CHAPTER 8

RECOGNIZING THE PATTERNS FOR DIAGNOSING DISEASES OF EYE
Vision is a gift from God to humans. Eyes see images and send the signal to the brain, which perceives the images. Any problem in the eye can have an impact on vision. A disease of the eye, if not detected at the right time, can lead to permanent loss of vision. It is possible to prevent the loss of good vision through periodic screening and early diagnosis.

8.1 STRUCTURE OF EYE

The main parts of the eye are [106], as shown in figure 8.1

![Figure 8.1: Structure of Eye](image)

8.1.1: **Cornea:** It is the transparent circular part of the front of the eyeball. It refracts the light entering the eye through the lens, which is focused on the retina at the back of the eye. This is the transparent part of the eye which covers the eyeball.

8.1.2: **Retina:** It is a light-sensitive inner lining of the eye and sends electrical impulses to the brain. It contains millions of photoreceptor cells that receive light rays, process them, and send signals to the brain through the optic nerve. It works
like a film in a camera. It is composed of photo sensitive cells known as rods and cones. The human eye contains about 125 million rods which are necessary for seeing in dim light; and between six million to seven million cones that are used to see sharp accurate images and distinguish colors.

8.1.3: Iris: The colored part of the eye is known as iris. It is set of elastic pigmented tissues that are in front of the lens. It regulates the amount of light that enters the eye. The opening at the center of the iris is called pupil. The iris contains muscles that open or close the pupil in response to the brightness of surrounding light. The iris acts like a shutter of cameras.

8.1.4: Pupil: The circular opening in the center of iris through which light passes into the lens of the eye is called pupil. The iris muscles control the size of the pupil. The pupil looks like a black circle in the center of the eye which adjusts the aperture.

8.1.5: Choroid: It is the very vascular middle layer of the eye between the retina and the sclera that nourishes the outer portions of the retina. The choroid contains a pigment, that absorbs excess light to prevent blurring of vision. The choroid has one of the highest blood flows in the body.

8.1.6: Sclera: The white part of the eye is called sclera. It is a tough covering of the cornea that forms the external protective coat of the eye.

8.1.7: Ciliary Muscle: This connects the choroid to the iris and produces aqueous fluid, known as vitreous humor, fills the front part of the eye maintaining the eye pressure. It also allows focusing of the lens.

8.1.7: Convex Lens: This is clear part of the eye behind the iris and helps to focus light on the retina. The lens sits behind the iris and in front of the vitreous humor.
8.1.8: Optic Nerve: It is on the back of the eye and is attached to the retina. It receives impulses from the retina and relays them to the brain. The optic nerve leaves the eye at the optic disc and transfers all the visual information to the brain.

8.2 RETINAL IMAGES

Diseases in the eye can be manifestation of accidents or other factors like diabetes, hypertension etc. All the diseases cannot be diagnosed by the ophthalmologist by examining the patient’s eye. Additional inputs are required for some. The blood vessels in the eye are the only vessels in the body that can be photographed. Ophthalmic photography is a highly-specialized form of medical imaging, dedicated to the study and treatment of disorders of the eye [106]. The most common ophthalmic photographs are retinal (fundus) photographs, sometimes involving fluorescent dye (Fluorescein or Indocyanine Green angiography). Retinal images are the photographs of the eye which shows the internal structure of the eye like retina. This helps the ophthalmologist to observe the back of the eye and is used for diagnosing many diseases like age related macular degeneration (AMD), diabetic retinopathy etc. Diseases have a particular set of symptoms like formation of new blood vessels, discoloration of retina etc. that help in the diagnoses. Retinal images are broadly classified in two categories:

8.2.1.1: Color Fundus Photographs taken with the help of high resolution camera.

8.2.1.2: Fundus Fluorescein Angiogram (FFA).

A fluorescein dye is injected in the vein of the patient. On an average in 10 to 20 seconds, the dye travels to the blood vessels inside the eye. A camera equipped with special filters that highlight the dye is used to take a series of photographs as the fluorescein circulates through the blood vessels in the back of the eye. FFA is a grey scale image and is useful for evaluating many eye diseases that affect the retina. If there are any circulation problems; swelling,
leaking or abnormal blood vessels, the dye and its patterns will usually reveal these in the photographs.

These images provide information about pathological changes and can also indicate early signs of some systemic diseases, such as diabetes and hypertension. It is important to detect malign changes and abnormal structures of the retina as early as possible and monitor their progress during clinical therapy. Out of these two photographs FFA is not generally used until absolutely necessary as it is costly and painful for the patient.

8.3 NORMAL FUNDUS CONDITIONS

The normal fundus varies a little between individuals in the background color due to variations in retinal pigment but the optic disc and vessels are remarkably uniform.

The background’s reddish-orange color of the fundus is due to the retinal pigment epithelial layer overlaying the choroids. Sparse pigmentation (e.g. in myopia) will allow choroidal vessels to be seen in the fundus. The retina itself is transparent hence the background reddish-orange color of the pigment epithelial layer and choroids is observed through the retina [107].

