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Earthquake Detection and Forecasting with Machine Learning

1. Background

Impending rupture in man-made structures, natural landslides or earthquake faults is sometimes preceded by slow preparatory strain and increased acoustic emissions. Modern broad-band seismic data records both the very short-lived (seconds to minutes), dynamic rupture instability events and the long-lived (hours), slow deformation instability events during the preparatory or nucleation phase. These processes emit low amplitude signals which can be hidden in plain sight within noisy time series, and difficult to detect with traditional methods. In addition, the precise nature of these emissions and their generating process remain unclear. Recently, machine learning (ML) and specifically convolutional neural networks (CNNs), have shown great potential in revealing patterns hidden in the noise. A few examples of successful seismological applications are opening interesting research avenue. In addition to seismological data from natural events, laboratory experiments performed on rocks provide an opportunity to deepen our exploration of the dynamics of rupture onset, under a controlled and well-monitored environment.

2. Aims and methods

A CNN prototype has been tested at Durham University and has shown promising results in detection and forecasting of both natural earthquakes (a few hours in advance of magnitude 6 events off the coast of Japan) and ruptures in laboratory experimental rock samples. However, the accuracy of the CNN method in locating and in estimating the magnitude of the future event is yet unknown. In addition, it was not tested in many different tectonic environments. The aim of this PhD is to develop and generalise the ML approach for the analysis of seismic signals, to test its generality, and explore the geophysical origin of the detected signal in the framework of the seismic cycle. In addition, the student will investigate the potential integration of the ML in (1) seismic Early Warning protocols, (2) real-time scenarios of probabilistic forecasting and risk mitigation, (3) automation and improvement in the detection, location and classification of seismic events in regional seismic catalogues (it has been shown that up to 60% more events can be detected by using CNN methods).

The student will select seismic data available from the Global Seismic Network broadband stations and accelerometric regional networks, to create a catalogue of earthquake-related signals and classify them by region, type of focal mechanism and depth. The catalogue will then be used to train a CNN and to conduct ML analysis using Multi-Dimensional Scaling and Boosted Learning Trees to classify time windows as possible precursors or back-ground noise.

The target sites will be zones that have high seismic activity and good quality regional seismic data. Examples of optimal target sites are East coast of Japan, West coast of Chile, California.

3. Training

The student will receive training in the following areas:

- Handling of Big Data; source material from public databases; organise and classify seismic events and build a structured catalogue with metadata information.
- Essentials of earthquake source physics and tectonic context where earthquakes happen.
- Use of Python libraries such as Keras for Machine Learning and high-level statistics for advanced analysis of time series.

5. Further reading & information

✦ Ong V., Nielsen S., Giani S., Johnson P. (2022). Detection of earthquake precursors using neural networks. https://essopenarchive.org/doi/full/10.1002/essoar.10511752.2

✦ Galea, A. and Capelo, L. (2018). Applied Deep Learning with Python: Use scikit-learn, TensorFlow, and Keras to create intelligent systems and machine learning solutions. Packt Publishing, 2018.

✦ Goyal, P. and Pandey, S. and Jain K. (2018). Deep Learning for Natural Language Processing: Creating Neural Networks with Python. Apress.

✦ Guerin-Marthe, S., Nielsen, S., Bird, R., Giani, S. & Di Toro, G (2018). Earthquake Nucleation Size: Evidence of Loading Rate Dependence in Laboratory Faults. Journal of Geophysical Research: Solid Earth 124(1): 698-708. https://doi.org/10.1029/2018JB016803

✦ Hulbert, C. et al. (2018). Similarity of fast and slow earthquakes illuminated by machine learning. Nature Geoscience 12: 69-74.

✦ Karim, F. et al. (2018) LSTM fully convolutional networks for time series classification, IEEE access 6, 1662-1669.

✦ Pattanayak, S. (2017). Pro Deep Learning with TensorFlow: A Mathematical Approach to Advanced Artificial Intelligence in Python. Apress.

✦ Rouet-Leduc, B., Hulbert, C. & Johnson, P. A. (2019), “Continuous chatter of the cascadia subduction zone revealed by machine learning”, Nature Geoscience 12(1), 75-79.

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