How AI Enhances & Accelerates Diabetic Retinopathy Detection

With ongoing advances in computing hardware and the availability of high-quality data sets, AI in the form of deep learning-based systems can apply algorithms to provide more accurate and faster diagnosis of diabetes-related progressive eye disease.
EXECUTIVE SUMMARY

Diabetic retinopathy (DR) is a serious eye disease associated with long-standing diabetes that results in progressive damage to the retina, eventually leading to blindness. The disease does not show explicit symptoms until it reaches an advanced stage; however, if DR is detected early on, vision impairment can be prevented with the use of laser treatments.

The existing DR screening process is handicapped by a lack of trained clinicians. Moreover, the screening process is time-consuming. The delay in delivering results can lead to lost follow-ups, miscommunication, and missed or postponed treatments – all of which may increase the probability of vision loss.

The California Health Care Foundation (CHCF) recently found that among the patients who were referred to a specialist by a general physician, only 23% consult an ophthalmologist. Among the rest, 15% were unaware about the disease, another 15% did not make a screening appointment, 22% failed to attend their appointments and 25% opted out of treatment.¹

Based on such statistical data, we see a need for an automated DR detection system that can input retinal images from color fundus photography, provide a quick DR classification...
with confidence and refer the patient to specialists if needed. This will enable doctors addressing DR cases to utilize their time effectively and thereby treat more DR patients in a timely fashion.

Our DR automated detection system solution makes use of machine learning techniques such as convolutional neural networks (CNN) – neural networks that are used to analyze and classify visual imagery. Our approach mimics the role of the clinical practitioner who uses the fundus image from the screening to assess DR onset before consulting the doctor.

In the future, clinicians will be able to use our DR detection and grading solution with a mobile-attached, hand-held fundus camera to diagnose DR immediately and guide patients toward further treatment. The solution would run on the mobile device as an application service.

This white paper chronicles our journey in developing an AI-based diabetic retinopathy diagnostic tool to enable clinicians to identify DR symptoms. It also examines our challenges in building a diagnostic solution and applying the CNN model for DR identification. The white paper concludes with key benefits and a future roadmap for our DR solution.
BUT FIRST, SOME ESSENTIAL (AND SCARY) FACTS

Our journey started with a social outreach project in a Bangalore-based clinic, the Vittala International Institute of Ophthalmology (VIIO), when the hospital requested our assistance to build a DR screening tool that would help diagnose more patients.

VIIO was founded by Dr. Krishna R Murthy, based on his vision that “No one shall go blind for want of money or lack of care.”

But there are many patients in India who lack coverage, including access to effective quality eye care. DR is an eye disease that results in vision loss for an individual who is affected by diabetes (diagnosed or undiagnosed) over a prolonged period. Hyperglycemia, or raised blood sugar, is a common effect of uncontrolled diabetes, and over time it seriously damages many bodily systems, especially the nerves and blood vessels.

According to the World Health Organization (WHO), in 2000 31.7 million people were affected by diabetes in India. This figure is projected to rise by 2030 to 79.4 million, the largest number of any country. It is estimated that 10% to 15% of the diabetic population have DR, and everyone with diabetes has the potential to develop it over time.

According to the Centers for Disease Control and Prevention’s (CDC) National Diabetes Statistics Report 2017, which analyzes health data through 2015, 30.3 million U.S. citizens, nearly one in ten, have diabetes and 84.1 million adults, approximately one in three, have prediabetes.

According to the International Diabetes Federation (IDF), 425 million people worldwide suffered from diabetes and diabetes-related complications as of 2015. This number is expected to reach 642 million by 2040. And according to CDC, 16 million people will be affected by diabetic retinopathy by 2050.

