A HANDWRITTEN METHOD FOR DIGIT RECOGNITION SYSTEM

A PROJECT REPORT

Submitted by

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SYLLABUS

CHAPTER-01
INTRODUCTION

HANDWRITTEN digit recognition is the ability of a computer system to recognize the handwritten inputs like digits, characters etc. from a wide variety of sources like emails, papers, images, letters etc. This has been a topicof research for decades. Some of the research areas include signature verification, bank check processing, postal address interpretation fromenvelopes etc.

Here comes the use of Deep Learning. In the past decade, deep learning has become the hot tool for Image Processing, object detection, handwritten digit and character recognition etc. A lot of machine learning tools have been developed like scikit-learn, scipy-image etc. andpybrains, Keras, Theano, Tensorflow by Google, TFLearn etc. for Deep Learning. These tools make the applications robust and thereforemore accurate. The Artificial Neural Networks can almost mimic the human brain and are akey ingredient in image processing field. For example, Convolutional Neural Networks with Back Propagation for Image Processing, Deep Mind by Google for creating Art by learning from existing artist styles etc..

Handwriting Recognition has an active community of academics studying it. The biggest conferences for handwriting recognitionare the International Conference on Frontiers in Handwriting Recognition (ICFHR), held ineven-numbered years, and the InternationalConference on Document Analysis and Recognition (ICDAR), held in odd-numberedyears. Both of these conferences are endorsed by the IEEE. Active areas of research include: Online Recognition, OfflineRecognition, Signature Verification, Postal-Address Interpretation,Bank-Check Processing, Writer Recognition.

Classification of images and patterns has been one of the major implementation of Machine Learning and Artificial Intelligence. People are continuously trying to make computers intelligent so that they can do almost all the work done by humans

Handwriting recognition system is the most basic and an important step towards this huge and interesting area of Computer Vision

1.1 Project Overview

Deep Learning has emerged as a central tool forself-perception problems like understanding images, voice from humans, robots exploringthe world. The project aims to implement the concept of Convolution Neural Network which is one of the important architecture of deep learning. Understanding CNN and applying it to the handwritten recognition system, is the majortarget of the proposed system .

There is a reason behind using CNN for handwritten digit recognition. Let us consider a multi-layer feedforward neural network to beapplied on MNIST dataset which containsimages of size 28×28 pixels (roughly 784 pixels). So if a hidden layer has about 100 units,then the first layer weights comes up to about 78k parameters, which is large but manageable. However, in the natural world the size of the image is much larger . If we consider the size ofthe typical image which is around 256×256 pixels (roughly about 56,000 pixels), then the first layer weights will have about 560k parameters! So that becomes too manyparameters and hence make it unscalable forreal images. Hence, it will be so large that itwill become very difficult to generalize the newdata fed into the network. Convolution Neural Network extracts the feature maps from the 2D images by applying filters and hence making the task of feature extraction from the images easier.

1.2 Purpose

Convolution Neural Network extracts the feature maps from the 2D images by applying filters and hence making the task of feature extraction from the images easier. Basically, convolution neural network considers the mapping of image pixels with the neighbourhood space rather than having a fully connected layer of neurons. Convolution NeuralNetworks has been proved to be a very important and powerful tool in signal and image processing. Even in the fields of computer vision such has handwriting recognition, naturalobject classification and segmentation, CNN has been a much better tool compared to allother previously implemented tools .

The broader aim in mind was to develop a M.L. model that could recognize people'shandwriting. However, as we began developing the model we realized that the topic in hand wastoo tough and would require tremendous data tolearn. Example to accurately classify a cursive handwriting will be very tough. Thus we settled on classifying a given handwritten digit image as the required digit using three different algorithms and consequently testing its accuracy.

CHAPTER-02
LITERATURE SURVEY

2.1 EXISTING PROBLEM

The technology is developing day by day but no significant developments are undertaken for the betterment of these people. Communications between deaf-mute and a normal person has always been a challenging task. It is very difficult for mute people to convey their message to normal people. Since normal people are not trained on hand sign language. In emergency times conveying their message is very difficult. The human hand has remained a popular choice to convey information in situations where other forms like speech cannot be used. Voice Conversion System with Hand Gesture.

2.1 REFERENCES

[1] Dr.Kusumgupta2 ,"a comprehensive review on handwritten digit recognition using various neural network approaches", international journal of enhanced research in management & computer applications, vol. 5, no. 5, pp. 22-25,

2016.

[2]   Ishani Patel, ViragJagtap andOmpriyaKale."A Survey on Feature Extraction Methods for Handwritten Digits Recognition", International Journal of Computer Applications,vol. 107, no. 12, pp. 11-17, 2014.

[3] Y LeCun,"COMPARISON OF LEARNING ALGORITHMS FOR HANDWRITTEN DIGIT RECOGNISATION".In:International conference on Artificial Neural networks,France, pp. 53–60. 1995.

