Hardik Patil

Predicting difficulty of an Endodontic Case using Neural Networks

Problem statement

Endodontic treatments act as a successful conservative treatment plan in several cases. But, it can fail due to multiple reasons that a general dentist is unable to foresee before initiating the treatment or due to conditions that may not be controllable by the dentist. This often leads to retreatment, referral to an endodontist or extraction of the tooth. In order to avoid such failures, prompt referral of the case to an endodontist is required after assessing the case. Machine Learning (ML) is becoming the new frontier of technological advancements in dentistry. Predictive algorithms have been employed in various domains to come to the aid of experts in the said domain. Utilizing the American Association of Endodontists' (AAE) Endodontic Case Difficulty Assessment Form, which is a standard used to assess an endodontic case, ML algorithms are proposed to make a decision whether the case should be referred to an endodontist before initiating the treatment.

Introduction

The most important part of any successful dental procedure is careful diagnosis and treatment planning. Through proper assessment of a case, a dentist recognises the difficulties associated with the successful treatment of the case, and understands the risk of an inadvertent failure of the case can be prevented by referral to a specialist. A poor case selection leads to an endodontic failure. Dentists usually rely on clinical evaluations, radiographs and their experience for treatment planning of an endodontic case. Often a clinician faces a dilemma whether referral to an endodontist is required or not. The American Association of Endodontists (AAE) Case Difficulty Assessment Form is a standard form used to collect data related to a case, which makes it possible to misdiagnose and mistreat a patient. It allows a dentist to perform proper case selection- based upon his or her skills, experience and comfort level. In this manner, cases that are beyond the experience and comfort level of a general dentist can be referred to an endodontist to manage the patient's endodontic needs and assure delivery of effective endodontic care.

Technology has proven to be a boon in various domains of medical treatment. Machine Learning, is a domain that aims at building self-learning algorithms, which can improve with experience. It has been finding a large number of applications in medical treatment since its inception, to assist the physician in diagnosis. The general principle about learning in terms of medical treatment is, to collect diagnostic knowledge from the previous cases, apply it on new patients to assist the physician and increase speed of diagnostic phase. Machine is becoming a new frontier for use of technology in dentistry. Primarily, in the diagnostic phase to reinforce decisions of a dentist, to train students and to aid non-specialist dentists. In this study, Machine Learning algorithms are fed with patient records collected using the AAE Case Difficulty Assessment Form along with an expert's decision for each record concerning the referral of the patient to a specialist. The algorithm learns from the given data and derives a classifier which can be used to make decisions for new patients in future. Machine Learning algorithms are predictive and have a level of accuracy associated with its predictive quality. Even though the accuracy may not have a perfect score, they do give acceptable results provided the training was done using quality data and correct algorithm was selected based on the type of features found in the data.

Dataset

The dataset used in this study has been acquired from Nair Hospital Dental College's Endodontics Department with the approval of the ethics committee. It is a set of anonymous records of root canal patients' pre-treatment assessments along with a tag whether they were referred to a specialist or not. The dataset is realized from the AAE form by considering each question on the form as a feature, making it 17 features. The columns are given weights as per its severity to finally sum up and get a numeric value for each of the 17 features, as listed

Features

1. Medical History
2. Anesthesia
3. Patient Disposition
4. Ability to open mouth
5. Gag reflex
6. Emergency condition
7. Diagnosis
8. Radiographic difficulties
9. Position in the arch
10. Tooth isolation
11. Crown morphology
12. Canal and root morphology
13. Radiographic appearance of canal(s)
14. Resorption
15. Trauma history
16. Endodontic treatment history
17. Periodontal-Endodontic condition

Target

1. Refer to specialist or not

The dataset contains 324 instances and it will be split randomly into 80-20% to generate training and test set. The dataset contains no missing values.

Tools and Algorithms

TensorFlow

TensorFlow is an open source Machine Learning API available majorly for Python and Go. It provides a vast number of complex calculation APIs and canned ML algorithms to use and takes care of the optimization of the calculations to produce results as fast as possible. TensorFlow can be installed for Python using **pip**, the Python package manager.

```
pip install tensorflow
```

TensorFlow has the ability to take advantage of GPU if present on a system. To do so, TensorFlow binary has to built from its source code openly available on GitHub, the build is dependent on **Bazel** which runs on Linux and Darwin operating systems. Running TensorFlow on GPU increases the speed of training by many folds.

