CORRESPONDENCE

The whole is greater than the sum of its parts: combining classical statistical and machine intelligence methods in medicine

We kindly thank Drs Ramachandran and van den Heuvel for their interest in our article.[1 2] We broadly defined machine learning (the field concerned with algorithms to find structure or patterns in data) as a set of techniques to enable artificial intelligence (the field concerned with programming computers to mimic human intelligence). Methods commonly taught in statistics classes like linear regression, discriminant analysis, principal components analysis, and so on are used to find structure or patterns in data and can be considered as algorithms for machine learning. It is thus difficult to define a fine line between where statistics ends and where machine learning begins—some of the methods have both flavours of both methods. For example, unsupervised machine learning techniques like representation learning, dimensionality reduction and clustering have assumptions influenced by both approaches. We want to emphasise that the difference between what is called statistics, statistical learning, machine learning, data science and artificial intelligence is as much philosophical as it is practical.

We are familiar with the excellent paper by Leo Breiman that differentiates statistics from machine learning.[3] Breiman's paper enumerates two models for analysing data. First, assume a given model structure (eg, Y is linearly related to β multiplied by X) and then use data to find the parameters of that model (find β). Second, assume there is some unknown relationship between X and Y and use an algorithm to most accurately model Y given X. The first is the more traditional statistical approach whereas the second model resembles a more typical machine learning approach. As Breiman notes, the focus on model 1 in the statistical community has 'led to irrelevant theory [and] prevented statisticians from working on exciting new problems.' Machine learning models try to overcome the limitations of traditional statistical models and allow simultaneous assessment of a large number of samples and variables. Poor choice of algorithms and evaluation metrics may either lead to the development of a model that is either too sensitive or specific. While there is no standard operating procedure to develop or evaluate a machine learning model in medicine, it should be noted that machine learning models are error prone. We advocate for developing new reporting guidelines to ensure interpretation, reproducibility and ethical, legal and social implications of machine intelligence models. For example, a general reporting framework is available for high-dimensional statistical model[4] (https://www.equator-network.org/reporting-guidelines/tripod-statement/); such standards are urgently needed for enhancing reproducibility in machine intelligence methods in medicine, including cardiology.

The reason new artificial intelligence, machine learning and deep learning methods (collectively *machine intelligence*) have attained great prominence in recent years is because they have enabled many new and exciting advances in the use of data to solve essential problems which have not been solved with the applications of classical statistical methods. However, we do not view statistics and machine learning as antagonistic, but instead as complementary and continuous depending on the goal. To conclude, as we are getting closer to realising computing systems capable of general intelligence,[5] combining machine intelligence methods with statistical methods could improve diagnoses, interventions and outcomes in the context of all fields of medicine, including cardiovascular medicine.

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