Seismic Phase Picking with Deep Learning

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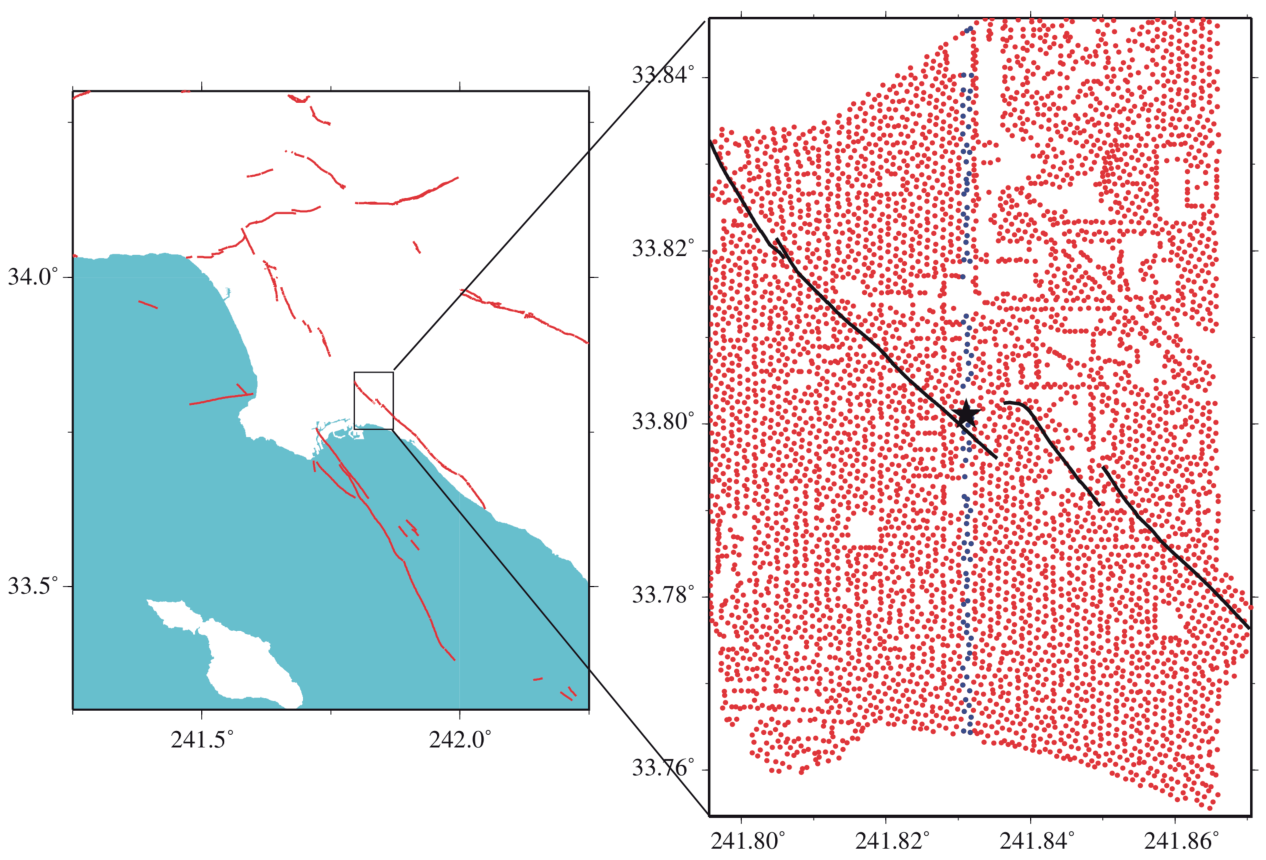
Motivation

Introduction

The popularisation of the use of large-N arrays of seismometers has resulted in a significant increase of the size of the datasets recorded during these experiments. Therefore, new challenges have arisen on how to process all these data efficiently, and in an automated fashion. This is particularly true in the case of induced seismicity monitoring, where often a large number of number of events are recorded at high frequency sampling rates.

Latest development in computational power and the popularization of GPUs have made possible to apply machine learning methods to several problems, from arrival picking and phase detection to earthquake location.

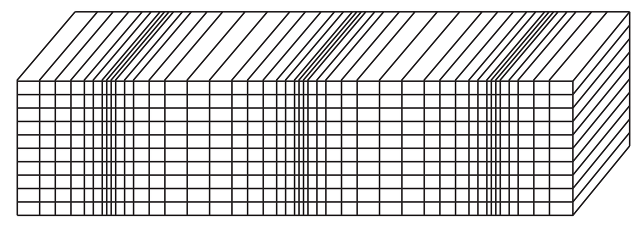
These methods have shown better results than other automatic pickers based on signal amplitude or high-order statistcs.