[4] FaisalTehseen Shah, Kamran Yousaf,"Handwritten Digit Recognition Using Image Processing and Neural Networks", Proceedings of the World Congress onEngineering, vol., 2007.

[5] Viragkumar N. Jagtap , Shailendra K. Mishra,"Fast Efficient Artificial Neural Network for Handwritten

Digit Recognition",International Journal of Computer Science and Information Technologies, vol. 52, no. 0975-

9646, pp. 2302-2306, 2014.

[6] Saeed AL-Mansoori,"Intelligent Handwritten Digit Recognition using Artificial Neural Network", Int. Journal of Engineering Research and Applications, vol. 5, no. 5, pp. 46-51, 2015.

2.3 PROBLEM STATEMENT DEFINITION

- Many physical and cognitive challenges disabled individuales face at woík and in daily life.
- AI can cíeate life changing oppoítunities foí people with limited vision
- AL poweíed poweíe self díiving caís and otheí foíms of autonomous tíanspoítation incíedible fíeedom of mobility for house
- AL technology helping disabled people opens up new opportunitiesfor accessibility,inclusion in society and indepedent living
- AL voice assisted technologiesm, like Echo,google home etc havecíeated new means of accesibilty foí specially disabled people

CHAPTER-03
IDEATION & PROPOSED SOLUTION

3.1 EMPATHY MAP CANVAS
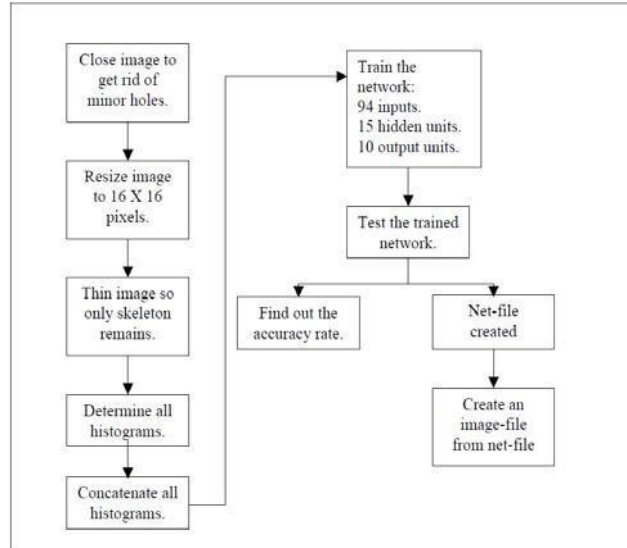
3.2 IDEATION & BRAINSTORMING

The Convolutional layer is the core building block of a CNN. The layer's parameters consist of a set of learnable filters (or kernels), which have a small receptive field, but extend through the full depth of the input volume. During the forward pass, each filter is convolved across thewidth and height of the input volume, computing the dot product between the entriesof the filter and the input and producing a 2- dimensional activation map of that filter. As a result, the network learns filters that activatewhen they see some specific type of feature at some spatial position in the input..

Feature Extraction: All neurons in a feature share the same weights .In this way all neurons detect the same feature at different positions.
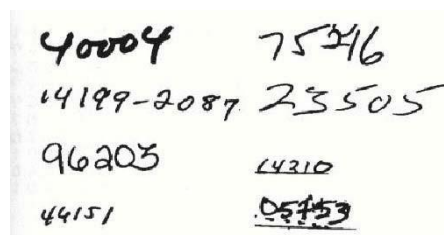
3.3 PROPOSED SOLUTION

 • The first layer of the architecture is the User layer. User layer will comprise of the people who interacts with the app and for the required results.

• The next three layers is the frontend architecture of the application. The application will be developed using Bootstrap which is the open source platform for HTML, CSS and JavaScript. The application is deployed in the localhost which is shown on the browser. Through the app, the user will be able to upload pictures of the handwritten digits and convert it into the digitalized form.

3.4 PROBLEM STATEMENT FIT
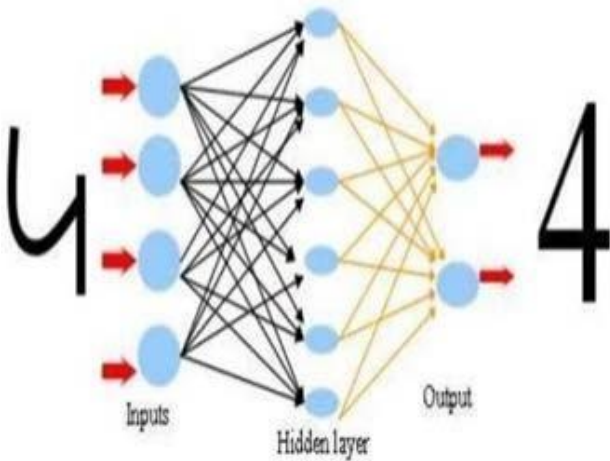
CHAPTER-04
REQUIREMENT ANALYSIS

4.1 FUNCTIONAL REQUIREMENTS

	Functional Requirement (Epic)	Sub Requirement (Story / Sub-Task)

| FUNCR-1	User Registration	**BAD WRITING** As a user who does not write clearly on papers or on gadget displays **Digital signature**
FUNCR-2	User Confirmation	**NOT AWARE OF WRITING** As a user who is not aware of the proper shape or alignment of the pattern of a digit. **Confirmation via Email**
FUNCR-3	User Registration	**COLOR BLINDNESS**: As a user who is color blind,I want a digit recognizer that could speak aloud what digit has been displayed **Registration through Gmail**