A Global Health Challenge in the Making

425 Million People
Diabetics worldwide

62 Million People
India’s diabetics

10%–15%
Incidence of diabetic retinopathy among diabetics

10,000
Retina specialists in India

Source:
www.ncbi.nlm.nih.gov/pmc/articles/PMC2636123/
www.ncbi.nlm.nih.gov/pmc/articles/PMC3920109/
www.diabetesatlas.org/
SYMPTOMS OF DIABETIC RETINOPATHY

There are few early symptoms of DR. Symptoms usually develop gradually due to high blood sugar levels damaging blood vessels in the retina. Typical symptoms of retinopathy include one or more of the following:

- Sudden changes in vision.
- Distorted vision.
- Blurred vision.
- Floaters in your vision.
- Seeing dark spots or patches.
- Reduction in night vision.

Over the course of time, DR worsens and progresses to proliferative retinopathy. This is where reduced blood flow to the retina stimulates the growth of fragile new blood vessels on the retina's surface. The affected person's vision is damaged by the new blood vessels, leading to additional health complications, including:

- Bleeding inside the eye.
- Retinal detachment due to the formation of scar tissue that pulls on the retina.
- A form of severe glaucoma where new blood vessels grow on the surface of the iris.

Complications of retinopathy in later stages can include severe, permanent vision loss.

CHALLENGES OF DEVELOPING THE DIAGNOSTIC TOOL

The key challenges faced in building a diagnostic tool include:

- **Data set availability**: To train deep learning algorithms requires annotated representative data from a varied set of fundus cameras and various geographies.
- **Fundus image analysis**: Image analysis with computer vision is a challenge due to the wide and varied set of fundus images with different patterns and color variations.
- **Fundus images from multiple cameras**: Another primary challenge is handling retinal images from different types of fundus cameras.
- **Lack of diabetic specialists**: Availability of diabetic specialists is very low compared with the number of patients who are tested per month (see Figure 1). Moreover, it takes between one and four days for clinicians to grade the images and advise next steps to the patient. This combined factor clearly shows the need for automation.
An automated detection system is required for DR screening that can input and read retinal images from color fundus photography, and provide rapid results with high confidence on whether the patient is affected by DR and should consult a specialist.

We’ve developed an AI-based DR diagnostic tool (see Figure 2) to help doctors detect and grade the level of DR disease based on the fundus images. Our DR tool will enable doctors to view variations from multiple fundus camera images with the help of image preprocessing techniques. The tool makes use of emerging machine learning technology to process fundus images quickly – and as accurately – as manual screening. Most important, it reduces the time taken for the whole process to less than a minute (in initial pilots), from a minimum of 15 minutes manually. We are confident this speed will improve over time.
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The core of our solution is based on a deep CNN, which extracts diagnostic features using a deep learning algorithm trained to classify images across labels (see Figure 3) to determine whether or not the patient has DR. As part of the preprocessing steps to support different fundus cameras, color space normalization is applied to the input fundus images. Other image preprocessing includes illumination correction, noise removal and image normalization (i.e., removing unwanted regions and rescaling to a standard size).

Our DR screening solution has been trained with fundus data sets from Kaggle – one of the largest and most diverse data analytics communities in the world – and VIIO. The combined data set amounts to nearly 100,000 images.

**DIABETIC RETINOPATHY PREDICTION & GRADING**

DR prediction is the process of identifying whether the patient is affected by DR, given the set of the patient’s input fundus images. DR grading is the process of identifying the stage of DR with the input of fundus images. This process makes use of a huge corpus of fundus images with labels varied from 0 to 4:

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<th>No DR</th>
<th>Mild</th>
<th>Moderate</th>
<th>Severe</th>
<th>Proliferative DR</th>
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<tr>
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<td>3</td>
<td>Severe</td>
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<tr>
<td>4</td>
<td>Proliferative DR</td>
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**A Sample Set of DR Images**

- **Without DR**
- **Early Diabetic Retinopathy**
- **Mild NPDR**
- **Moderate NPDR**
- **Severe NPDR**
- **PDR and Neovascularization**

Source: Getty Images and VIIO

*nonproliferative diabetic retinopathy
Stages of Diabetic Retinopathy

A deep learning model has been trained with a corpus of fundus images that have undergone a series of image preprocessing operations. The images are used to extract features using CNN, which in turn passes the features on to a classification model to predict whether the given image is affected by DR or not, and predict the disease grading level (see Figure 4). The stages are as follows:

1. **Mild nonproliferative retinopathy**: The earliest stage of the disease consists of microaneurysms caused by swelling in the retina’s tiny blood vessels.
2. **Moderate nonproliferative retinopathy**: Blood vessels that nourish the retina may swell and distort. As the disease progresses, they may also lose their ability to transport blood.
3. **Severe nonproliferative retinopathy**: Blood supply to areas of the retina are blocked by blood vessels. These areas secrete growth factors that signal the retina to grow new blood vessels.
4. **Proliferative diabetic retinopathy (PDR)**: At this advanced stage, the new blood vessels are likely to leak and bleed. Growth factors secreted by the retina trigger the proliferation of new blood vessels, which grow along the inside surface of the retina and into the vitreous gel that fills the eye. This causes permanent vision loss due to retinal detachment.

Diabetic Retinopathy Process Flow

![Diabetic Retinopathy Process Flow Diagram](image)

**WHY A CNN**

As defined in an Unsupervised Feature Learning and Deep Learning (UFLDL) tutorial, a CNN comprises one or more convolutional layers (a set of learnable filters), followed by one or more fully connected layers as in a standard multilayer neural network. The CNN’s architecture is designed to take advantage of the 2-D structure of an input image. This is achieved in the translation of invariant features.
One benefit of a CNN is that it is easier to train and typically has many fewer parameters than fully connected networks with the same number of hidden units. In deep learning, convolutional layers are exceptionally good at finding appropriate features in images in each layer to form a hierarchy of nonlinear features that gain complexity. The final layer(s) use(s) all these generated features for classification or regression (see Figure 5).

**A Typical Deep CNN**

![A Typical Deep CNN](image)

A deep CNN works by modeling small pieces of information, consecutively, in a process called deep learning. This implies it can cover a wide range of image variations. A CNN typically uses multilayer processing and is more accurate since it continuously learns to extract more meaningful features from an image.

**KEY BENEFITS OF OUR APPROACH**

General practitioners and other caregivers can easily diagnose DR using simple and affordable innovations that have the potential to make a huge impact both on the disease’s social and economic dimensions:

- Early detection of DR can help allow people to retain their sight and enable specialists to focus on treatments.
- Our automatic feature extraction uses deep learning techniques and iterative learning to continuously improve outcomes.
- The overall solution can incorporate customer feedback.
• Our advanced image processing capabilities allow clinicians to work even with low-resolution fundus images.

• Relatively lower cost than manual methods.

• Accuracy of 90% according to our initial pilots, which improves as additional data sets are gathered.

• Highly scalable process with quick response time.

• Solution is extensible (e.g., for detection of glaucoma, retinopathy of prematurity, etc.).

INITIAL RESULTS

Our model was built by applying image preprocessing techniques to a fundus data set from EyePACS using GoogleNet CNN architecture.12

Figure 6 shows the validation accuracy, training loss and validation loss tested against 10,583 EyePACS fundus images with a validation accuracy of 86.3% for a four-grade classification (No DR, Mild/Moderate NPDR, Severe NPDR and PDR).

Charting DR Identification Hits & Misses

![Figure 6]
The DR tool can assist the doctor with patient fundus image analysis, which in turn helps to quickly inform the next steps in the patient’s treatment. Also, doctors can attend to more patients that need attention.

**THE WAY FORWARD**

WHO believes that 80% of all visual impairment caused by DR can be cured with regular screening and early detection. Diabetes mellitus (DM) and its complications including DR has become one of the 21st century’s major health challenges. Emerging healthcare technologies focus on reducing unnecessary visits to medical specialists, minimizing the overall cost of treatment and optimizing the number of patients seen by each doctor. Major vision loss due to DR is preventable with timely remedial intervention like eye exams (including visual acuity testing, tonometry and pupil dilation) and regular screening at the earlier stages by using a DR diagnostic and grading screening tool.