The optic disc is the prominent feature of the fundus situated just adjacent to the central area of the fundus (the macula). It is slightly oval in shape and marks commencement of the optic nerve. Fine capillaries cover its surface giving it a lighter red color in contrast to the darker fundus color. The disc has clear margins and in its center there is a depression called the physiological cup.

The veins are observed as columns of bluish blood to the central retinal vein at the disc. The arteries are narrower than veins and appear as red columns of blood in transparent walls carrying oxygenated blood from the central retinal artery away from the optic disc to supply the retina.

The macula is the central feature of the fundus. It appears as a darker red spot on the surrounding fundus with a bright center point called fovea. A typical fundus photograph is shown in figure 8.2.
8.4 THE EYE DISEASE DIAGNOSED WITH THE HELP OF RETINAL IMAGES

Commonly occurring diseases which can be diagnosed with the help of retinal images are [108], [109]:

1. Diabetic Retinopathy (DR)
2. Age related Muscular Degeneration (AMD)
3. Central Serous Retinopathy (CSR)
4. Cystoid Muscular Edema (CME)
5. Retinal Vein Occlusion (RVO)
6. Retinal Artery Occulation (RAO)
7. Choroiditis and inflammation of Retina
8. Optic disc pit

8.4.1 Diabetic Retinopathy (DR)
Diabetic Retinopathy, a compilation of diabetes, is caused by changes in the blood vessels of the retina. These damaged blood vessels leak fluid and lipids, which get deposited on the retina resulting in blurred images being sent to brain. Another serious complication of diabetic retinopathy is bleeding inside the eye (vitreous hemorrhage) which occurs in late stage of disease. It is the leading cause of blindness among adults in India. People with untreated diabetes are said to be twenty five times more prone to blindness than the general population.

There are two types or stages of DR

i. **Nonproliferative Diabetic Retinopathy (NPDR)**

   This is an early stage of diabetic retinopathy. Fine blood vessels within the retina become narrowed or obstructed while others enlarge to form tiny balloon-like sacs. These altered vessels leak blood and fluid, causing the retina to swell or form deposits called exudates. This problem is called macular edema or diabetic maculopathy. Sight is not seriously affected if treated in time. If left untreated, macular edema can worsen and vision deteriorates. Reading and close work may become more difficult. In some diabetes patients, vision may be permanently impaired due to reduced blood supply to the central part of retina- a condition called macular ischemia.

ii **Proliferative Diabetic Retinopathy (PDR)**

   Proliferative diabetic retinopathy is the advanced stage and more serious form of diabetic retinal disease. It affects up to twenty percent of diabetics and can cause severe loss of sight, including blindness. Abnormal blood vessels begin to grow on the surface of the retina or the optic nerve. The new blood vessels, called neovascularisation, have weaker walls and may rupture and bleed into vitreous (the clear gel like substance that fills the cavity of the eye). This leaking blood blocks the light, causing severe impairment of vision. These abnormal blood vessels frequently grow scar like tissues with them which may pull the retina away from its normal position at the back of the eye (retinal detachment).
**Signs and Symptoms**

Generally, people with mild NPDR do not have any visual loss. A dilated eye examination is the only way to detect changes inside the eye before loss of vision begins.

In PDR the following symptoms are significant.

1. seeing dark floaters
2. experiencing loss of central or peripheral vision
3. experiencing visual distortions or blurriness
4. experiencing temporary or permanent vision loss

In PDR following abnormalities are observed.

1. Cotton wool spots: They are small, whitish fluffy superficial lesions which obscure underlying blood vessels and are clinically evident only in the post-equatorial retina.
2. Intraretinal micro vascular abnormalities (IRMA): These include fine red lines that run from arterioles to venules, thus resembling focal areas of flat retinal new vessels. The main distinguishing features of IRMA are their intraretinal location, their failure to cross major retinal blood vessels and absence of leakage.
3. Venous changes consist of dilatation, looping, beading and segmentation.
4. Arterial changes consisting of narrowing, silver wiring and obliteration resembling a branch retinal artery occultation.
5. Dark blot hemorrhages representing hemorrhagic retinal infarcts and are located within the middle retinal layers.

In NPDR following abnormalities might be observed

1. Micro aneurysms: They are tiny, round red dots initially appearing temporal to the fovea. When coated with blood they may be indistinguishable from blot hemorrhages.
2. Hard exudates: They are waxy, yellow lesions with relatively distinct margins. They are often arranged in clumps and/or rings at the posterior pole. A ring of hard exudates often exhibits microaneurysms at its centre.
3. Intraretinal hemorrhages arising from the venous end of capillaries and located in the compact idle layers of the retina with a resultant red, dot-blot configuration.

4. Retinal nerve fibre layer hemorrhages arising from the larger superficial pre-capillary arterioles and are flame shaped.