4.2 NON-FUNCTIONAL REQUIREMENTS

FR No.	Non-Functional Requirement	Description
NF-1	**Usability**	• Visual and Audio Help • Text size scaling • Reverse contrast
NF-2	**Security**	Important information: • Walking in single file or in narrow space. • Steps, Stairs and Slope. • Kerbs and Roads.
NF-3	**Reliability**	To determine reliability measures are: • Test-Retest Repeatability • Individual Repeatability
NF-4	**Performance**	To determine predictors of success in reading with low vision aids, in terms of reading acuity, optimum Acuity reserve, and maximum reading speed, for observers with low vision for various causes.
NF-5	**Availability**	Lack of adequate low vision services and barriers to their provision and uptake impact negatively on efforts to prevent visual impairment and blindness.
NF-6	**Scalability**	There is a large selection of device to help people with low vision. Some are "Optical", glass lenses such as magnifying glasses and telescopes.

CHAPTER-05
PROJECT DESIGN

5.1 DATA FLOW DIAGRAMS

Input   Conv   Pool   Conv   Pool   FC   Output
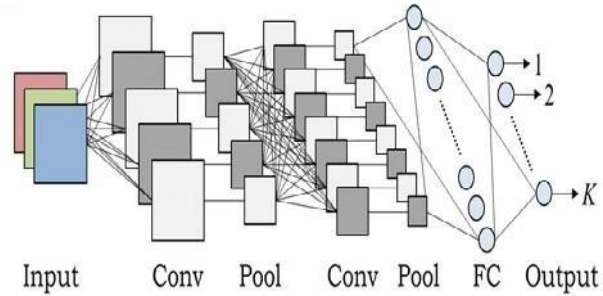
5.2 SOLUTION & TECHNICAL ARCHITECTURE

Appendix A – Methodology.

1) Close the image to get rid of minor holes.
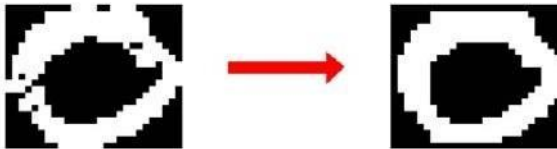
2) Resize the image to 16 X 16.
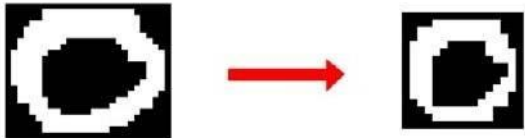
3) Thin the image so only the skeleton remains.

4) Determine all the histograms.
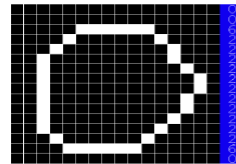
Determine horizontal histograms.
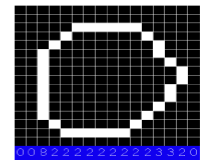
Determine vertical histograms.
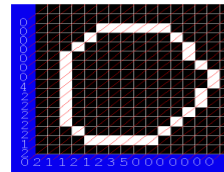
Determine right diagonal histograms.
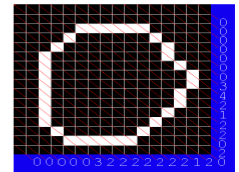
Determine left diagonal histogram

5) Concatenate all the histograms.

(0062222222222260
0082222222223320
000000042222212021121 2350000000
00000322222221202022 12430000000)

