Predicting Micro-Earthquakes with Deep Neural Networks

Finding the optimal size of recorded seismic waves

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1 Background

Earthquake prediction:

- Minimize damages by sending warnings of earthquakes.
- Done by detecting primary waves generated by earthquakes.
- Faster than shear waves but not destructive..

Micro-earthquake:

- Low intensity earthquakes, below 2.5 magnitude [1].
- More frequent than major earthquakes.
- Important in locations vulnerable to seismic shocks.
- May hint at larger earthquakes [2].
- Data can help model hidden fault lines.

Dataset:

- Recordings of seismic waves from the New Zealand earthquake dataset from 2007 to 2019 [3].

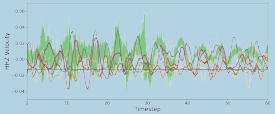


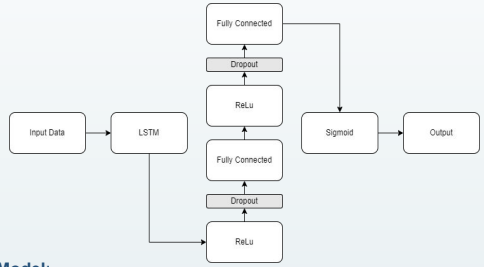
Figure 1: Seismic waves from 5 recording stations from a high magnitude earthquake sample.

2 Main Question

What is the optimal size of recordings for predicting micro-earthquakes?

- Train neural network to predict microquakes three seconds before the impact.
- Understand the relationship between the size of samples and performance of the model.

3 Research Method



Model:

- LSTM based neural network used as a binary classifier.
- Binary Cross Entropy as loss criterion.
- AdamW as loss optimizer.

Dataset:

- Recordings cleaned and standardized.
- 10'000 events, 50% micro-earthquakes, 50% calm periods.
- Recordings of vertical waves from 38 recording stations.

Parameters to optimize:

- Length of the recording T (seconds)..
- Sampling rate of the recording HZ.

Experimental settings:

- 1000 epochs.
- 60% training, 20% validation, 20% test.
- Samples stratified and shuffled.

Evaluation:

- Perform grid-search over T and HZ.
- Compare test accuracy and variance.
- Analyze precision and recall values.

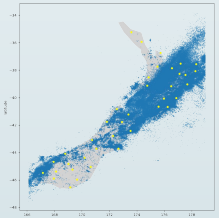
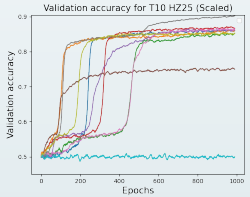
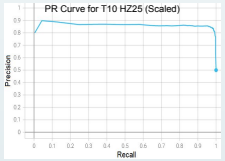


Figure 2: Distribution of the 38 stations across New Zealand (yellow dots) as well as earthquake distribution (blue marks).

4 Results





- No benefit from larger sample sizes.
- All parameters can reach high accuracy.
- Best parameters are:
  - T10 and 25HZ (250 data-points)
  - Variance is due to low learning rate.
  - Can reach high recall value.

5 Discussion

- Model can predict microquakes with very small samples.
- Primary waves can be detected very close to the shear waves in the recordings.
- Microquakes in the dataset are all close to the recording stations and most microquakes go undetected.

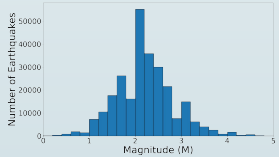


Figure 3: Magnitude distribution of earthquakes in the dataset.

6 Conclusion

- Because of the low strength signal of microquakes, wide networks of stations are required.
- Bottleneck for detecting microquakes on a large scale is in the coverage of recording stations.

Future work: explore how far in the future microquakes can be predicted while using small sample sizes.

[1] S. M. Mousavi, W. L. Ellsworth, W. Zhu, L. Y. Chuang, and G. C. Beroza, "Earthquake transformer - an attentive deep-learning model for simultaneous earthquake detection and phase picking," Nature Communications, vol. 11, no. 1, p. 3952, Aug. 2020, number: 1 Publisher: Nature Publishing Group. [Online]. Available: https://www.nature.com/articles/s41467-020-17591-w
[2] "Microquakes May Hint at the Big Ones." [Online]. Available: https://www.science.org/content/article/microquakes-may-hint-big-ones
[3] "GeoNet FDSN webservice." [Online]. Available: https://www.geonet.org.nz/data/tools/FDSN