

Cloud Atlas

An LstmEncoder for UHECR AirShowers

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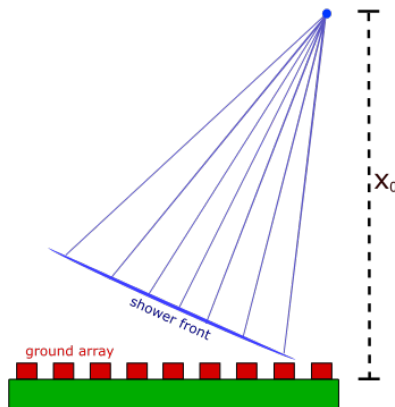
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UHECR Airshower

When *Ultra High Energy Cosmic Rays* (UHECR) enters the atmosphere they produce a particle cascade.

Detection: grid of water-Cherenkov ground based detectors.

Prediction: X_0 height at which the shower forms.



Dataset, first glance

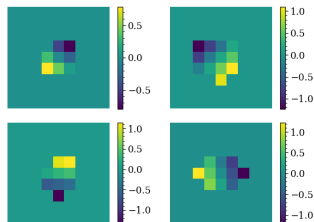
Dataset: 10^5 simulated events:

- 9x9 grid of detectors
- most intense at center
- 80 frames of time series (40 MHz sampling rate)
- 1 frame of times of first arrival

Single record shape: $(80 + 1, 81)$

pd4ml package splits by default in
70% train 30% test

Times of arrival



Detector time series

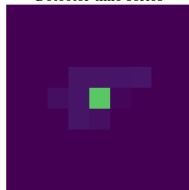


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Split the dataset

Dataset was already split in test and train.

We put it all back together, shuffled it and divided with the following percentage:

- 70% *train*
- 20% *test*
- 10% *validation*

For the design of the net it is convenient using `numpy` structured arrays



Split the dataset: funky_dtype

```
1 # custom numpy dtype
2 funky_dtype = np.dtype(
3     [
4         ("outcome", np.float64),
5         ("time_series", np.float32, (80, 81)),
6         ("toa", np.float32, (9, 9, 1)),
7     ])
8
```

All data relative to a single event is clustered in a single numpy object, transformation is:

$$(80 + 1, 81) \longrightarrow [(\text{"toa"}, (9, 9, 1)), (\text{"timeseries"}, (80, 9, 9))]$$

Data can be accessed "as a dictionary", depending on what is needed.

DataFeeder class

Ensures an easy way to train the subnets separately Class DataFeeder main features:

- shuffles data randomly
- input fields can be specified
- can be extended to more complex training strategies
- returns a generator

Using a generator (`keras.utils.Sequence`)

- inherit multiprocessing features
- has default callbacks
- avoids memory overload

FeederProf (DataFeeder) class

Curriculum learning

Using a pre-trained network data can be “scored” and then sorted in ascending order of difficulty
(work in progress) This can lead to a learning speed-up and improvements in resolution

Caveat: this training strategy is not well suited (conceptually at least) for regression tasks, since it is not clear what a “difficult” sample would look like.

Data Augmentation

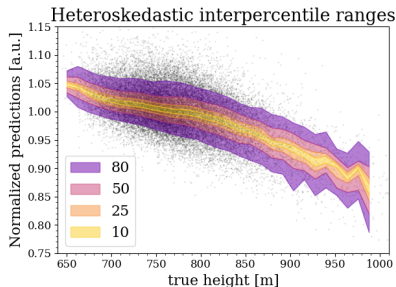
Dataset has a lack of high events ($X > 850\text{m}$) so a first network training showed a worse resolution for samples corresponding to this range

Strategy

Increase the number of samples that overcome a certain height threshold using the symmetries of the problem

Data is augmented using

- flip up-down
- flip left-right
- diagonal flip
- rotation of 90°



Resolution

The reference article suggests using the resolution:

Resolution

defined as the standard deviation of the distribution given by the difference between the predictions and the actual values of X_{max}