5.3 USER STORIES

Customer Journey Map
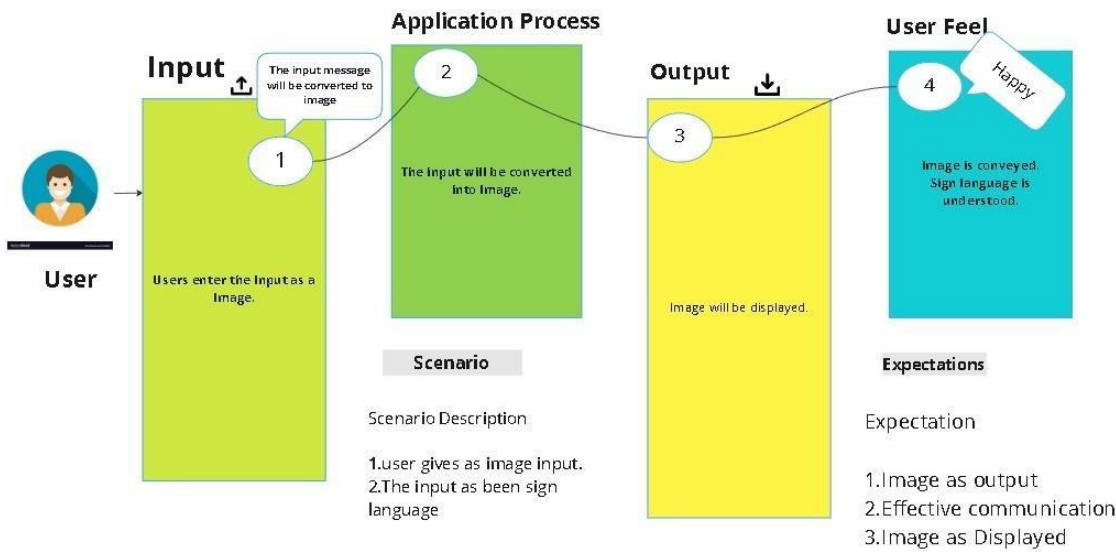
CHAPTER-06
PROJECT PLANNING & SCHEDULING

6.1 SPRINT PLANNING AND ESTIMATION

All the required datasets are collected and documented.

Dataset Details

The dataset used is the MNIST database ofhandwritten digits.It consists of a training set of 60,000 examples, and a test set of 10,000 examples.The digits have been size-normalized and centered in a fixed-size image.The images are of size 28*28 pixels.It is a good database forpeople who want to try learning techniques and pattern recognition methods on real-world data while spending minimal efforts on preprocessing and formatting. The dataset istaken fromhttp://yann.lecun.com/exdb/mnist/

6.2 SPRINT DELIVERY SCHEDULE

In business, System Analysis and Design refers to the process of examining a business situation with the intent of improving it through better procedures and methods. System analysis and design relates to shaping organizations, improving performance and achieving objectives for profitability and growth. The emphasis is on systems in action, therelationships among subsystems and their contribution to meeting a common goal. Looking at a system and determining how adequately it functions, the changes to be made and the quality of the output are parts of system analysis. Organizations are complex systems that consist of interrelated and interlocking subsystems. Changes in one part of the system have both anticipated and unanticipated consequences in other parts of the system. The systems approval is a way of thinking about the analysis and design of computer based applications. It provides a framework for visualizing the organizational and environmental factors that operate on a system. Proposed Application Module: The proposed application has been implemented using Python on terminal. The user is given two options in thehome image: Simple Upload, Model Form Upload. Simple Upload will allow the user to upload the image and predict it then and there. After navigating away from that page, the linkto the uploaded image is lost. The Model Form Upload will allow the user to upload the image with description. With this link, the user will be able to store the image and see its link on the home page itself. By clicking on the link, the user will be able to get the result from the CNN classifier

6.3 REPORTS FROM JIRA

Sprint report

Determine overcommittment and excessive scope creep and understand completed work in each sprint.

Burndown chart

Track progress towards sprint goals to manage progress and respond accordingly.

Release burndown

Track and monitor the projected release date for versions and take action if work is falling behind Projected schedule.

Velocity chart

Track work from sprint to sprint to helps teams determine the velocity and better estimate thework

a team realistically achieve in future sprints.

Optimize kanban flow for continuous delivery

Better predict future performance and spot bottlenecks with agile reports for [kanban teams](#).

Cumulative flow diagram

Easily spot blockages by seeing the number of issues that increase in any given state.

Control chart

Determine future performance with cycle and lead times for your product, version, or sprint