8.4.2 Age Related Muscular Degeneration (AMD)

Age-related macular degeneration (AMD) is a very common cause of reduced vision as the age increases. Although this condition may cause significant reduction in vision, it never leads to complete blindness as it affects only the central part of the vision and the side, or peripheral, vision is always left intact. Retina has two main parts - the macula and the peripheral retina. The macula is the part of the retina that is responsible for seeing fine detail, such as reading, seeing facial features and interpreting different colors. It is this part of the retina that is affected by age-related macular degeneration due to "wear and tear" changes in the macular region. It is thought that waste materials from this very active part of the eye builds up as the mechanisms for removing them become less efficient thus damaging the cells over a period of time. The retinal pigment epithelium, which is the outer layer of the retina, fails to carry out its function as a result of which there is accumulation of the breakdown products. These are of two types

i. **Non-exudative or Dry AMD**

Dry type is caused by aging and thinning of the tissues in the macula, which results in gradual visual loss. It is characterized by yellowish deposits in the macular region which may undergo subsequent atrophy or may progress to wet form. Dry AMD is caused by the accumulation of "Drusen" beneath the macula. Drusen are small, yellowish deposits that form within the layers of the retina. These drusen are clumps of non-cellular matter that are related to the base membrane of the retina. As the drusen build up beneath the macula, it tends to dry out and the cells within it begin to die. The macula becomes thin and loses its function.

ii. **Exudative or Wet AMD**
In the "wet" type of AMD, blood vessels grow under the macula. This causes hemorrhage, swelling, and scar tissue. If these abnormal blood vessels leak blood or fluid; the macula will become raised and distorted. Patients my see dark spots in their center of vision, and straight lines may look wavy. The loss of vision brought about by the effects of wet-AMD can be severe and often progresses rapidly.

**Signs and Symptoms**
Most people do not have many symptoms except for blurring of vision. The Amsler Grid test evaluates the fixation. The Amsler grid looks like graph paper - a series of small squares - with a dot in the center of the grid. The patient is instructed to stare at the dot and notice if any lines appear wavy or missing. A patient with AMD perceives a straight line as distorted. In advanced cases, the vision in the central area is completely affected and patient is unable to see any grid pattern.

### 8.4.3 Central Serous Retinopathy (CSR)
Central serous retinopathy is a self-limiting disease of young or middle-aged males. It is characterized by a usually unilateral, localized detachment of the sensory retina at the macula with or without associated PED (pigment epithelial detachment).

**Signs and Symptoms**

i. It is associated with unilateral blurred vision.

ii. The elevation of the sensory retina gives rise to an acquired hypermetropia with disparity between the subjective and objective refraction of the eye.

iii. A round or oval detachment of the sensory retina present at the posterior pole.

iv. The subretinal fluid may be clear or turbid and small precipitates may be present on the posterior surface of the sensory detachment.

v. Smoke-stack appearance in the angiogram. It is due to the leakage of dye through the retinal pigment.

vi. Ink-blot appearance may also be present but are less common.
8.4.4 Cystoid Macular Edema (CME)

Cystoid macular edema is the result of accumulation of the fluid in the outer plexiform and inner nuclear layers of the retina centered about the fovea and the formation of fluid filled cyst-like changes. In short term CME is usually innocuous; long-standing cases, however, usually lead to coalescence of the fluid-filled microcysts into large cystoid spaces and subsequent lamellar hole formation at the fovea with irreversible damage to central vision. CME is common and non-specific condition that may occur with any type of macular edema.

**Signs and Symptoms**

i. Visual acuity may already be impaired by pre-existing disease such as branch vein occlusion.

ii. In angiograms flower-petal pattern of hyperfluorescence may be seen which is caused by accumulation of dye within microcystic spaces in the outer plexiform layer of the retina.

8.4.5 Retinal Vein Occlusion (RVO)

Retinal vein occlusion may occur due to other diseases present in the eye which hinders the flow of blood in the veins. Venous occlusion causes elevation of venous and capillary pressure with stagnation of blood flow. It is mainly of two types.

i. Branch Retinal Vein Occlusion (BRVO): Occlusion in any branch of the vein in the retina. It affects only the quadrant in which the branch lies.

ii. Central Retinal Vein Occlusion (CRVO): When occultation is in the central vein of the retina. This again is of two types: Non-ischaemic CRVO and Ischaemic CRVO.

**Signs and Symptoms**

In BRVO

i. Venous dilation and tortosity peripheral to the site of occlusion.

ii. Flame-shaped and dot-blot hemorrhages, retinal edema, and cotton wool spots affecting the sector of the retina drained by the obstructed vein.
In Non-ischaemic CRVO following are observed:

i. Sudden unilateral blurred vision.
ii. Visual impairment is moderate to severe.
iii. Variable tortuosity and dilation of all branches of the central retinal vein.
iv. Retinal dot-blot and flame-shaped hemorrhages, throughout all four quadrants and most numerous in the periphery.
v. Occasional cotton wool spots.