Example of network of large-N stations: 5300 3-component stations. 10 km x 7 km

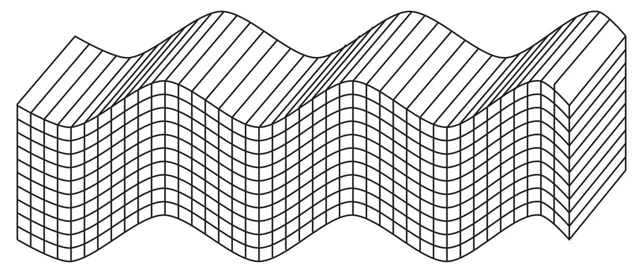
Body Waves

Primary (P) Waves



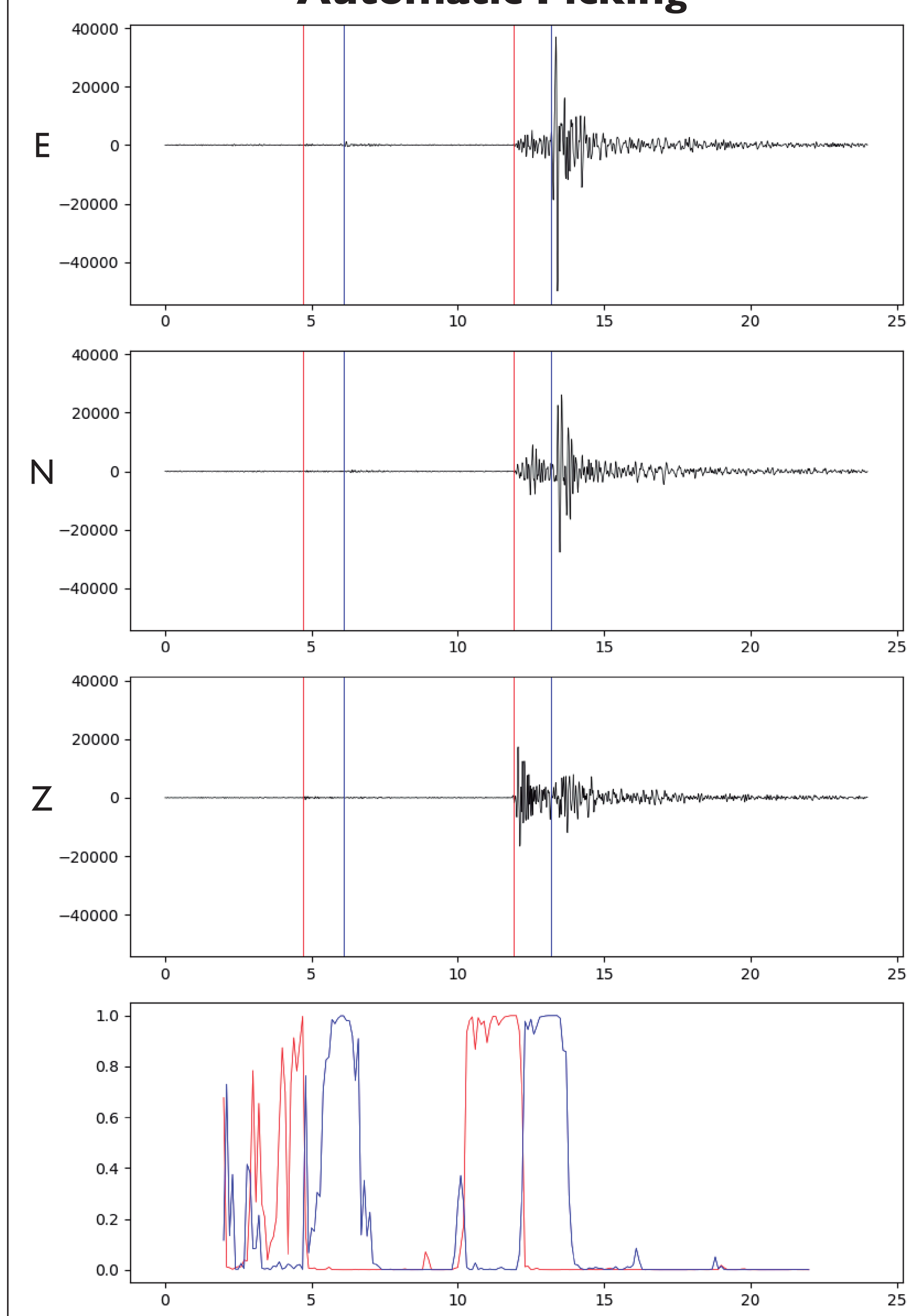
Longitudinal, compressional waves
Vibration in the direction of propagation
Faster waves, arrive first at stations

Secondary (S) Waves



Transversal, shear waves
Vibrate perpendicular to the direction of propagation
Slower than P waves, arrive later at stations

Automatic Picking



Horizontals and vertical components of a seismogram and probability of detection of P (red) and S (blue) waves

A Simple Model Developing

Development of a simple model using convolution layers, widely used in computer vision problems, due to the visual nature of phase picking when performed by an operator.