Work management made easier with Jira reports

 Identify trends and work smarter, with out-of-the-box reports for issue analysis and forecastingin
Jira Softwa
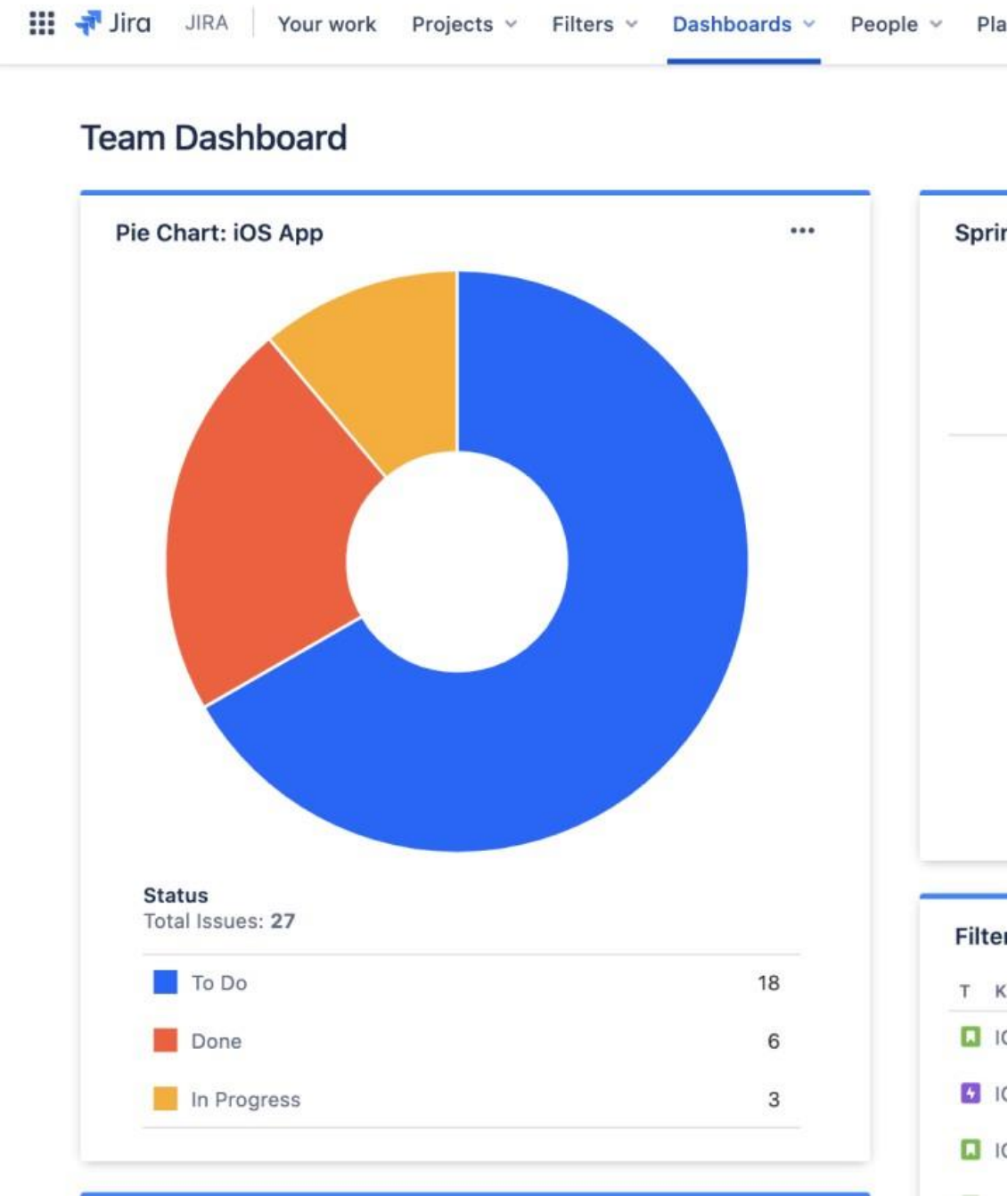
CHAPTER-07
CODING AND SOLUTIONING

7.1 FEATURE 1

A method for solving problems

This method is from the book *How to Solve It* by George Pólya. It originally came out in 1945 and has sold over one million copies.

His problem-solving method has been used and taught by many programmers, from computer science professors (see Udacity's Intro to CS course taught by professor David Evans) to modern web development teachers like Colt Steele.

Let's walk through solving a simple coding problem using the four-step problem-solving method. This allows us to see the method in action as we learn it. We'll use JavaScript as our language of choice. Here's the problem:

Create a function that adds together two numbers and returns that value.
There are four steps to the problem-solving method:
1. Understand the problem.
2. Devise a plan.
3. Carry out the plan.
4. Look back.

7.2 FEATURE 2

Step 1: Understand the problem.

When given a coding problem in an interview, it's tempting to rush into coding. This is hard to avoid, especially if you have a time limit.

However, try to resist this urge. Make sure you actually understand the problem before you get started with solving it.

Read through the problem. If you're in an interview, you could read through the problem out loud if that helps you slow down.

As you read through the problem, clarify any part of it you do not understand. If you're in an interview, you can do this by asking your interviewer questions about the problem description. If you're on your own, think through and/or Google parts of the question you might not understand

This first step is vital as we often don't take the time to fully understand the problem. When you don't fully understand the problem, you'll have a much harder time solving it.

To help you better understand the problem, ask yourself:

What are the inputs?

What kinds of inputs will go into this problem? In this example, the inputs are the arguments that our function will take.

Just from reading the problem description so far, we know that the inputs will be numbers. But to be more specific about what the inputs will be, we can ask:

Will the inputs always be just two numbers? What should happen if our function receives as input *three* numbers?

Here we could ask the interviewer for clarification, or look at the problem description further.

The coding problem might have a note saying, "You should only ever expect two inputs into the function." If so, you know how to proceed. You can get more specific, as you'll likely realize that you need to ask more questions on what kinds of inputs you might be receiving.

Will the inputs always be numbers? What should our function do if we receive the inputs "a" and "b"? Clarify whether or not our function will always take in numbers.

Optionally, you could write down possible inputs in a code comment to get a sense of what they'll look like:

//inputs: 2, 4

Next, ask:

What are the outputs?

What will this function return? In this case, the output will be one number that is the result of the

two number inputs. Make sure you understand what your outputs will be.

