a 2, only student numbers starting with 2 must still be considered. To account for this fact an additional node is added above the individual digit probabilities. This node represents the probability of each student number being present in the image. This node will have ± 900 states, depending on the number of student numbers. The student number graph can be seen in Figure A.3. Next a derivation for $P(studentNumber/Image)$ is needed.

In the below equations, 'Digits' represents the 8 digit random variables. The first step is to apply Bayes rule as seen in Equation A.2.

A.2 Deriving the intended student entry

$$P(StudentNumber, Digits/Image) = \frac{P(Image/StudentNumber, Digits) * P(StudentNumber, Digits/Image)}{P(Image)} \quad (A.2)$$

When all the digits are known, the image becomes independent of the student number. This can be seen in Equation A.2. Also the chain rule states that Equation A.4 must be true.

$$P(Image/StudentNumber, Digits) = P(Image/Digits) \quad (A.3)$$

$$P(StudentNumber, Digit) = P(Digit/StudentNumber) * P(StudentNumber) \quad (A.4)$$

Next the Digit random variable is summed out to produce $P(studentNumber/Image)$, as seen in Equation A.5.

$$P(StudentNumber/Image) = \sum_D \frac{P(Image/Digits) * P(Digit/StudentNumber) * P(StudentNumber)}{P(Image)} \quad (A.5)$$

Applying Bayes rule again the following equality can be presented, as seen in Equation A.6.

$$P(StudentNumber/Image) = P(Image/Digits) = \frac{P(Digits/Image) * P(Image)}{P(Digits)} \quad (A.6)$$

Thus the result can be seen in Equation A.7. $P(StudentNumber)$ can be taken out of the sum, due to it being independant of $Digits$.

$$P(StudentNumber/Image) = P(StudentNumber) * \sum_D \frac{P(Digits/Image) * P(Digits/StudentNumber)}{P(Digits)} \quad (A.7)$$

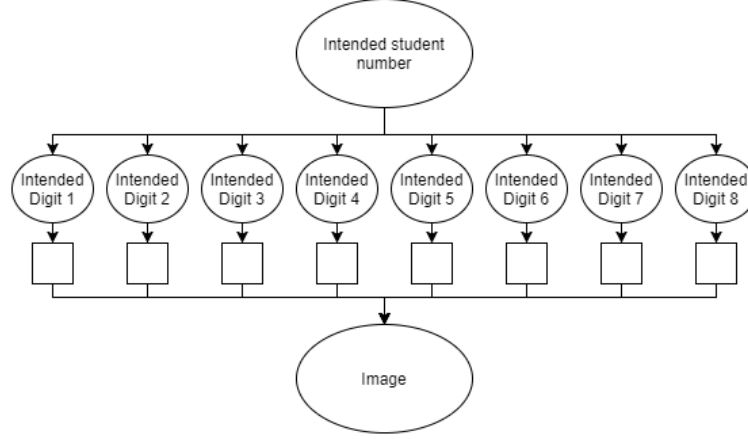


Figure A.3: Graphical setup of determining student number.

$P(\text{StudentNumber})$ can be initialized as a equal distribution, because every student number is equal as likely to be in a given test. $P(\text{Digits}/\text{StudentNumber})$ is a value that is trained from data. This value symbolizes the probability that the user intended to write down a given digit given that student's student number. This number is thus strongly correlated with the student number. If the first digit of the student number is 1, Digit1 will have a high probability of being 1. The only values that still needs to be calculated are thus $P(\text{Digits}/\text{Image}) = P(\text{Digit1}/\text{Image}) * \dots$. This derivation is covered in the next section.