TensorFlow can be used for Inference/ Prediction in Java. To export a TensorFlow model so as to use it in Java or any of the supported languages, the canned ML algorithm estimators give a predefined function. The model gets saved as a graph along with information about the variables in the graph. In Java, training is not possible so it would be a good practice to make this model constant (freezed). Freezing a model converts all variables into constants and gives a single graph file which for most of the cases is very compact, rarely penetrating into the MegaByte values.

DNNClassifier

This is one the available canned estimators in TensorFlow which provides a high level of abstraction with respect to its internal working. Even so, the network created is highly configurable. A DNNClassifier is basically a fully connected neural network with zero or more possible hidden layers. The activation functions, and optimization algorithms can be chosen from a wide variety. It handles the pain of saving checkpoints and model graphs automatically during the training and utilizes them on retraining by default.

Our network has an input layer with 17 input features and the output layer has one neuron making binary classifications. There are two hidden layers each with 5 neurons.

The hidden layers use the ReLU activation function which is given by

$$f(x) = x^{+} = \max(0, x)$$

The function basically makes all negative inputs as zero and keeps positive inputs as is. So the range of output will be [0,inf)

The optimization algorithm used to minimize the loss function is Adagrad Optimizer which is known to be best suitable for Neural Networks. Initial learning rate fed to the optimizer was 0.1 and Adagrad Optimizer reduces the learning rate as it closes into a minima while optimizing.

Learning happens over epochs inside a deep neural network when error is back propagated to adjust the weights of connections between neurons of adjacent layers. Our algorithm uses 1000 epochs over the training set and is analyzed for accuracy over the blind test set. The learning happens over mini batches of input data, the batch size used in this model is 128.

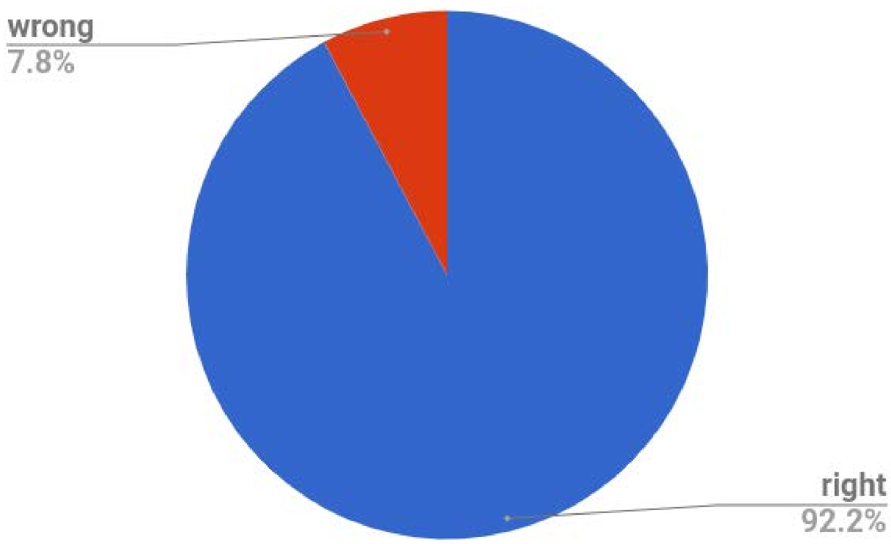
Android

The GUI of our application is built as an Android app using Java which is fed with the frozen model graph. It provides the same AAE form as an interface to make predictions for future patients. Patient information is sensitive and this application cannot be used for fun, hence security is taken into consideration and a Firebase powered backend regulates authorized access to the form and the ML model.