Create some examples.

Once you have a grasp of the problem and know the possible inputs and outputs, you can start working on some concrete examples.

Examples can also be used as sanity checks to test your eventual problem. Most code challenge editors that you'll work in (whether it's in an interview or just using a site like Codewars or HackerRank) have examples or test cases already written for you. Even so, writing out your own examples can help you cement your understanding of the problem.

Start with a simple example or two of possible inputs and outputs. Let's return to our addition function.

Let's call our function "add."

What's an example input? Example input might be:

// add(2, 3)

What is the output to this? To write the example output, we can write:

// add(2, 3) ---> 5

This indicates that our function will take in an input of 2 and 3 and return 5 as its output.

Create complex examples.

By walking through more complex examples, you can take the time to look for edge cases you might need to account for.

For example, what should we do if our inputs are strings instead of numbers? What if we have as input two strings, for example, add('a', 'b')?

Your interviewer might possibly tell you to return an error message if there are any inputs that are not numbers. If so, you can add a code comment to handle this case if it helps you remember you need to do this.

// return error if inputs are not numbers.

Your interviewer might also tell you to assume that your inputs will always be numbers, in which case you don't need to write any extra code to handle this particular input edge case.

If you don't have an interviewer and you're just solving this problem, the problem might say what happens when you enter invalid inputs.

For example, some problems will say, "If there are zero inputs, return undefined." For cases like this, you can optionally write a comment.

// check if there are no inputs.

// If no inputs, return undefined.

For our purposes, we'll assume that our inputs will always be numbers. But generally, it's good to think about edge cases.

Computer science professor Evans says to write what developers call *defensive* code. Think about what could go wrong and how your code could defend against possible errors.

Before we move on to step 2, let's summarize step 1, understand the problem:

```
-Read through the problem.

-What are the inputs?

-What are the outputs?

Create simple examples, then create more complex ones.
```

2. Devise a plan for solving the problem.

Next, devise a plan for how you'll solve the problem. As you devise a plan, write it out in pseudocode.

Pseudocode is a plain language description of the steps in an algorithm. In other words, your pseudocode is your step-by-step plan for how to solve the problem.

Write out the steps you need to take to solve the problem. For a more complicated problem, you'd have more steps. For this problem, you could write:

// Create a sum variable.

Add the first input to the second input using the addition operator.

// Store value of both inputs into sum variable.

// Return as output the sum variable.

Now you have your step-by-step plan to solve the problem.

For more complex problems, professor Evans notes, "Consider systematically how a human solves the problem." That is, forget about how your code might solve the problem for a moment, and think about how *you* would solve it as a human. This can help you see the steps more clearly.

3. Carry out the plan (Solve the problem!)

The next step in the problem-solving strategy is to solve the problem. Using your pseudocode as your guide, write out your actual code.

Professor Evans suggests focusing on a simple, mechanical solution. The easier and simpler your solution is, the more likely you can program it correctly.

Taking our pseudocode, we could now write this:

```
function  add(a,  b)  {
  const sum = a + b;
  return sum;

}
```

Professor Evans adds, remember not to *prematurely optimize.* That is, you might be tempted to start saying, "Wait, I'm doing this and it's going to be inefficient code!"

First, just get out your simple, mechanical solution.

Step 4: Look back over what you've done.

Once your solution is working, take the time to reflect on it and figure out how to make improvements. This might be the time you refactor your solution into a more efficient one.

As you look at your work, here are some questions Colt Steele suggests you ask yourself to figure out how you can improve your solution:

- Can you derive the result differently? What other approaches are there that are viable?
- Can you understand it at a glance? Does it make sense?
- Can you use the result or method for some other problem?
- Can you improve the performance of your solution?
- Can you think of other ways to refactor?
- How have other people solved this problem?

One way we might refactor our problem to make our code more concise: removing our variable and using an implicit return:

```
function  add(a,  b)  {
  return a + b;

}
```

With step 4, your problem might never feel finished. Even great developers still write code that they later look at and want to change. These are guiding questions that can help you.

If you still have time in an interview, you can go through this step and make your solution better. If you are coding on your own, take the time to go over these steps.

When I'm practicing coding on my own, I almost always look at the solutions out there that are more elegant or effective than what I've come up with.

7.3 DATABASE SCHEMA

The Aito database schema is a description of how the database is constructed and internally processed. A schema contains the information of:

- The name of the tables
- The name and the ColumnType of the columns in each table
- The Analyzer of a column if needed
- The relationships (links) between tables

The Aito database requires a defined schema before executing other operations. The schema is defined in the JSON format and populate to Aito using the Schema API Endpoint.