Layers used

Convolution:
    learns local patterns
    deeper layers learn complex patterns

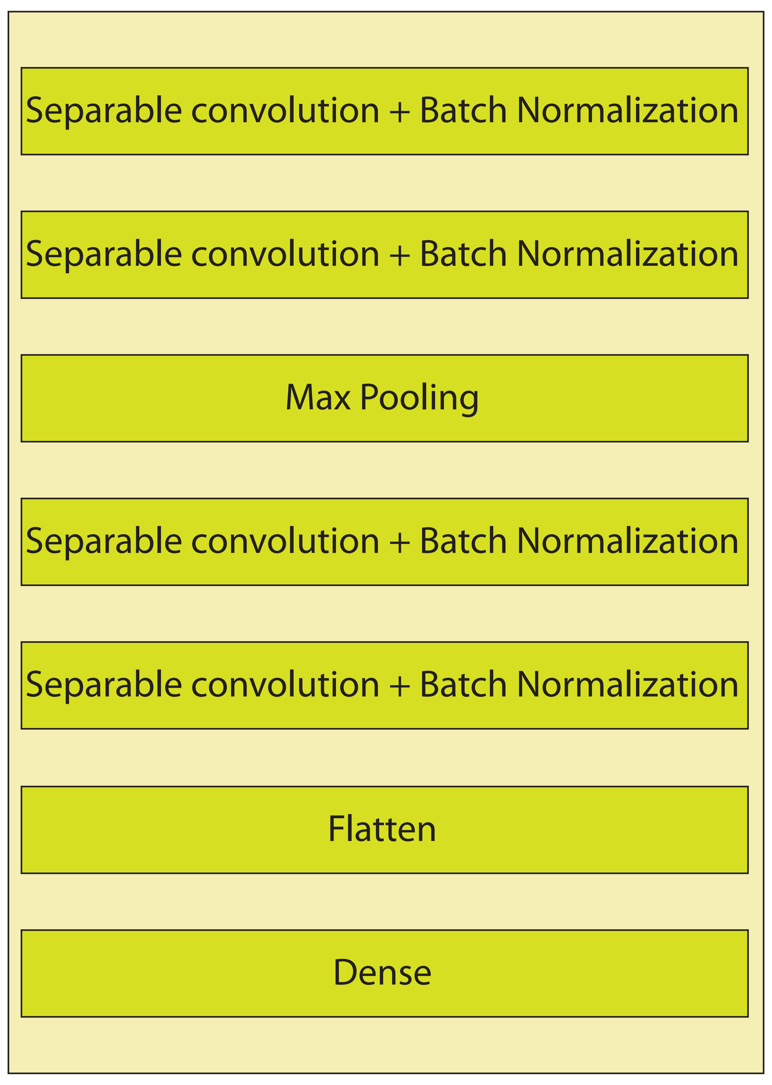
Batch normalization:
    allows deeper networks

Max Pooling:
    filters less significative values

Flatten:
    connects convolutional and dense layers

Dense:
    used as a classifier

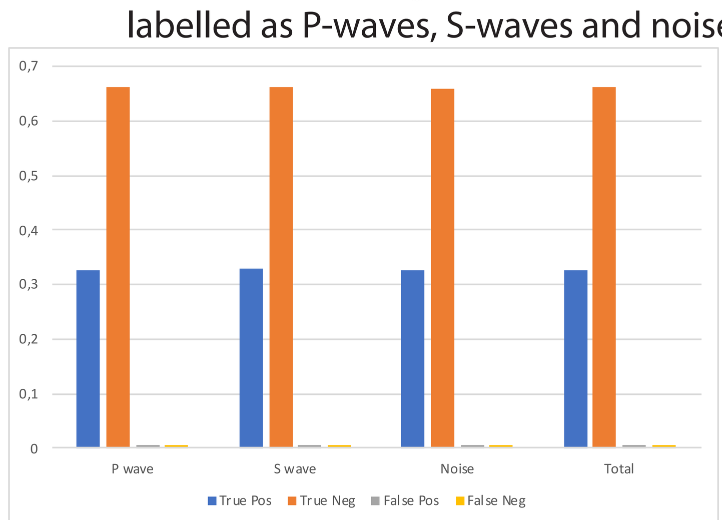
Model architecture



Architecture of the convolutional network developed

Network Training

Dataset (Southern California):
4.8 Million seismograms
labelled as P-waves, S-waves and noise