In Ischaemic CRVO following are observed:

i. Unilateral, sudden and severe visual impairment.
ii. Visual impairment is profound.
iii. Marked tortuosity and engorgement of all branches of the central retinal vein.
iv. Extensive dot-blot and flame-shaped hemorrhages involving the peripheral retina and posterior pole.
v. Numerous cotton wool spots.

8.4.6 Retinal Artery Occultation (RAO)

These are of two types:

i. Branch retinal artery occultation (BRAO)
ii. Central retinal artery occultation (CRAO)

Signs and Symptoms

In BRAO following are observed:

i. Sudden and profound altitudinal or sectoral visual field loss.
ii. Visual impairment is variable.
iii. Retinal cloudiness corresponding to the area of ischaemia resulting from edema.
iv. Narrowing of arteries and veins with sledding and segmentation of blood column.
v. Angiogram shows delay in arterial filling and masking of background fluorescence by retinal swelling which is confined to the involved sector.

In CRAO following are observed:
i. Sudden and profound loss of vision.

ii. Visual impairment is profound except when a portion of the papillomacular bundle is supplied by a cilioretinal artery.

iii. Attenuation of arteries and veins with sludging and segmentation of the blood column.

iv. Extensive retinal cloudiness.

v. The orange reflex from the intact choroid stands out at the thin fovea in contrast to the surrounding pale retina giving rise to the cherry red spot appearance.

vi. In eyes with a cilioretinal artery, part of the macula will remain of normal color.

8.4.7 Choroiditis

Choroiditis is characterized by deep yellow or greyish patches with fairly well-demarcated boarders. Inactive lesions appear as white, well-defined areas of choriotinal atrophy with pigmented borders.

8.4.8 Optic Disc Pit

Unilateral dark, round or oval pit in larger than normal optic disc appears. About fifty percent of eyes develop a serous detachment of the macula.

8.5 NEURAL NETWORK FOR DIAGNOSING DISEASES OF EYE

Medical image analysis is important for clinical diagnosis for physicians. This enables the physician to measure important structures in an image, compare sequential images, aggregate images similar in content and finally obtain automated diagnosis from images. A system that accepts retinal image and gives an output which is complete diagnosis is ideally desired. Being complicated, this is divided into two main subsystems: The system which will localize and distinguish various normal features (like optic disc, fovea etc.) and abnormal features (like exudates, hemorrhages etc.) from the images. The second subsystem which will produce a diagnosis from the detected features from the image (output of the first subsystem). The first subsystem deals with the image processing. The input to this subsystem will be the retinal image and the output from it will be list of all detected features. The second subsystem
diagnoses the diseases using artificial neural network given the extracted features of image. An attempt has been made to develop a neural network for diagnosing the diseases given the extracted features.

8.5.1 Collection of Retinal Images and Preparation of Database

The retinal images which are the colored fundus photographs have been taken from the Grewal Eye Institute, Chandigarh. The images are in JPEG format.

As the main objective was to get the diagnosis, no work is done on the image processing aspect. The database is developed with the help of expert ophthalmologist. A set of forty two features were identified in the fundus photographs. They are stored as true/false based on whether they are present/seen in the fundus photographs or not. These features are:

8.5.1.1 Optic Disc Symptoms
i. Shape of optic disc not defined properly. The optic disc is normally circular or oval in shape with proper edge distinguishing it from the background.
   The feature is set to ‘true’, if edges were not defined properly.
ii. Size of optic disc. The normal size of the optic disc is 1.5mm.
iii. The cup to disc (CD) ratio. The normal value is less than or equal to 0.4.
iv. Unilateral dark round/oval pit around optic disc.
v. Bright lesion near/around optic disc.

8.5.1.2 Blood Vessels Symptoms
i. New membranes/vessels.
ii. Entanglement of blood vessels.
iii. Bending of blood vessels.
iv. Torturing of blood vessels.
v. White marks along blood vessels.
vi. Bleeding along blood vessels.
vii. Looping of blood vessels.
viii. Bleeding of blood vessels (whole).
ix. Bleeding of blood vessels (branch).
8.5.1.3 Macular Region Symptoms

i. Multiple cysts like lesions in center of macula.

ii. Macula not defined properly.

iii. Pigmentation in macula.

iv. Multiple yellow/white patches in macular region.

v. Elevated blister like area at macula.

vi. Black pigmentation at macula.

vii. Cherry red spot: The orange reflex from the intact choroid stands out at the thin fovea in contrast to the surrounding pale retina giving rise to the cherry red spot appearance.

viii. Color of macula (normal dark brown).

ix. Hemorrhage at macula.