The DR tool can assist the doctor with patient fundus image analysis, which in turn helps to quickly inform the next steps in the patient’s treatment. Also, doctors can attend to more patients that need attention. Note: The tool is not a replacement for a doctor.
Future Roadmap

Advances in mobile hardware and OS support for machine and deep learning are enabling both iPhone and Android smartphones to run stronger forms of AI for offline medical imaging solutions. The iPhone, for example, supports deep learning through its core machine learning framework; Android smartphones support TensorFlow (an open-source software library for machine intelligence).

Many new-age handheld fundus cameras (both mydriatic and non-mydriatic) can be attached directly to iPhone and Android mobile phones. Also, the cost and size of mobile-ready handheld fundus imaging equipment is gradually declining while fundus image quality is improving.

These developments are opening up new possibilities for running DR detection and grading algorithms. These algorithms can either run directly on the fundus camera itself (DR on device) or run on mobile device/desktop (DR on mobile) or on the cloud (DR on the cloud) to provide an immediate outcome.

The new-age, intuitive and less expensive fundus cameras coupled with a device, mobile or cloud DR detection solution are expected to pave a new way of thinking about DR treatment. If proven, this approach could overcome the barriers to reaching more diabetic patients and provide regular DR screening checkups worldwide.

FOOTNOTES

11. ufldl.stanford.edu/tutorial/supervised/ConvolutionalNeuralNetwork/.
REFERENCES


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ABOUT THE AUTHORS

Gundimeda Venugopal
Lead, Cognizant’s Cognitive Computing & Data Sciences Lab

Gundimeda Venugopal leads the Cognitive Computing & Data Sciences Lab’s research team within Cognizant’s Global Technology Office. He has more than 23 years of IT industry experience in the areas of enterprise architecture, large-scale application and framework development, artificial intelligence, machine learning, NLP, web spidering, information extraction, computer vision, speech processing, biometrics, enterprise search, object-oriented design, web development, middleware, databases/LDAP, performance tuning, embedded systems, networking, protocol design and in-support systems. Venu was the solution architect for multiple large-scale application development projects. He received a B.Tech. in electrical and electronics engineering from J.N.T.U College of Engineering, Kakinada, and an M.Tech. in computer science from Jawaharlal Nehru University, New Delhi. He has filed two patents, written articles for three research publications and won two innovation awards. Venu delivered guest lectures in the areas of digital communications (IIIT, Gwalior) and e-governance (IIM, Bangalore). He can be reached at Venugopal.Gundimeda@cognizant.com | Linkedin: www.linkedin.com/in/venugopalgundimeda/.
Ramakrishnan Viswanathan is a Manager of Business Development within Cognizant's Cognitive Computing & Data Sciences Lab within the company's Global Technology Office, focusing on AI ML services and emerging technologies. In addition to his time spent in GTO and Cognizant’s Application Value Management Practice, Ram has over 13 years of experience in pre-sales, strategic partnership, business development, client relations and business analysis for Cognizant’s strategic engagements. He has an executive program in sales and marketing (EPSM) degree from Indian Institute of Management, Calcutta (IIMC). Ram has also published compelling point of views on AI and cognitive technology. He can be reached at Ramakrishnan.Viswanathan@cognizant.com | LinkedIn: www.linkedin.com/in/ramakrishnanviswanathan.

Rajkumar Joseph is an Architect within Cognizant’s Cognitive Computing & Data Sciences Lab within the company’s Global Technology Office. He has over nine years of experience in innovation, research and product development in computer vision, artificial intelligence, data science, mobile computing and IoT. Rajkumar received an M.Tech. in industrial mathematics and scientific computing from Indian Institute of Technology Madras (IITM) and completed an executive program in business analytics (EPBA) from Indian Institute of Management, Calcutta (IIMC). With a multidisciplinary academic background, he has filed eight patents, written articles for three research publications and won three innovation awards. Rajkumar can be reached at Rajkumar.Joseph@cognizant.com | LinkedIn: www.linkedin.com/in/rajkumar-j/.
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