ORIGINAL ARTICLE

Machine Learning in Radiology: Applications Beyond Image Interpretation

SA-CME

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Abstract

Much attention has been given to machine learning and its perceived impact in radiology, particularly in light of recent success with image classification in international competitions. However, machine learning is likely to impact radiology outside of image interpretation long before a fully functional "machine radiologist" is implemented in practice. Here, we describe an overview of machine learning, its application to radiology and other domains, and many cases of use that do not involve image interpretation. We hope that better understanding of these potential applications will help radiology practices prepare for the future and realize performance improvement and efficiency gains.

Key Words: Artificial intelligence, machine learning, deep learning, radiology, workflows

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INTRODUCTION

Machine learning is a branch of artificial intelligence that has been employed in a variety of applications to analyze complex data sets and find patterns and relationships among such data without being explicitly programmed [1]. Arthur Samuel was among the first researchers to apply machine learning, teaching a computer to improve playing checkers based on training with a human counterpart in 1959 [2]. Machine learning algorithms analyze data features as inputs, and by the process of iterative improvement can produce linear and nonlinear predictive models that detect signals, classify patterns, or prognosticate outcomes [3]. Machine learning is sometimes categorized into two main types, supervised and unsupervised [4,5]. In supervised learning, the data set is already annotated with ground truth labels from which the algorithm learns. In unsupervised learning, the algorithm detects patterns in data when the outcome is unknown.

There are many types of machine learning algorithms, including artificial neural networks (ANNs), support vector machines, k-nearest neighbors, and random forest [4,6,7]. More recently, there has been a resurgence of interest in multilayered or deep ANNs, given their ability to work well with complex and high-dimensional data sets [8].

The relatively recent success of machine learning, particularly ANNs, can be attributed to three primary factors: (1) availability of Big Data—very large data sets that exceed the capability of conventional data analysis; (2) requisite parallel processing power that exists in

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modern-day graphics-processing units, which facilitates training of modern machine learning algorithms; and (3) advanced deeper algorithms and optimization techniques for training [9-11].

Machine learning has been used across many industries, including banking and finance, manufacturing, marketing, and telecommunications [11]. Some more common every day examples include e-mail spam filters, face recognition, search engines, speech recognition, and language translation. Many large capital corporations in the digital world including Microsoft (Microsoft Corp, Redmond, Washington, USA), Google (Menlo Park, California, USA), Apple (Apple Inc, Cupertino, California, USA), Facebook (Facebook, Inc, Menlo Park, California, USA), Baidu (Baidu Inc, Beijing, China), and Amazon (Amazon Inc, Seattle, Washington, USA) incorporate machine learning in their products [12-17].

MACHINE LEARNING WITHIN RADIOLOGY

One recent success in machine learning has been the ability to classify images [7]. Much of this success can be attributed to the availability of large annotated data sets for machine learning researchers. For example, Pascal Visual Object Classes, CIFAR-10, and ImageNet contain up to millions of annotated images. In particular, the ImageNet Large Scale Visual Recognition Competition challenge that began in 2008 has led to breakthroughs in artificial intelligence [18-21]. The use of deep or multilayered ANNs, often now broadly referred to as "deep learning," led to an increase in performance of the top-five accuracy (percent of cases where the answer was within the top-five predictions) from approximately 75% in 2011 to 97% in 2016 [22,23]. Since 2012, all of the winning entries in international challenges have used some variant of deep ANNs, with current accuracy comparable or exceeding human performance.

Machine learning and deep neural networks have had similar success with other high-dimensional complex data sets for performing speech recognition and language translation [15,16]. Accordingly, machine learning has the potential to solve many challenges that currently exist in radiology beyond image interpretation. One of the reasons there is great excitement in radiology today is the access to digital Big Data [9]. Many institutions have implemented electronic health care databases over the past two decades, including for images in PACS, radiology reports and ordering information in Radiology Information Systems, and electronic health records that encompass information from other sources, including clinical notes, laboratory data, and pathology records. Moreover, radiology images themselves are rich in metadata stored in the DICOM format, which may be leveraged as well. As such, there are great opportunities to uncover complex associations within the data using machine learning that would otherwise be difficult for a human to do [24]. This has potential implications for population health, earlier prediction of disease, and improvement in quality, efficiency, and cost-effectiveness of care [25-27].

There are a number of ways in which machine learning can help radiology practices today, including many tasks that are frequently performed by radiologists and ordering clinicians, such as imaging appropriateness assessment, creating study protocols, and standardization of radiology reporting, that could benefit from automation [28-30]. Although many of these examples could be implemented using conventional procedural programming methodologies, the machine learning approach holds the promise to perform these tasks with a higher level of proficiency that can improve over time as the system "learns" new data.

USE CASES IN RADIOLOGY (BEYOND IMAGE INTERPRETATION)

Machine learning has potential to assist radiologists with many of the tasks that they perform in addition to image interpretation, particularly in scenarios in which current IT solutions may not be optimal. The following are some use cases where machine learning technologies can have an impact in radiology. It should be noted that many of the following cases would require clinical validation before use.

Creating Study Protocols

One of the roles of a radiologist is to appropriately create study protocols based on their order indication and other relevant clinical parameters [29]. This involves reviewing clinical and ordering information stored in an electronic health record, referencing relevant lab values, prior images, and radiology reports. This can be a time-consuming but important task. However, recent studies demonstrate that machine learning algorithms utilizing information extracted from the provided study indications can be accurate in determining protocols of studies in both brain and body MRIs [31,32]. Tools like these could be useful and time-saving in clinical practice (Fig. 1).