8.5.1.4 Background Symptoms

i. Hard drusen: They are small, round, discrete yellow-white spots associated with focal dysfunction of RPE (retinal pigment epithelium).

ii. Soft drusen: They are larger and have indistinct margins.

iii. Hard exudates: They are waxy, yellow lesions with relatively distinct margins. They are often arranged in clumps and/or rings at the posterior pole.

iv. Soft exudates/ Cotton wool spots: They are small, whitish fluffy superficial lesions which obscure underlying blood vessels and are clinically evident only in the post-equatorial retina.

v. Blot hemorrhages.

vi. Dot hemorrhages.

vii. Subretinal disiform scaring.

viii. Loss of retinal pigmentation.

ix. Laser treatment marks (grey).

x. Laser treatment marks, round circular (grid).

xi. Micro aneurysms: They are tiny, round red dots initially appearing temporal to the fovea.

xii. Candle wax exudates.
xiii. Multiple patches of retinal inflammation.
xiv. Discoloration of retina.
xv. Bleeding from retina.
xvi. White marks.
xvii. Nothing seen properly.
xviii. Yellow patches in peripheral retina.
xix. Green/grey patches in peripheral retina.

8.5.1.5 Outputs of Neural Network

A total of twenty abnormal conditions (i.e. diseases) and one normal eye condition were taken as the desired outputs needed from the network. These were:

i. AMD (Age related Muscular Degeneration)
ii. AMD-CNVM
iii. DR(Diabetic Retinopathy)
iv. NPDR(Nonproliferative diabetic retinopathy)
v. PDR(Proliferative diabetic retinopathy)
vi. CME(Cystoid Muscular Edema)
vii. Optic disc pit
viii. Myopic degeneration
ix. Vasculitis
x. Post laser
xi. GHPC(Geographical Helicoids Perepeplary Choroditis)

xii. CSR(Central Serous Retinopathy)
xiii. CRVO (Central Retinal Vein Occultation)
xiv. BRVO(Branch Retinal Vein Occultation)
xv. CRAO(Central retinal artery Occultation)
xvi. Vitreous hemorrhage
xvii. Multifocal choroditis
xviii. Disc edema
xix. Macular hemorrhage
xx. Optic neuritis
The dataset used contains 130 records which have the observed features from the image and the diagnosed output. This database was then divided into two sets: one for training the network which contains 90 records and the rest 40 records were used for the testing purpose.

8.5.2 Choice of Network Architecture

Network architecture or topology plays an important role for neural net classification, and the optimal topology will depend upon the problem in hand. The multi layer perceptrons (MLP) are highly suitable for any classification task i.e. pattern recognition. This is due to the reason that the MLPs build hyper surfaces that divide the output space into different classes that have dissimilar properties. By training an MLP, we separate the output space into regions. The output space will not only separate (classify) the input data patterns but it will also separate data patterns, which it has not seen before. The ability of a MLP to correctly classify input data patterns that it has not seen before (has not been trained with) is termed generalization. The linear separation of classes in the output domain is a remarkable property of the MLP. Such a neural network builds hyperplanes to divide the output into different classes.

8.5.2.1 Factors Affecting the Performance of Neural Network

Number of Nodes in the Input Layer

The number of input nodes can generally be easily determined because the number of nodes in the input layer is equal to the number of inputs that we want to feed into the network. In the networks developed forty two input nodes corresponding to each symptom have been used. The value of each symptom can be true or false depending on whether the symptom is seen in the fundus photograph or not.

Number of Nodes in the Output Layer

The number of nodes in the output layer is equal to the number of outputs i.e. diseases that are to be diagnosed. There were twenty one output nodes, twenty for commonly occurring diseases and one for normal eye.
Number of Hidden Layers

Generally one hidden layer with sufficient number of nodes is enough for most of the problems that use neural networks. One should try to use as few hidden layers as possible because the addition of each hidden layer significantly increases the network complexity, increases the number of weighted connections between the nodes and unnecessary addition of the hidden layers will lead to slower learning. However, having more than one hidden layer has few advantages when they are used in the networks where their use is essential, like better learning of relationship between inputs and outputs, faster learning and at times having more than one hidden layer can help in avoiding the pitfalls of the local minima. After trying many combinations our optimized network has 3 hidden layers in it.

Number of Hidden Nodes

While the number of input units and output units are dictated by the dimensionality of the input vectors and the number of categories, respectively, the number of hidden units is not simply related to such obvious properties of the classification problem. There are no correct guidelines for determining the number of nodes in hidden layers. If the patterns are well separated or linearly separable, then few hidden units are needed; conversely, if the patterns are drawn from complicated densities that are highly interspersed, then more hidden units are needed. However, in some complex problems the number of hidden nodes may be more than the number of input nodes and/or output nodes.

By hit and trail method the optimized network has 3 hidden layers with 11, 9 and 7 nodes in hidden layer 1, layer 2 and layer 3 respectively.