CHAPTER-08
TESTING

8.1 TEST CASES

Sprint	Functional Requirement (Epic)	User Story Number	User Story / Task
Sprint-1	Data Collection	USN-1	Collect Dataset .
Sprint-1	Image processing	USN-2	Image preprocessing
Sprint-2	Model Building	USN-3	Import the required libraries, add the necessary layers and compile the model

				Dhanush Shankar
Sprint-2	CNN MODEL	Training the image classificationmodel using CNN	7	Balamurugan Vignesh
Sprint-3	Training and Testing	Training the model and testing themodel's performance	9	Praveen E
Sprint-4	Implementationof the application	Converting the input sign language images into English alphabets	8	Dhanush Shankar

CHAPTER-09
RESULTS

9.1 PERFORMANCE METRICS

As a small business owner, you will always want to keep an eye on how your business is performing.

Whether that is keeping an eye on your sales, your customer satisfaction, or even your warehouse efficiency.

A business that is performing well, is a business that is making money.

But how do you measure performance? And what are performance metrics?
Let's take a closer look.

Performance metrics are data used to track processes within a business.

This is achieved using activities, employee behavior, and productivity as key metrics.These metrics are then used by employers to evaluate performance.

This is in relation to an established goal such as employee productivity or sales objectives.

CHAPTER-10
ADVANTAGES & DISADVANTAGES

In order to have a learning task that is reasonably workable, agreat amount of pre-processing of the digits is carried out using conventional Artificial Intelligence (AI) techniques. This is done before the digits are fed to the ANN.[2] The difficult task is there are some handwritten digits that often run together or not fully connected. Numeral 5 is an example. But once these tasks have been carried out, the digits are available as individual items. But the digits are still in different sizes. Therefore a normalization step has to be performed so we can have to have digits in equal sizes.

 After the digits are normalized, they are fed into the ANN. This is a feed-forward network with three hidden layers. Theinput is a 16 x 16 array that corresponds to the size of a normalized pixel image. The first hidden layer contains 12 groups of units with 64 units per group. Each unit in the group is connected to a 5 x 5 square in the input array and all 64 units in the group have the same 25 weight values.

The second hidden layer consists of 12 groups of 16 units. This layer operates very similar to the first hidden layer, but now it seeks features in the first hidden layer. The thirdhidden layer consists of 30 units that are fully connected to the units in the previous layer. The output units are in turn fully connected to the third hidden layer.

1) Simulations & results

An image is fed into the network to train. Back-propagation neural network is used for training the network. Although it is only one image, it contains 100 samples of the same number. For every 10 epochs, the information is saved into the network. After training, the network is tested and the accuracy rate reached to 99%. This is a very high accuracy rate.

The network was not stable because the training results changes everyday. If we take numeral —2" as an example, today we might have to train 20 times in order to reach 99% accuracy, but tomorrow we maybe have to train 25 times in order to reach 99% accuracy.

The following graph is the average number of times that a data needs to be trained in order to reach 99% accuracy: Training times.

Example: In Weather Forecasting using AI they have reduced the majority of human error.

Training times to 99% accuracy rate
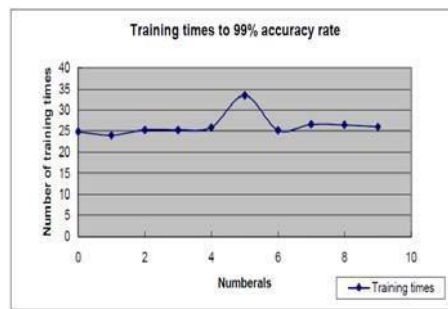
2) Takes risks instead of Humans:

From the training results (See Appendix B for table results) and from the above graph, we can see that the system has more trouble identifying numeral —5". Here is the test resultafter training 26 times (See Appendix B for table results).

Test results after training 26 times

Example:

Test results after training 26 times
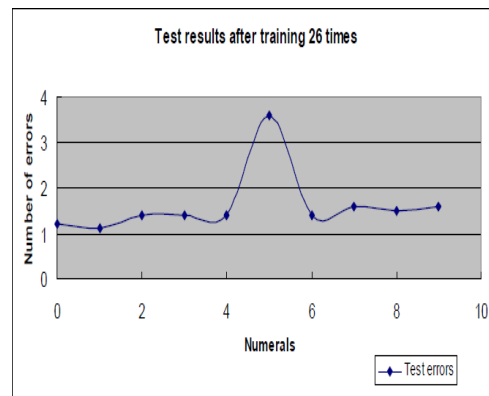
AI Robots can be used in such situations where intervention can be hazardous.

3) Available 24x7:

After training 26 times, the network is tested. We can see thatthere were more errors for numeral —5". This means that numeral —5" still need more network training to reach an accuracy of 99%.

