dl-assignment-13

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1 Deep Learning — Assignment 13

Assignment for week 13 of the 2023 Deep Learning course (NWI-IMC070) of the Radboud University.

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Instructions: * Fill in your names and the name of your group. * Answer the questions and complete the code where necessary. * Keep your answers brief, one or two sentences is usually enough. * Re-run the whole notebook before you submit your work. * Save the notebook as a PDF and submit that in Brightspace together with the `.ipynb` notebook file. * The easiest way to make a PDF of your notebook is via File > Print Preview and then use your browser's print option to print to PDF.

1.1 Objectives

In this assignment you will 1. Think about the design of deep neural networks on a higher level 2. Read papers that use deep learning in an application

This week's assignment does not involve any programming.

1.2 13.1 Predicting the weather (7 points)

Most people don't like to be oustide in the rain. Fortunately, we nowadays have radar sensors, that can show the amount of precipitation over a wide area in real time. Weather services like buienradar use this data to forecast when it will rain. But the models they use are often quite simple: just move the rainclouds according to the current wind patterns.

In this assignment you will investigate whether you you can do better with deep learning.

More concretely: The task that we have in mind is to predict the amount of rain up to 3 hours in advance, for the entire country of the Netherlands. The input will be radar images of the amount of rain *currently* falling. For training, there is historical radar data going back several years. You may assume that the data has been gathered with a sample rate of 5 minutes, and at a resolution of 1500m per pixel. See the KNMI website for more information.

(a) Are there risks of unfair biases in this task? Explain your answer. (1 point)

No, we cannot think of any.

(b) Suppose we want to use a deep neural network for this task. How would the input data be represented? (1 point)

For now, consider using only the current radar data as input.

A matrix indicating the amount of rain falling at the moment in a specific location.

(c) What are the targets for prediction? How are they represented? (1 point)

The expected amount of rain per pixel, also represented as a matrix.

(d) If we want to make a prediction for the entire country of the Netherlands, how large should the input be to contain all the relevant information? (1 point)

Bigger than the Netherlands, ideally that big that rain popping up on the edge of the observed area takes at least 3h until it reaches the Netherlands.

Rainclouds act differently depending on the terrain. So it can be useful for the model to know which areas of the radar image are above sea, rivers, forests, cities, mountains (as if), etc.

(e) How can you include this information in the input to the model? (1 point)

We could overlay the data with another matrix encoding the underlying terrain as an additional channel.

(f) If information on the type of terrain is not available, could it be learned instead? If so, how? (1 point)

Probably yes, if the network knows the positions of the rain falling (which it does in our representation of the data), it could probably learn how rain is behaving in that specific area. As the positions of rivers and sea do not change (so quickly, hopefully), the network could learn their influence.

The weather also depends on the time of day, in particular on whether the sun is shining. And on the time of year, especially the temperature.

(g) How could the time of day and time of year be given as inputs to the network? (1 point)

We could use positional encoding to add this information to our input matrix.

1.3 13.2 Weather prediction models (4 points)

Consider a model that uses only the current radar data and terrain as input, to predict rain 3 hours in the future.

(a) What kind of model would you use for this task? (1 point)

We expect attention-based models to work best. Transformer networks may be suitable here, especially because they can handle sequential data when using positional encoding.

(b) How would the performance of a model that takes only a single radar image as input compare against the simple baseline model that moves the radar image in the wind direction? (1 point)

No too good, because the AI model does not know in which direction the cloud has moved in the recent past and does not know the wind direction. It may remember in which direction the clouds are typically moving most of the time, but this is not as accurate.

To improve the model, it makes sense to take the temporal aspect into account, by including historical data. So radar scans from 5 minutes ago, 10 minutes ago, etc.

(c) Give two ways to include this additional data into the model. (2 points)

We could use multiple channels or concatenate the different inputs, using positional encoding.

1.4 13.3 MetNet (4 points)

We are not the first people to think about this problem. The paper MetNet: A Neural Weather Model for Precipitation Forecasting has tried to tackle the task of predicting rain from radar images.

(a) Have a look at the MetNet paper and compare their method to your answers in 13.1 and 13.2. What are they doing the same, what are they doing differently? (3 points)

Input encoding: * Similarly to our suggestion, MetNet uses a tensor with the different values for each pixel and multiple channels. We suggested using the channels for the different time slices, while the MetNet paper uses an additional dimension for that.

Output encoding: * Our suggestions do not include reducing the surface area in which we predict compared to the input, while the MetNet paper does this. Similar to our idea, MetNet tries to predict the amount of rain per pixel, but instead of predicting a specific values, MetNet uses 512 bins to put the amount of rain into.

Model: * We proposed using a transformer architecture, while MetNet combines a couple of architectures, namely convolutional, LSTM, and self-attention.

(b) Can the trained MetNet be used in the Netherlands using data from KNMI, without retraining? How? Or why not? (1 point)

No, this does not seem possible for two reasons. Firstly, the area covered by KNMI is less than 1024x1024 square kilometers. The other, more important reason is, that the KNMI data do not include the GOES-16 satellite images used in the dataset. Probably, they aren't existent at all, as the satellite is stationed above the US.

1.5 13.4 MetNet - version 2 and 3 (4 points)

You may have noticed that the MetNet paper came out 3 year ago (you can tell the year from the `/YYMM.NNNNN` arxiv url). After that two new models have been released by the same group: * MetNet-2: Skillful Twelve Hour Precipitation Forecasts using Large Context Neural Networks * MetNet-3: Deep Learning for Day Forecasts from Sparse Observations

(a) What method is used by MetNet-2 to get a larger receptive field in the convolutions? (1 point)

Exponentially increasing dilation factors

(b) How many parameters do the original MetNet and MetNet-3 have? Is one model significantly larger than the other? (1 point)

225M parameters for MetNet 227M parameters for MetNet3

This shows that the number of parameters is essentially the same for both generations of the network.

(c) Estimate how much CO was emitted for training MetNet-3. (2 points)

Hint: You can find information on the power consumption of google TPUs here (the reported numbers are per chip, not per pod).

Hint 2: Make a reasonable assumption for the CO / kwH (see lectures, or here)

$512 \cdot 0.22 \cdot 7 \cdot 24 \approx 19000$ kWh $\Rightarrow$ 19000kWh $\cdot\, 0.25\frac{kg}{kWh} = 47500kg$ of CO_2 equivalent emissions. This corresponds to round about half a rail car of coal.

1.6 The end

Well done! Please double check the instructions at the top before you submit your results.

This assignment has 19 points. Version 6262555 / 2023-12-11