8.6 RESULTS

The results obtained show the diagnostic accuracy for the test database used. The resulting comparison charts have been drawn. The results for the optimum topology of the neural network are in the form of special files saved using EasyNN-plus. A complete compilation of the results is in the CD-ROM attached. Graphical interpretations of these results are presented. The results
have been obtained by developing a large number of neural networks and are
being presented.

8.6.1 Number of Hidden Layers and Hidden Nodes
The input nodes in the input layer and the output nodes in the output layer in
Multilayer perceptron are decided prior to the neural network training, as the
information about them is available. But the number of hidden nodes in hidden
layer has to be decided by trial and observation method. Different neural
networks with different number of nodes in hidden layer were trained. A network
with one hidden layer was created and it was trained with varying number of
nodes (Figure 8.3).

![Variation in accuracy with the number of nodes in first hidden layer](image)

**Figure 8.3: Variation in Accuracy with Number of Nodes in Hidden Layer**

Since the difference between accuracies achieved between 10 and 11 nodes in
hidden layer is not much, both were further experimented. It has been observed
on the basis of the second hidden layer that the number of nodes in first hidden
layer should be 11 as these number of hidden neurons in this layer gives better
accuracy.
Figure 8.4: Variation in Accuracy with Number of Nodes in Second Hidden Layer when Number of Nodes in First Hidden Layer was set to 10.

Figure 8.4 shows the variation in accuracy in two hidden layer network when number of nodes in first hidden layer was set to 10 and number of nodes in second hidden layer was varied. Similarly figure 8.5 shows the variation in accuracy in two hidden layer network when number of nodes in first hidden layer was set to 11.

Figure 8.5: Variation in Accuracy with Number of Nodes in Second Hidden Layer when Number of Nodes in First Hidden Layer was set to 11

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With two hidden layers neural networks, it is observed that the accuracy is in the range of 77.5% to 85% (figure 8.4 and 8.5). The difference in accuracies with eleven nodes in hidden layer one and eight to ten nodes in second hidden layer was experimented with. The difference was not much. Further experimentation was carried out with networks having:

i. Nodes in first hidden layer equal to eleven.
ii. Nodes in second hidden layer equal to eight, nine and ten.
iii. Nodes in third hidden layer equal to five, six, seven and eight.

The results are shown in figure 8.6.

As seen from the graph the accuracy of the three hidden layer networks did not increase and the maximum accuracy remained 85% with 11-9-7 and 11-10-8 networks. Since 11-9-7 network has less number of hidden nodes, it was selected for further investigation.

The other parameters like learning rate and momentum were varied for the network. Figure 8.7 shows the variation in accuracy with change in momentum with constant learning rate of 0.2 on 11-9-7 network. As shown in the graph after changing the momentum the accuracy of 90% was achieved.
8.6.2 Number of Cycles

The number of cycles that the neural network takes to learn depends on a number of factors: learning rate, momentum, number of hidden layers, number of nodes in each hidden layer, number of training examples, target error etc.

Figure 8.8: Variation in Training Cycles as Number of Nodes in First Hidden Layer with Target Error set to 0.01
Figure 8.8 and figure 8.9 show the effect of an increase in the number of nodes in the first hidden layer on the number of cycles which generally decrease with increase in the nodes. It is also clear that if the target error is halved from 0.01 to 0.005, the number of training cycles roughly doubles.

8.6.3 Learning Rate

The back-propagation algorithm has two important parameters: learning rate and momentum. The optimum value of these two parameters for the neural network has been decided by testing different configurations of learning rate and momentum, and analyzing the results. It was found that these parameters have a great effect on the number of cycles that the network takes to converge to a solution or acceptable error. Figure 8.10 shows variation in number of cycles with change in learning rate at constant momentum 0.4 and target error 0.01 on neural network with one hidden layer having ten hidden nodes.
8.6.4 Momentum

To study the effect of momentum on convergence of neural network, neural network (three hidden layers network with 11, 9 and 7 nodes in first, second and third hidden layers respectively) was trained with different values of momentum at constant leaning rate of 0.2 and for a target error of 0.01, the effect is shown in figure 8.11.
8.6.5 The Identified Optimized Neural Network

By making and testing many networks with different parameters, the network with parameters as shown in table 6.1 have the maximum accuracy of 90%.

<table>
<thead>
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<th>NAME OF VARIABLE</th>
<th>VALUE</th>
</tr>
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<tbody>
<tr>
<td>Number of nodes in input layer</td>
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</tr>
<tr>
<td>Number of nodes in output layer</td>
<td>21</td>
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<tr>
<td>Number of hidden layers</td>
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<td>11</td>
</tr>
<tr>
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<td>9</td>
</tr>
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<td>Number of nodes in third hidden layer</td>
<td>7</td>
</tr>
<tr>
<td>Learning rate</td>
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</tr>
<tr>
<td>Momentum</td>
<td>0.4</td>
</tr>
<tr>
<td>Target error</td>
<td>0.01</td>
</tr>
</tbody>
</table>