Values of True Positive, True Negative, False Positive and False Negative obtained during the testing

Data divided into:

Training data:	70%
Validation data:	10%
Test data:	20%

Results over test data:

Accuracy:	98,3%
False positives:	~0,5%

Picker Performance

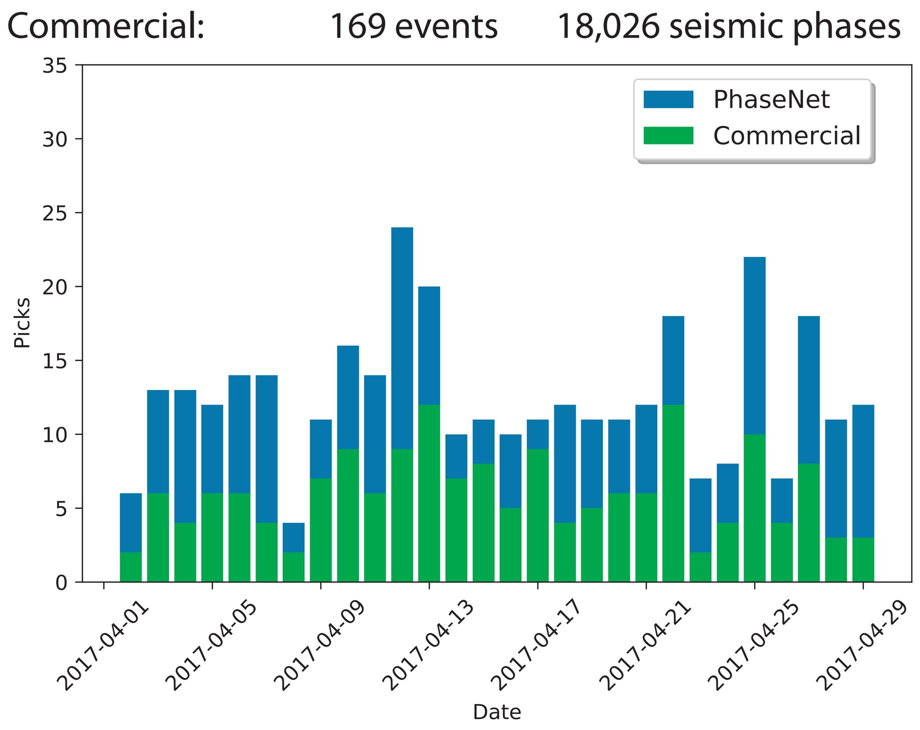
Comparison with non Deep Learning picker

To evaluate the performance of Deep Learning pickers a test has been conducted using the continuous recording data of a large-N experiment with 441 stations on western Pyrenees during 4 weeks.

The data was processed using a DL picker (PhaseNet) and a modern commercial picker based on high-order statistics.

In order to select picks that are compatible with seismic events an associator was used in both cases.

- PhaseNet:	352 events	64,595 seismic phases
- Commercial:	169 events	18,026 seismic phases

