**Network Applications in Earthquake Prediction (1994–2019): Meta-Analytic and Statistical Insights on Their Limitations**

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Abstract

In the last few years, deep learning has solved seemingly intractable problems, boosting the hope to find approximate solutions to problems that now are considered unsolvable.

近幾年，深度學習已經解決表面上棘手的問題，提振希望找到解決現在被認為無法解決的問題的近似解決方案

Earthquake prediction, the Grail of Seismology, is, in this context of continuous exciting discoveries, an obvious choice for deep learning exploration.

地震預測，地震學的聖杯，是在連續興奮發現的景況，對深度學習探勘是一個明顯的選擇

We reviewed the literature of artificial neural network (ANN) applications for earthquake prediction (77 articles, 1994–2019 period) and found two emerging trends: an increasing interest in this domain over time and a complexification of ANN models toward deep learning.

我們複習有關地震預測的人工神經網路應用的文章(77篇，在1944~2019間)然後找到2種新興趨勢:隨著時間推移，在這個領域有逐漸增加的利益和人工神經網路的複雜性朝向深度學習

Despite the relatively positive results claimed in those studies, we verified that far simpler (and traditional) models seem to offer similar predictive powers, if not better ones.

儘管相關正面的結果在這些文章已公布，我們以驗證較簡單的模型似乎提供相似的預測力量，如果不是較好的一個

Those include an exponential law for magnitude prediction and a power law (approximated by a logistic regression or one artificial neuron) for aftershock prediction in space.

那些包含大小預測的指數分布和空間中餘震預測的冪定律

Because of the structured, tabulated nature of earthquake catalogs, and the limited number of features so far considered, simpler and more transparent machine-learning models than ANNs seem preferable at the present stage of research.

因為地震目錄自然列表的結構和到目前為止考慮的功能數量有限，比ANN更簡單透明的機器學習模型似乎在現階段的研究更受喜愛

Those baseline models follow first physical principles and are consistent with the known empirical laws of statistical seismology (e.g., the Gutenberg–Richter law), which are already known to have minimal abilities to predict large earthquakes.

那些基準模型遵守第一原理和統計地震學的已知經驗定律(例如 GR Law)一致，已經知道有最小能力預測大地震

Introduction

Deep learning is rapidly rising as one of the most powerful go to techniques not only in data science(Jordan and Mitchell,2015；Lecun et al,2015) but also for solving hard and intractable problems of physics(Carleo and Troyer,2017；Hen et al, 2018；Pathak et al,2018)

深度學習快速成為一種強力的科技，不只是資料科學還有解決困難棘手的物理問題

This is explained by the greater performance of such techniques to discover hidden patterns in very large data sets. One of the main advantages of artificial neural networks(ANNS), which encompass both shallow and deep neural networks(DNNs), is that they do not require feature extraction and feature engineering, as relatively unprocessed data can be used directly to train the network with potentially very good results.

被這類科技較好的表現解釋，發現大量數據的隱藏模式最主要的優勢之一為ANNs，包含淺層和深度神經網路，他們不需特徵提取和特徵工程，作為相對未處理的檔案可以直接被用於訓練潛在網絡非常好的結果

It is not surprising that machine learning at large-including deep learning has become popular in statistical seismology(Bergen et al,2019; Kong et al,2019) and gives fresh hope for earthquake prediction ,or, more generally, probabilistic forecasts(Rouet-Leduc et al,2017; DeVries et al,2018; Hulbert et al,2019)

機器學習大範圍包含深度學習已經在統計地震學非常熱門和給予地震預測新興的希望，或是更普遍地概率預報

This challenge has long been considered impossible(Geller et al 1997) , although the seismological community has already gone through several cycles of optimism and pessimism over the past decades.

這個挑戰已經長期考慮可能，雖然地震共同體已經走過樂觀與悲觀好幾個周期在過去數十年

It appears that we have now entered a new phase of enthusiasm with machine-learning-based earthquake forecasting, which is reflected by the associated media euphoria.

看來我們現在已經進入了以機器學習為主的地震預報熱情的新階段，體現在媒體的欣喜中

Another boost of activity comes from the generation of improved earthquake catalogs based on convolutional neural network, although the potential use of those “Big Data catalogs” to improver earthquake predictability has yet to be investigated.

另一個活動的促進來自卷積神經網絡的改進地震目錄生成，雖然使用大數據目錄改善地震預測的潛力還有待調查

Given the current rapid expansion of the field, there is a real risk of inflation. It is , therefore, essential to invest a concrete and sober effort to discipline this research sector with technical rigor and baseline model benchmarks.

鑒於該領域的快速發展，有通貨膨脹的實際風險，因此最重要的是必須投入具體而合理的努力，以嚴格的技術和基準模型基準來規範該研究部門

In fact, designing a suitable ANN architecture can be a highly iterative process based on extensive hyper parameterization tuning and some filtering procedures.

事實上，基於廣泛的超參數化調整和一些過濾過程，設計合適的ANN體系結構可能是一個高度迭代的過程

How do such choices affect, not only the model performance, but the way the model is physically interpreted? Linked to the flexibility of ANNs and their black-box nature, can we miss critical scientific insights in the modeling process?

這些如何影響?不僅影響模型性能，還影響模型的物理解釋方式與人工神經網絡的靈活性及其黑盒性質有關，我們可以在建模過程中錯過重要的科學見解嗎?

Mignan and Broccardo recently demonstrated that a far simpler model can do as well as, if not better than a DNN, thus providing a preliminary answer to those questions.

Mignan和Broccardo 最近證明，如果不是DNN更好的模型，那麼簡單得多的模型也可以做到，從而為這些問題提供初步答案

That study was, however , limited to the forcasting of aftershocks in space, following up on the study of DeVries.

但是該研究僅限於對空間餘震的預測，對DeVries研究的後續

In the present article, we aim to answer the aforementioned questions by going beyond the study of Mignan and Broccardo, first by providing a comprehensive survey of the ANN-based earthquake prediction literature and second by investigating how simpler models, which can be related to first physical principles, compare to the prediction performances of published neural networks.

在現今的文章，我們為了回答先前所提到的問題，藉由超越Mignan 和Broccardo 的研究，首先對通過基於ANN的地震預測進行全面的調查，其次，研究與第一物理原理相關的更簡單的模型與已發布的神經網絡的預測性能相比如何

We will finally conclude with some recommendations for future uses of a neural network in earthquake predictability research.

最後，我們將對神經網絡在地震可預測性研究中的未來使用提出一些建議