Table 8.1: The Optimized Neural Network for Diagnosing Eye Diseases

The optimized network has the learning curve shown in figure 8.12 with parameters shown in figure 8.13. The importance of each input is shown in figure 8.13 while relative error of each training data is shown in figure 8.15. All these graphs are generated automatically in EasyNN-plus software.
Figure 8.12: Learning Curve of Optimized Neural Network

| Learning rate: | 0.200000 |
| Momentum:      | 0.200000 |
| Maximum error: | 0.053461 |
| Average error: | 0.010000 |
| Minimum error: | 0.001432 |

Figure 8.13: Parameters of Optimized Neural Network

<table>
<thead>
<tr>
<th>Layer:</th>
<th>Input</th>
<th>Hidden 1</th>
<th>Hidden 2</th>
<th>Hidden 3</th>
<th>Output</th>
</tr>
</thead>
<tbody>
<tr>
<td>Nodes:</td>
<td>42</td>
<td>11</td>
<td>9</td>
<td>7</td>
<td>21</td>
</tr>
<tr>
<td>Weights:</td>
<td>462</td>
<td>99</td>
<td>63</td>
<td>147</td>
<td></td>
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</tbody>
</table>
The first 42 of 42 Inputs in descending order.

<table>
<thead>
<tr>
<th>Column</th>
<th>Input Name</th>
<th>Importance</th>
<th>Relative Importance</th>
</tr>
</thead>
<tbody>
<tr>
<td>28</td>
<td>dot hemr</td>
<td>17.1076</td>
<td></td>
</tr>
<tr>
<td>26</td>
<td>S Ex</td>
<td>15.6435</td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>dark pit around OD</td>
<td>15.4968</td>
<td></td>
</tr>
<tr>
<td>25</td>
<td>H Ex</td>
<td>14.2024</td>
<td></td>
</tr>
<tr>
<td>11</td>
<td>looping BV</td>
<td>13.1522</td>
<td></td>
</tr>
<tr>
<td>0</td>
<td>shape OD</td>
<td>12.9208</td>
<td></td>
</tr>
<tr>
<td>23</td>
<td>HD</td>
<td>12.2197</td>
<td></td>
</tr>
<tr>
<td>32</td>
<td>laser(grid)</td>
<td>12.0335</td>
<td></td>
</tr>
<tr>
<td>8</td>
<td>torturing BV</td>
<td>11.8990</td>
<td></td>
</tr>
<tr>
<td>17</td>
<td>yellow pitch in mac</td>
<td>11.7117</td>
<td></td>
</tr>
<tr>
<td>13</td>
<td>bleeding of BV(branch)</td>
<td>11.4653</td>
<td></td>
</tr>
<tr>
<td>5</td>
<td>new BV</td>
<td>11.4610</td>
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</tr>
<tr>
<td>24</td>
<td>SD</td>
<td>11.3255</td>
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<tr>
<td>15</td>
<td>mac nt def</td>
<td>10.4525</td>
<td></td>
</tr>
<tr>
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<td>loss retinal pigm</td>
<td>10.2526</td>
<td></td>
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<td>9</td>
<td>white marks along BV</td>
<td>9.5262</td>
<td></td>
</tr>
<tr>
<td>37</td>
<td>bleeding from retina</td>
<td>8.1114</td>
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</tr>
<tr>
<td>22</td>
<td>hemr in mac</td>
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<td>CD ratio</td>
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<tr>
<td>18</td>
<td>blister</td>
<td>8.3294</td>
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<tr>
<td>40</td>
<td>yellow patches in p-re+</td>
<td>8.1000</td>
<td></td>
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<tr>
<td>27</td>
<td>blot hemr</td>
<td>8.0723</td>
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</tr>
<tr>
<td>33</td>
<td>micro aneu</td>
<td>8.0501</td>
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</tr>
<tr>
<td>39</td>
<td>nothing seen</td>
<td>7.6106</td>
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<tr>
<td>14</td>
<td>cyst lesions</td>
<td>7.1483</td>
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<tr>
<td>38</td>
<td>white marks</td>
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<tr>
<td>1</td>
<td>size OD</td>
<td>6.9218</td>
<td></td>
</tr>
<tr>
<td>12</td>
<td>bleeding of BV(whole)</td>
<td>6.7497</td>
<td></td>
</tr>
<tr>
<td>7</td>
<td>bendino BV</td>
<td>5.9898</td>
<td></td>
</tr>
<tr>
<td>34</td>
<td>candle wax Ex</td>
<td>5.8270</td>
<td></td>
</tr>
<tr>
<td>4</td>
<td>bright lesion arnd OD</td>
<td>5.2645</td>
<td></td>
</tr>
<tr>
<td>21</td>
<td>col of mac</td>
<td>5.0835</td>
<td></td>
</tr>
<tr>
<td>31</td>
<td>laser(grey)</td>
<td>4.9515</td>
<td></td>
</tr>
<tr>
<td>16</td>
<td>pigm in mac</td>
<td>4.8038</td>
<td></td>
</tr>
<tr>
<td>29</td>
<td>scaring</td>
<td>4.1478</td>
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</tr>
<tr>
<td>36</td>
<td>discol retina</td>
<td>3.6708</td>
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</tr>
<tr>
<td>10</td>
<td>bleeding along BV</td>
<td>3.5482</td>
<td></td>
</tr>
<tr>
<td>20</td>
<td>cherry red spot</td>
<td>3.3979</td>
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</tr>
<tr>
<td>19</td>
<td>black pigm mac</td>
<td>3.1597</td>
<td></td>
</tr>
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<td>6</td>
<td>entangle BV</td>
<td>2.8160</td>
<td></td>
</tr>
<tr>
<td>41</td>
<td>green/grey patches in +</td>
<td>2.0562</td>
<td></td>
</tr>
<tr>
<td>35</td>
<td>R inflamation</td>
<td>1.9921</td>
<td></td>
</tr>
</tbody>
</table>