A.3 Deriving the estimated digit

A.3 Deriving the estimated digit

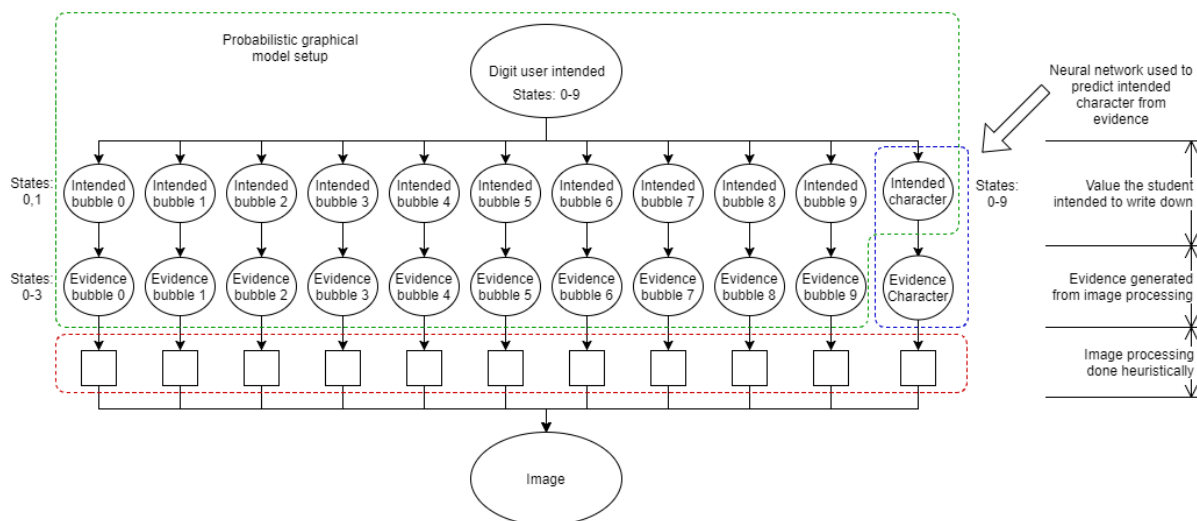


Figure A.4: Graphical setup of determining intended digit.

Appendix B

Implementation/Algorithms

Algorithms used in this project.

B.1 Deep Convolutional Neural Network

Appendix C

Validation and results

Validation and results of this system.

Appendix D

Outcome compliance

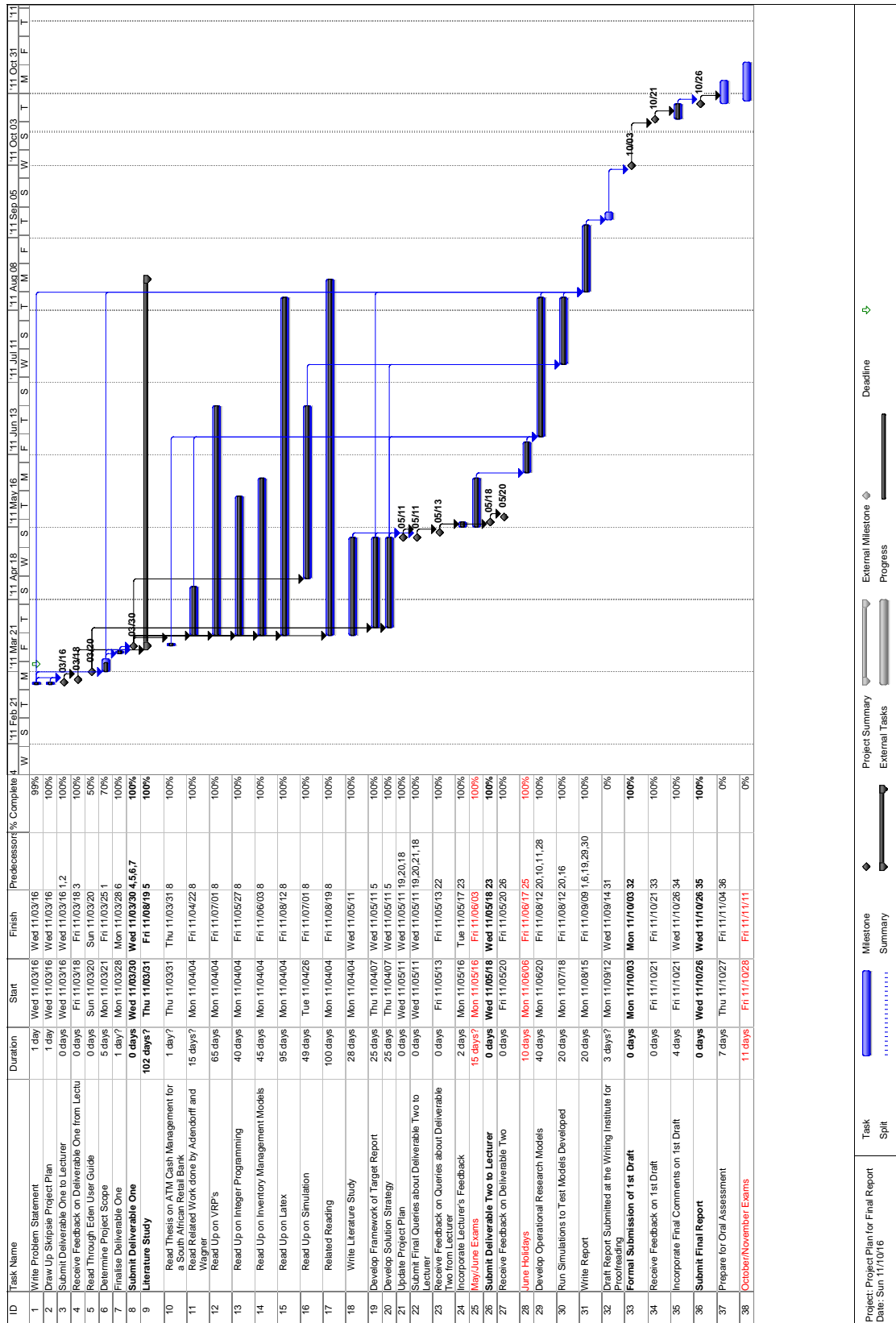


Figure D.1: Project plan for the final year project.