Analysis

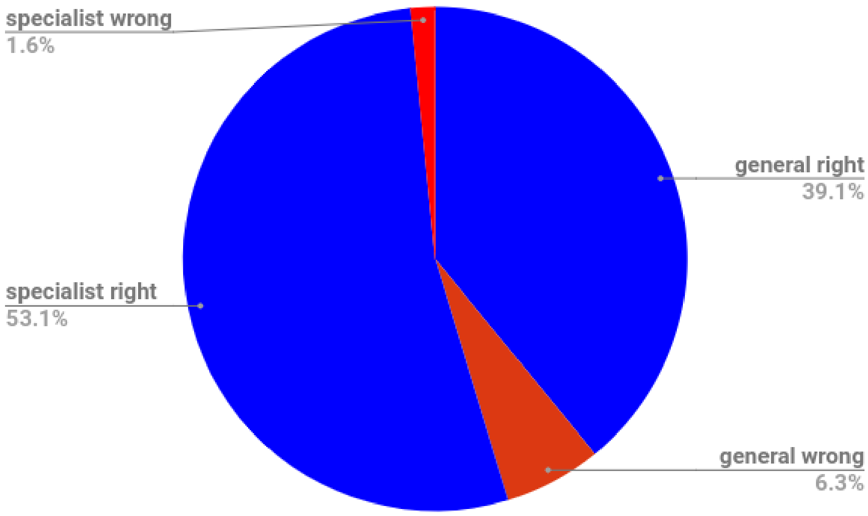
Accuracy

The accuracy achieved by our neural network can be observed in the following graph. The graphs were prepared from results obtained over the blind test set which can be a good approximation for unseen future patients. Since the dataset is split randomly each time training happens, the accuracy changes in the range of 89%-96%.

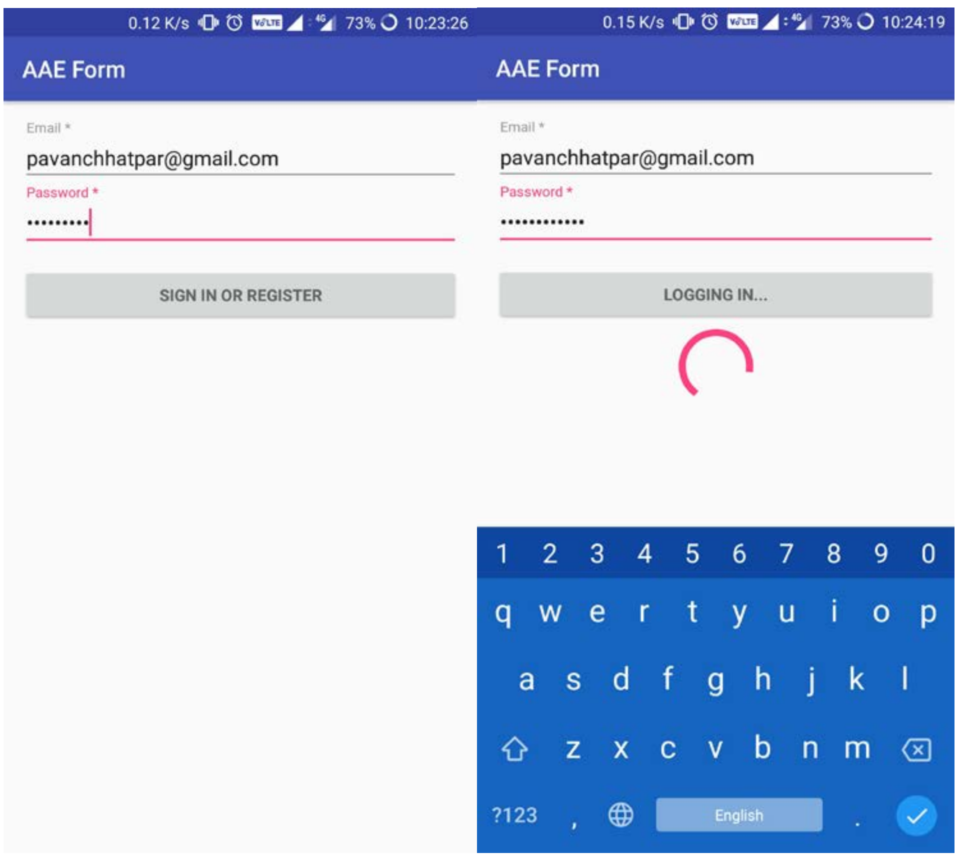


Distribution

On closer analysis from the perspective of practical usage, just an accuracy figure is not enough. True accuracy lies in misclassifying patients which are to be ideally referred to a specialist as less as possible. In other words, false negatives should be minimum. If a patient not needing a specialist gets referred to a specialist then the scenario is not so bad, the patient will get a better quality treatment. Our algorithm has performed well on these parameters too and the previous graph has been split to give details of the results in the following graph.



