Using LSTM network to identify P- and S-wave arrivals in seismic data
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Project

How to explore large basin efficiently with limited 1D-2D data?

Proposition:
Use passive sources of energy to image 3D volume and stitch together 1D-2D data.

Outcomes:
1. Quick (months not years)
2. Relatively cheap
3. Multiple data sets
4. Integrate all data in 3D
5. Sweet-spot basin
6. Environmentally friendly
Project

Gravity and magnetics

Solar wind and lightning
- Present everywhere
- MT used in industry many decades

Earthquakes and ocean noise
- Earthquakes image entire crust
- Ocean noise image upper crust

Human-generated noise
Project

Early Integration → Reduced Risk
Increased POS → Reduced Costs

- Passive-source seismic
- Gravity gradiometry
- Magnetotellurics
- Landsat / Field

Better Geology Models

- 2D seismic surveys
- 3D seismic surveys
- Drilling
Project

One earthquake

Three earthquakes

100s of earthquakes

(# earthquakes) * (# nodes) = # raypaths

Velocity cube derived from raypaths (tomographic imaging)

(Figures from Robert Clayton’s CalTech web site)
Project

Where would you drill?
Regional Survey
■ 500 km² area
■ 390 nodes
■ 3 months
Data from one node

Geophone Spatial Array

P-wave

S-wave

Horizontal 1

Δt

Horizontal 2

Vertical

Y Coordinate

X Coordinate

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Problem

Extreme amount of data

- 286 local earthquakes used in initial study
- 63,000 picks (+37k P-waves, +25k S-waves)
- Picked manually (> 5 months of effort)
- Much data from 286 left unpicked (> 68%)
**Solution**

Use a deep learning approach to problem
- Specialized form of machine learning
- Model learns directly from raw data
- Scales with data; avoids saturation
- Potential to use in other areas once trained

Turned to Mathwork’s specialists
- Software readily accessible to novice
- Mathwork’s staff are experienced in deep learning
- Shell already had working relations with Mathworks
- Staff very easy to work with and customer centric
Data preparation

(1) Use 3 component data (⇒ 3 features)

(2) Parse continuous data into 15s intervals

(3) Divide signal into three classes
   - Pre – signal prior to P-wave arrival
   - Passage – signal between P- and S-wave arrivals
   - Post – signal after S-wave arrival

(4) Normalize amplitudes for each channel
Data preparation

(5) Use data with different signals

- Variable signal-to-noise ratios
- Anthropogenic noise
- Strong events, weak events
- Variable frequency content
- Two different instruments
- Location of earthquakes
Data preparation

(6) Subset data

- Training set – used to train network
- Test set – used during training to modify hyperparameters
- Validation set – not used in training. Analyzed after training to determine how well the network performs.
Network selection

- Mathwork’s staff quickly realized similarities between the earthquake data and human speech!

- Long Short-Term Memory (LSTM)
  - Handles time-series data.
  - Long time durations with no signal, punctuated by short bursts of signal.
  - Uses information from far in the “past” and “present” time frame, hence the reason for the “Long” and “Short” in the name.
  - Used for speech recognition (Amazon Alexa, Apple Siri, Google Translate).
Network selection

bilateral LSTM (location in sequence is “remembered” in network)
Results

Train Geophysical BiLSTM

Accuracy

Loss

Cumulative Probability

P Arrival

Cumulative Probability

S Arrival

Error [in Samples]

30 m error
## Results

### Results from 9 earthquakes

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### Final product is velocity model (geology model)
Generalization
Generalization – Global Earthquakes

Can network trained on Albania earthquakes accurately detect “global” earthquakes?

What’s Different?
1. Geology
2. Instrumentation
3. Duration: 10sec vs 8min
4. Depth: 10km vs 100km
5. Magnitude <1 Mb vs >4 Mb
Generalization – Global Earthquakes

Can network trained on Albania earthquakes accurately detect “global” earthquakes?

What’s Different?
1. Geology
2. Instrumentation
3. Duration: 10sec vs 8min
4. Depth: 10km vs 100km
5. Magnitude <1 Mb vs >4 Mb
Generalization – NAM

Can network trained on Albania earthquakes accurately detect “local” earthquakes from Netherlands?

What’s Different?
1. Mechanism
2. Geology
3. Instrumentation (downhole vs surface)
4. Level of anthropogenic noise
5. Picking of NAM earthquakes done on bandpass-filtered data

Authors wish to acknowledge and thank Shell NAM for providing the NL data and letting us present results at this meeting.
Generalization – Quest CCS

Can network trained on Albania earthquakes accurately detect “local” earthquakes at Quest CCS facility in Canada?

What’s Different?
1. Mechanism
2. Geology (all EQ’s in below reservoir)
3. Instrumentation (downhole vs surface)
4. Level of anthropogenic noise
Generalization – Quest CCS

Excellent results but .....

Authors wish to acknowledge and thank Shell Canada and partners for providing the data and letting us present results at this meeting.
Generalization – Quest CCS

- Accuracy depends VERY STRONGLY on sequence length fed into network.
- We trained Albania on 221 sequence length, but optimal SeqLen for Quest is ~970. Hard to predict in advance!
- Not yet figured out why.
- Might limit applications to new fields?

![Accuracy vs Sequence Length](image)

- SeqLen = 920
  - Passage: 542, Post: 4715, Pre: 4200
  - True Classes: Passage: 95.4%, Post: 100.0%, Pre: 90.9%
  - Predicted Class: 95.9%, 44.1%
- SeqLen = 950
  - Passage: 969, Post: 4715, Pre: 4284
  - True Classes: Passage: 96.8%, Post: 100.0%, Pre: 100.0%
  - Predicted Class: 96.8%, 0.2%
- SeqLen = 1020
  - Passage: 864, Post: 4714, Pre: 4301
  - True Classes: Passage: 98.2%, Post: 100.0%, Pre: 98.1%
  - Predicted Class: 91.2%, 8.8%
- SeqLen = 1050
  - Passage: 852, Post: 4714, Pre: 4305
  - True Classes: Passage: 96.6%, Post: 100.0%, Pre: 98.9%
  - Predicted Class: 96.6%, 100.0%
How much training data is needed?

1% of data

- Train
  - passage: 63760
  - post: 8316
  - pre: 5443
  - True Class: 99.0%
  - Predicted Class: 97.0%
- Test
  - passage: 2544902
  - post: 532136
  - pre: 225148
  - True Class: 95.0%
  - Predicted Class: 99.0%

5% of data

- Train
  - passage: 35500
  - post: 1918
  - pre: 6412
  - True Class: 99.9%
  - Predicted Class: 97.4%
- Test
  - passage: 2605196
  - post: 62826
  - pre: 87319
  - True Class: 97.3%
  - Predicted Class: 94.6%

100% of data

- Train
  - passage: 6124024
  - post: 138789
  - pre: 75995
  - True Class: 99.1%
  - Predicted Class: 96.7%
- Test
  - passage: 2649106
  - post: 85487
  - pre: 39691
  - True Class: 98.3%
  - Predicted Class: 95.6%

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Thank you

Questions?