Appendix E

Project plan

The final year project plan is shown in Figure [E.1](#). This idea of this Gantt chart plan was to give the student an indication of the progress of the final year project. It was last updated as a final adjustment to the project report.

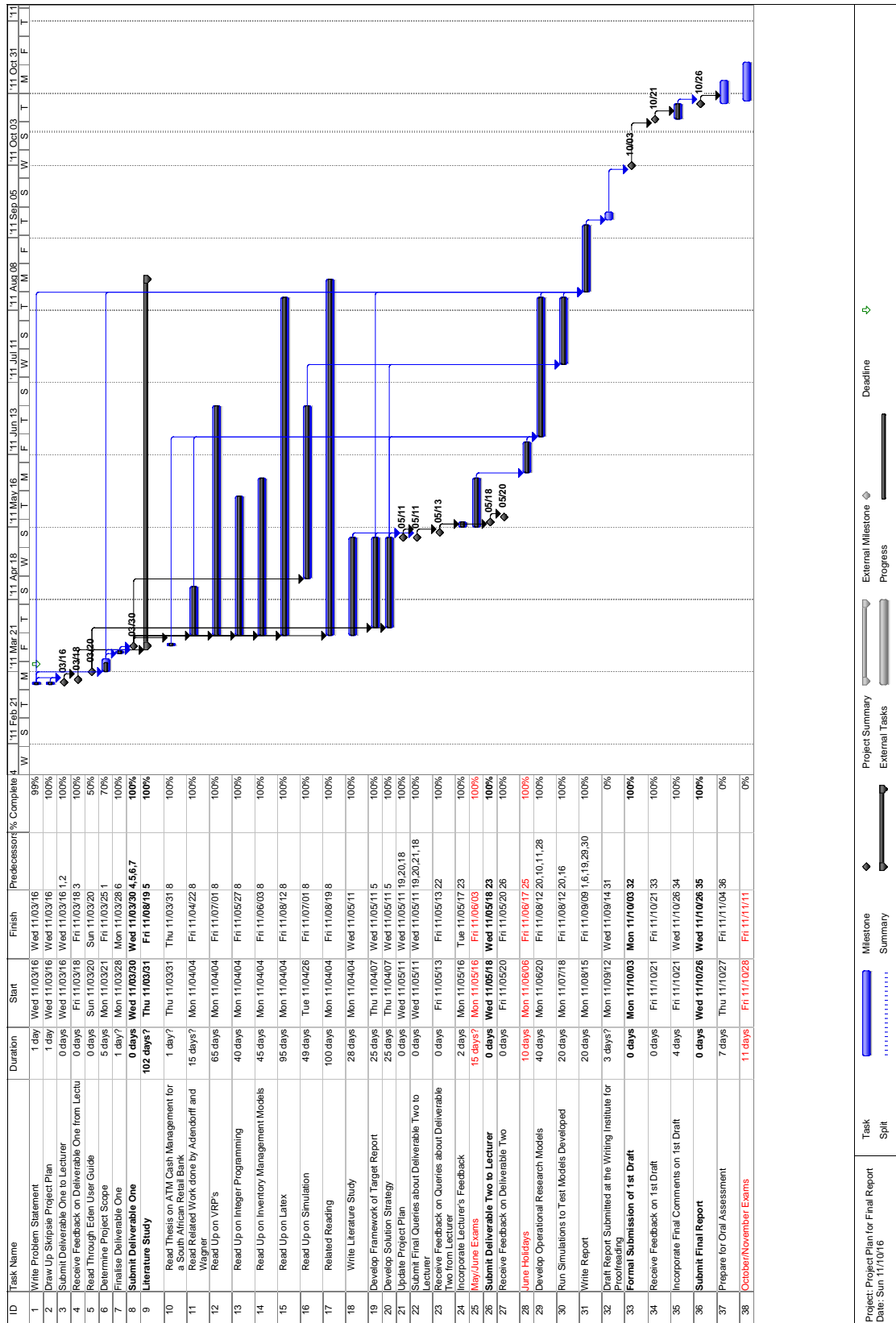


Figure E.1: Project plan for the final year project.