**Figure 8.14: Importance of Each Input**
The first 90 of 90 Example rows in descending order. Above target
Below target

Row  Example  Normalized Error [0 - 1]  Relative Error
82  i83  0.023581 0.023581
81  i82  0.014230 0.014230
78  i79  0.013979 0.013979
80  i81  0.013553 0.013553
76  i77  0.010860 0.010860
62  i63  0.010232 0.010232
61  i62  0.009569 0.009569
60  i61  0.009047 0.009047
59  i60  0.008252 0.008252
58  i59  0.007954 0.007954
57  i58  0.007862 0.007862
56  i57  0.007681 0.007681
55  i56  0.007429 0.007429
54  i55  0.006462 0.006462
53  i54  0.006442 0.006442
52  i53  0.006104 0.006104
51  i52  0.006073 0.006073
50  i51  0.005756 0.005756
49  i50  0.005100 0.005100
48  i49  0.004852 0.004852
47  i48  0.004697 0.004697
46  i47  0.004656 0.004656
45  i46  0.004423 0.004423
44  i45  0.004207 0.004207
43  i44  0.003863 0.003863
42  i43  0.003750 0.003750
41  i42  0.003139 0.003139
40  i41  0.002851 0.002851
39  i40  0.002597 0.002597
38  i39  0.002523 0.002523
37  i38  0.001970 0.001970
36  i37  0.001819 0.001819
35  i36  0.001480 0.001480
34  i35  0.001480 0.001480
33  i34  0.001479 0.001479
32  i33  0.001479 0.001479
31  i32  0.001427 0.001427
30  i31  0.001427 0.001427
29  i30  0.001427 0.001427
28  i29  0.001427 0.001427
27  i28  0.001427 0.001427
26  i27  0.001427 0.001427
25  i26  0.001427 0.001427
24  i25  0.001427 0.001427
23  i24  0.001427 0.001427
22  i23  0.001427 0.001427
21  i22  0.001427 0.001427
20  i21  0.001427 0.001427
19  i20  0.001427 0.001427
18  i19  0.000720 0.000720
17  i18  0.000720 0.000720
16  i17  0.000720 0.000720
15  i16  0.000720 0.000720
14  i15  0.000720 0.000720
13  i14  0.000720 0.000720
12  i13  0.000720 0.000720
11  i12  0.000720 0.000720
10  i11  0.000720 0.000720
9  i10  0.000720 0.000720
8  i09  0.000720 0.000720
7  i08  0.000720 0.000720
6  i07  0.000720 0.000720
5  i06  0.000720 0.000720
4  i05  0.000720 0.000720
3  i04  0.000720 0.000720
2  i03  0.000720 0.000720
1  i02  0.000720 0.000720
0  i01  0.000720 0.000720
-1  i00  0.000720 0.000720
-2  i-1  0.000720 0.000720
-3  i-2  0.000720 0.000720
-4  i-3  0.000720 0.000720
-5  i-4  0.000720 0.000720
-6  i-5  0.000720 0.000720
-7  i-6  0.000720 0.000720
-8  i-7  0.000720 0.000720
-9  i-8  0.000720 0.000720
-10 i-9  0.000720 0.000720
-11 i-10 0.000720 0.000720

Figure 8.15: Relative Error of Each Training Example

Target error 0.0100  Average training error 0.010019
8.7 CONCLUSIONS

On the basis of the development of neural networks and results obtained from them, it is concluded that:

1. Learning rate and momentum have a significant effect on the number of training cycles that the neural network takes to converge. As the learning rate increases the number of training cycles decreases, similarly as the momentum increases the number of training cycles decrease.

2. The number of training cycles were doubled when the target error was halved (other parameters remained same for the network).

3. The number of training cycles that the system needs for convergence also depends on the number of hidden layers and the number of nodes in the hidden layer(s).

4. The optimized network has accuracy of 90% in classifying the eye diseases.