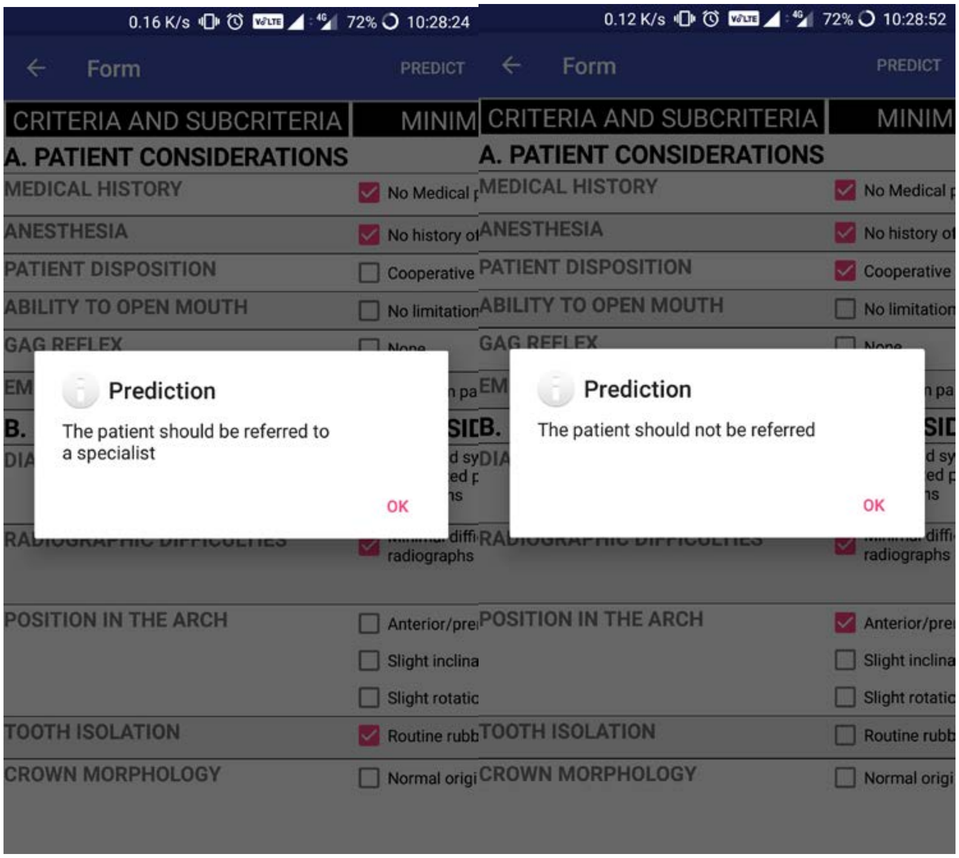
GUI Screenshots



Hardik Patil

Form PREDICT

CRITERIA AND SUBCRITERIA	MINIMAL DIFFICULTY	MODERATE DIFFICULTY	HIGH DIFFICULTY
A. PATIENT CONSIDERATIONS			
MEDICAL HISTORY	☐ No Medical problem (ASA Class 1*)	☐ One or more medical problems (ASA Class 2*)	☐ Complex medical history/serious illness/ disability (ASA Classes 3-5*)
ANESTHESIA	☐ No history of anesthesia problems	☐ Vasoconstrictor intolerance	☐ Difficulty achieving anesthesia
PATIENT DISPOSITION	☐ Cooperative and compliant	☐ Anxious but cooperative	☐ Uncooperative
ABILITY TO OPEN MOUTH	☐ No limitation	☐ Slight limitation in opening	☐ Significant limitation in opening
GAG REFLEX	☐ None	☐ Gags occasionally with radiographs/ treatment	☐ Extreme gag reflex which has compromised past dental care
EMERGENCY CONDITION	☐ Minimum pain or swelling	☐ Moderate pain or swelling	☐ Severe pain or swelling
B. DIAGNOSTIC AND TREATMENT CONSIDERATIONS			
DIAGNOSIS	☐ Signs and symptoms consistent with recognized pulpal and periapical conditions	☐ Extensive differential diagnosis of usual signs and symptoms required	☐ Confusing and complex signs and symptoms: difficult diagnosis ☐ History of chronic oral/facial pain
RADIOGRAPHIC DIFFICULTIES	☐ Minimal difficulty obtaining/interpreting radiographs	☐ Moderate difficulty obtaining/interpreting radiographs (e.g., high floor of mouth, narrow or low palatal vault, presence of tori)	☐ Extreme difficulty obtaining/interpreting radiographs (e.g., superimposed anatomical structures)
POSITION IN THE ARCH	☐ Anterior/premolar ☐ Slight inclination (<10°) ☐ Slight rotation (<10°)	☐ 1st molar ☐ Moderate inclination (10-30°) ☐ Moderate rotation (10-30°)	☐ 2nd or 3rd molar ☐ Extreme inclination (>30°) ☐ Extreme rotation (>30°)
TOOTH ISOLATION	☐ Routine rubber dam placement	☐ Simple pretreatment modification required for rubber dam isolation	☐ Extensive pretreatment modification required for rubber dam isolation
CROWN MORPHOLOGY	☐ Normal original crown morphology	☐ Full coverage restoration ☐ Porcelain restoration ☐ Bridge abutment ☐ Moderate deviation from normal tooth/ root form (e.g., taurodontism, microdens) ☐ Teeth with extensive coronal destruction	☐ Restoration does not reflect original anatomy/alignment ☐ Significant deviation from normal tooth/ root form (e.g., fusion, dens in dente)