We point out that

$$\sigma^2 = \frac{1}{N} \sum_i (\delta_i - \bar{\delta})^2$$

is a sensible estimator of “how much the net has gone wrong” only if $\bar{\delta} = 0$, for which the adopted resolution is equal to the *RMSE* of the distribution

$$RMSE^2 = \frac{1}{N} \sum_i (x_i - \hat{x}_i)^2$$

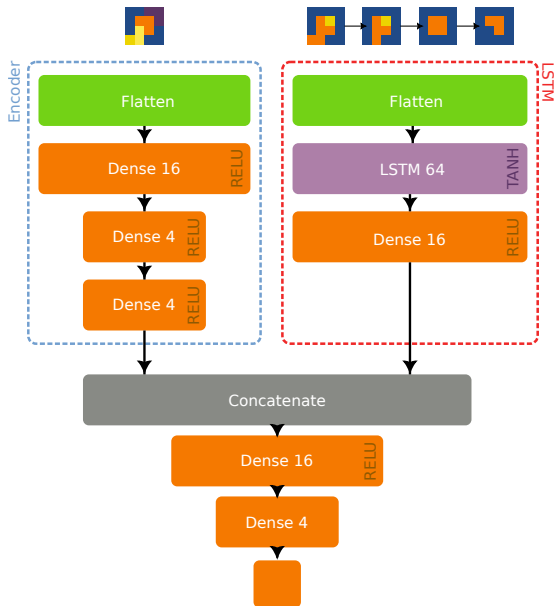
Since (on a typical train) $\bar{\delta} \approx 10m$ we preferred the RMSE.

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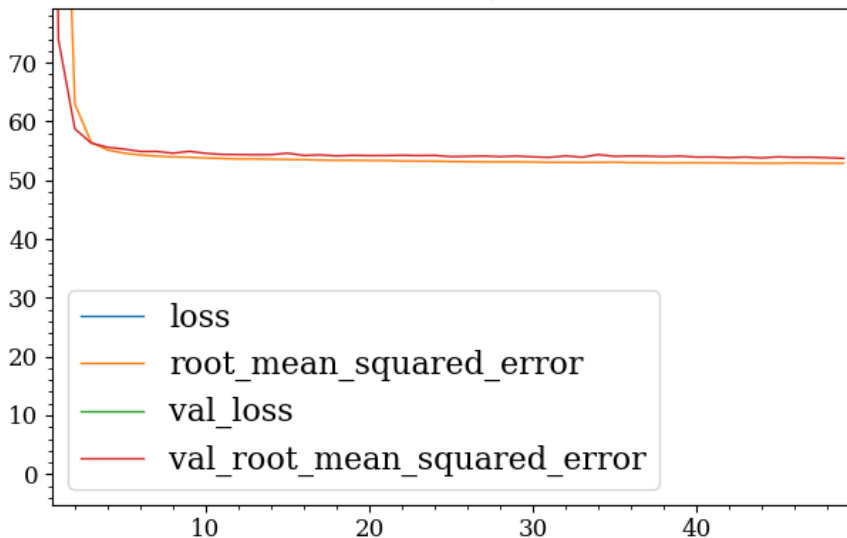
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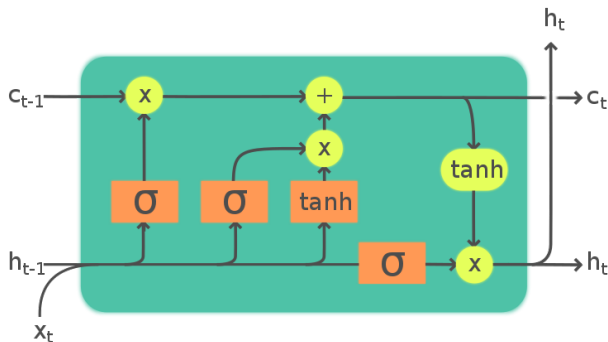
The assumption that lead to this design is that from the time of arrival matrix it is possible to infer some kind of “homogeneous” shower parameters (incidence angle, spread, etc.) while the time series can be processed by a recurrent network.