The following is the image-file produced using the net-file:

CHAPTER-11
CONCLUSION

An implementation of Handwritten DigitRecognition using Deep Learning has been implemented in this paper. Additionally, some of the most widely used Machine Learning algorithms i.e. CNN using Tensorflowhave been trained and tested on the same data to draw a comparison as to why we require deep learning methods in critical applications like Handwritten Digit Recognition. In this paper, I have shown that that using Deep Learning techniques, a very high amount of accuracy can be achieved. Using the Convolutional NeuralNetwork with Keras and Theano as backend, I am able to get an accuracy of 95.72%. Every tool has its own complexity and accuracy. Although, we see that the complexity of thecode and the process is bit more as compared to normal Machine Learning algorithms but looking at the accuracy achieved, it can be said that it is worth it. Also, the current implementation is done only using the CPU Thus we settled on classifying a given handwritten digit image as the required digitusing three different algorithms andconsequently testing its accuracy. In future we

CHAPTER-12
FUTURE SCOPE

In business, System Analysis and Design refers to the process of examining a business situation with the intent of improving it through better procedures and methods. System analysis and design relates to shaping organizations, improving performance and achieving objectives for profitability and growth. The emphasis is on systems in action, the relationships among subsystems and their contribution to meeting a common goal. Looking at a system and determining how adequately it functions, the changes to be made and the quality of the output are parts of system analysis. Organizations are complex systems that consist of interrelated and interlocking subsystems. Changes in one part of the system have both anticipated and unanticipated consequences in other parts of the system. The systems approval is a way of thinking about the analysis and design of computer based applications. It provides a framework for visualizing the organizational and environmental factors that operate on a system. Proposed Application Module: In business, System Analysis and Design refers to the process of examining a business situation with the intent of improving it through better procedures and methods. System analysis and design relates to shaping organizations, improving performance and achieving objectives for profitability and growth. The emphasis is on systems in

action, therelationships among subsystems and their contribution to meeting a common goal. Looking at a system and determining how adequately it functions, the changes to be made and the quality of the output are parts of system analysis. Organizations are complex systems that consist of interrelated and interlocking subsystems. Changes in one part of the system have both anticipated and unanticipated consequences in other parts of the system. The systems approval is a way of thinking about the analysis and design of computer based applications. It provides a framework for visualizing the organizational and environmental factors that operate on a system. Proposed Application Module.

CHAPTER-13
APPENDIX

1. Training results.

Numerals	Training 1	Training 2	Training 3	Training 4	Training 5	Training 6	Training 7	Training 8	Training 9	Training 10	Average
0	29	24	24	24	26	25	23	28	26	20	24.9
1	20	26	25	25	28	23	22	21	24	26	24
2	22	27	27	25	25	23	31	26	23	24	25.3
3	21	25	23	29	24	24	25	24	28	30	25.3
4	27	23	23	28	26	24	26	25	26	31	25.9
5	35	29	32	34	32	30	38	39	30	36	33.5
6	22	21	23	24	31	28	29	23	25	26	25.2
7	28	23	24	24	25	25	35	31	26	25	26.6
8	24	25	26	26	29	26	21	32	28	28	26.5
9	27	26	28	30	26	24	24	25	21	29	26

2. Test results.

Numeral	Test 1 Errors	Test 2 Errors	Test 3 Errors	Test 4 Errors	Test 5 Errors	Test 6 Errors	Test 7 Errors	Test 8 Errors	Test 9 Errors	Test 10 Errors	Average
0	2	1	1	1	1	1	1	2	1	1	1
1	1	1	1	1	2	1	1	1	1	1	1
2	1	2	2	1	1	1	3	1	1	1	1
3	1	1	1	2	1	1	1	1	2	3	1
4	2	1	1	2	1	1	1	1	1	3	1
5	4	2	3	4	3	3	5	5	3	4	4
6	1	1	1	1	3	2	2	1	1	1	1
7	2	1	1	1	1	1	4	3	1	1	2
8	1	1	1	1	2	1	1	3	2	2	2
9	3	1	2	3	1	1	1	1	1	2	2

3. Hidden Layers.

INPUT UNITS	94 units
HIDDEN UNITS	15 units
OUTPUT UNITS	10 units

SOURCE CODE

```python
# Grid structure

self.canvas.grid(row=0, column=0, pady=2, sticky=W, )
self.label.grid(row=0, column=1,pady=2, padx=2)
self.classify_btn.grid(row=1, column=1, pady=2, padx=2)
self.button_clear.grid(row=1, column=0, pady=2)


#self.canvas.bind("<Motion>", self.start_pos)
self.canvas.bind("<B1-Motion>", self.draw_lines)



def clear_all(self):
    self.canvas.delete("all")

def classify_handwriting(self):

    HWND = self.canvas.winfo_id() # get the handle of the canvas
    rect = win32gui.GetWindowRect(HWND) # get the coordinate of the canvasim
    = ImageGrab.grab(rect)

    digit, acc = predict_digit(im)
    self.label.configure(text= str(digit)+', '+ str(int(acc*100))+'%')



def draw_lines(self, event):
    self.x = event.x
    self.y = event.y
    r=8
    self.canvas.create_oval(self.x-r, self.y-r, self.x + r, self.y + r, fill='black')
```

```
app = App()
mainloop()
```

GITHUB-IBM PROJECT LINK

- https://github.com/IBM-EPBL/IBM-Project-48341-1660806879