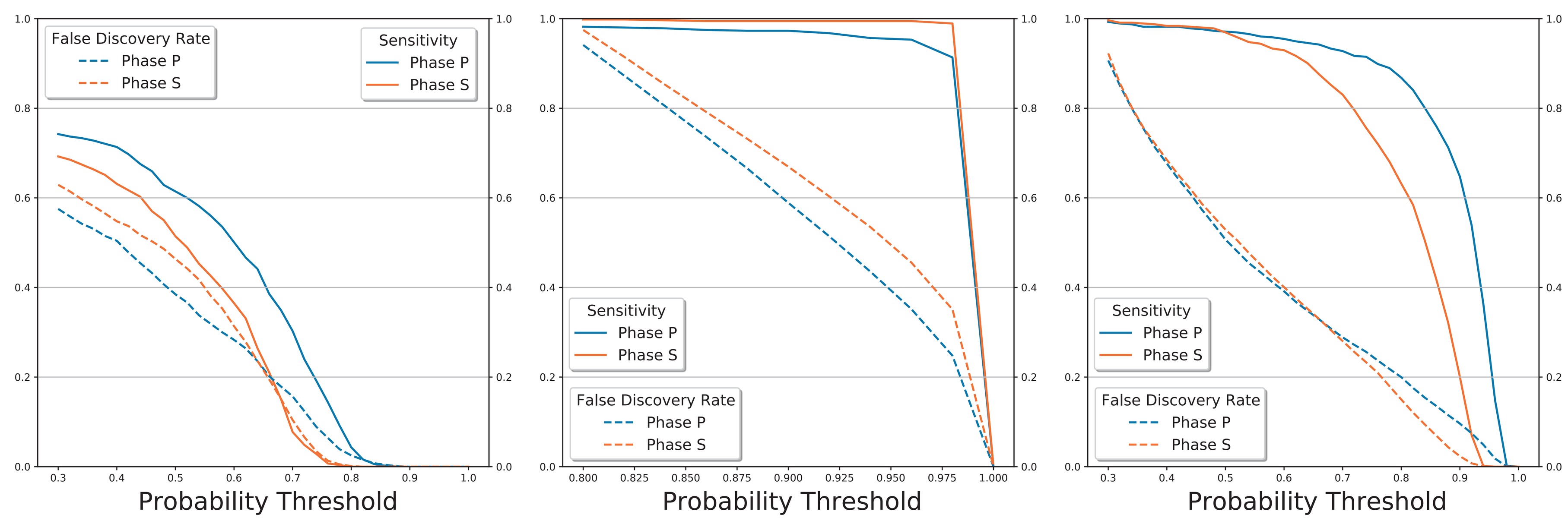


Detected picks using a Deep Learning and a commercial picker

Different Deep Learning Pickers Comparison

Different pickers have been compared using data from a seismic crisis of induced earthquakes in the vicinity of the CASTOR underground gas storage.

The obtained picks were compared with the dataset labelled by hand by a human operator.

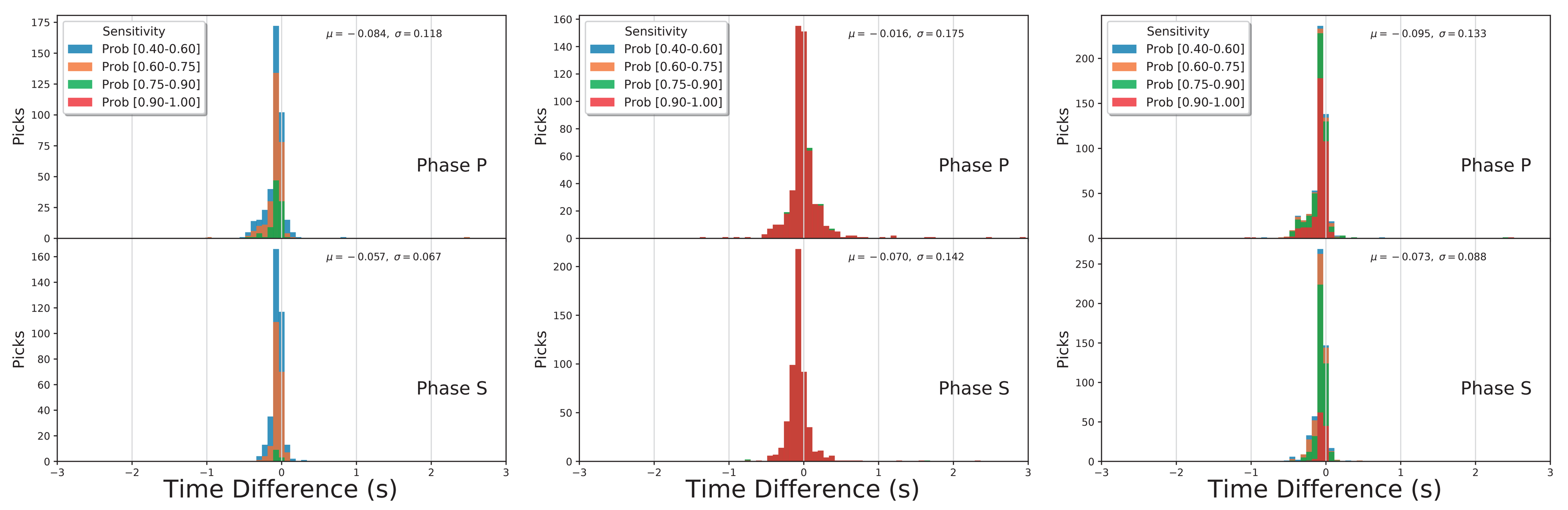


Metrics :

· Sensitivity: $\frac{\text{True positives}}{\text{Total picks}}$

· False discovery rate: $\frac{\text{False positives}}{\text{Total picks}}$

· Time difference between DL and human picks



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