CANAL AND ROOT MORPHOLOGY	☐ Slight or no curvature (<10°) ☐ Closed apex (<1 mm in diameter)	☐ Moderate curvature (10-30°) ☐ Crown axis differs moderately from root axis. Apical opening 1-1.5 mm in diameter	☐ Extreme curvature (>30°) or S-shaped curve ☐ Mandibular premolar or anterior with 2 roots ☐ Maxillary premolar with 3 roots ☐ Canal divides in the middle or apical third ☐ Very long tooth (>25 mm) ☐ Open apex (>1.5 mm in diameter)
RADIOGRAPHIC APPEARANCE OF CANAL(S)	☐ Canal(s) visible and not reduced in size	☐ Canal(s) and chamber visible but reduced in size ☐ Pulp stones	☐ Indistinct canal path ☐ Canal(s) not visible
RESORPTION	☐ No resorption evident	☐ Minimal apical resorption	☐ Extensive apical resorption ☐ Internal resorption ☐ External resorption
C. ADDITIONAL CONSIDERATIONS			
TRAUMA HISTORY	☐ Uncomplicated crown fracture of mature or immature teeth	☐ Complicated crown fracture of mature teeth ☐ Subluxation	☐ Complicated crown fracture of immature teeth ☐ Horizontal root fracture ☐ Alveolar fracture ☐ Intrusive, extrusive or lateral luxation ☐ Avulsion
ENDODONTIC TREATMENT HISTORY	☐ No previous treatment	☐ Previous access without complications	☐ Previous access with complications (e.g., perforation, non-negotiated canal, ledge, separated instrument) ☐ Previous surgical or nonsurgical endodontic treatment completed
PERIODONTAL-ENDODONTIC CONDITION	☐ None or mild periodontal disease	☐ Concurrent moderate periodontal disease	☐ Concurrent severe periodontal disease ☐ Cracked teeth with periodontal complications ☐ Combined endodontic/periodontic lesion ☐ Root amputation prior to endodontic treatment



Conclusion

Thus, we have prepared a prediction model to decide whether an endodontic case should be referred to a specialist or not. To make it easily usable by dentists in practice, a user friendly mobile app has also been prepared to make predictions on input data. The predictive model gives accuracy ranging between 89% - 96%.