Model at trained/ToaEncoder

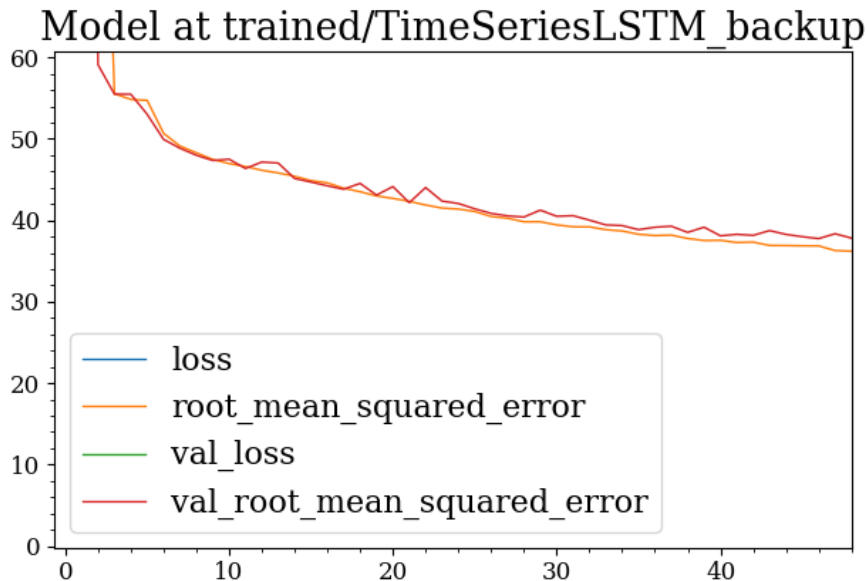


LSTM

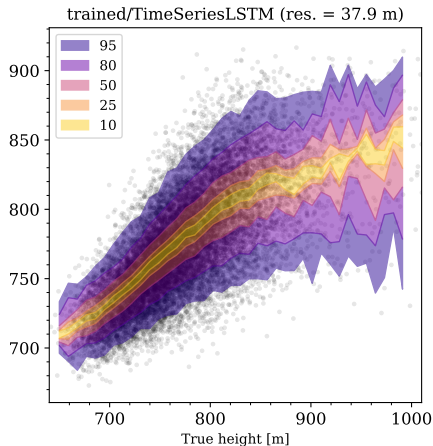
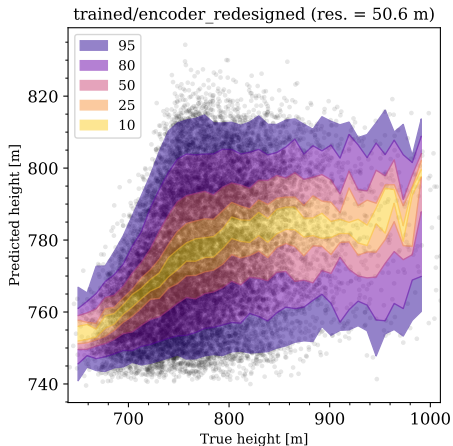
LSTM (*Long Short Term Memory*) cell is a variant of a typical recurrent RNN cell. It is able to learn long-term dependencies that brings along in a hidden state.



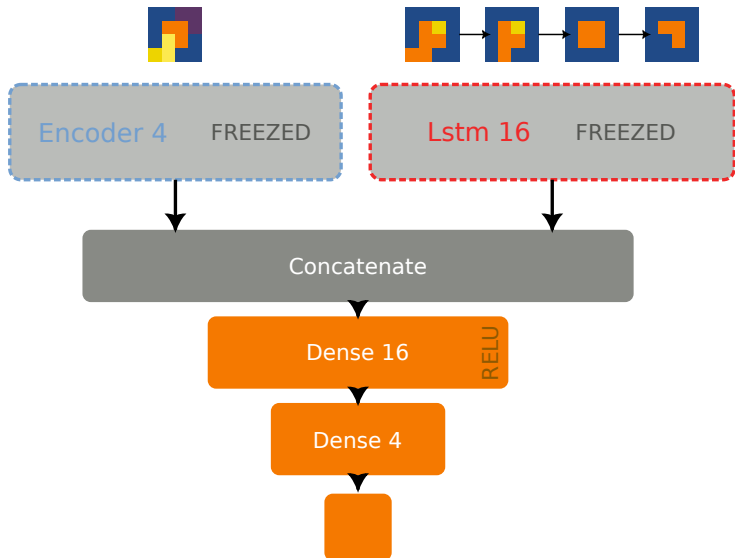
LSTM for the time series



Subnets performance

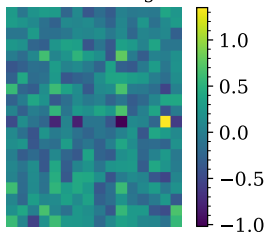


Subnets train freezing

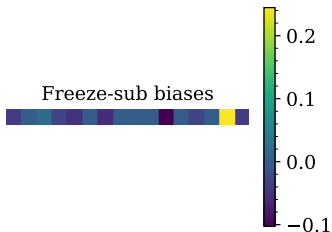


Subnets train freezing

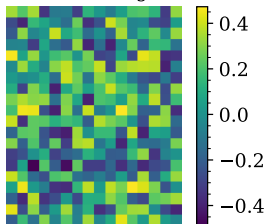
Freeze-sub weights



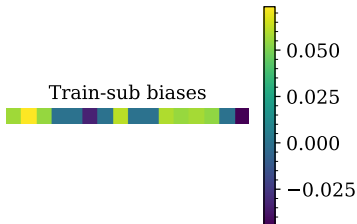
Freeze-sub biases



Train-sub weights



Train-sub biases



Network's output

Hyperparameters tuning

Whole Network performance

Test setup on CircleCI

Danke Schon