DD2437 Artificial Neural Networks and Deep Architectures (annda22 HT)

Exam 2022-10-24 at 16:00-19:00

Use a separate sheet for each question. Brief and concrete answers are preferred by all means. Do NOT give several mutually conflicting answers to a question (ingen helgardering). If you do, the alternative with lowest score will be chosen.

You are allowed to use your paper notes and a standard English-other language dictionary may be used. Please keep in mind that you are obliged to abide by *the code of honor* at EECS/KTH (https://www.kth.se/en/eecs/utbildning/hederskodex/inledning-1.17237).

To pass the exam with the minimum grade E you must get at least 50% in total (23p). For those fulfilling the criteria for E, additional credits up to the maximum of 46p in total offer the possibility of grades D-A

As previously mentioned, the final course assessment will be produced by summing up your exam points and the bonus lab points (provided that the exam is passed in the same period when the labs bonus points have been obtained), then the resulting sum will be subject to the same grade mapping as for the exam.

Please mark clearly on the answer sheet (front page) that you follow DD2432 course!

For PhD students following this course or DD3432 or DD3437:

Please mark clearly on the answer sheet (front page) that you are a PhD student!

Good luck!

Pawel and Erik

Question 1 (8p)

Hopfield networks can be used as a framework for abstract modelling of the human memory. Let's assume that the memory model should be driven by different sensory inputs, e.g. visual, auditory, somatosensory (sense of touch), olfactory (sense of smell), and should form composite episodic memories (memories of our sensory experience – situations we experience in everyday life). In other words, given a combination of sensory inputs the network memory model should learn this composite input pattern and store it for later recall. Given this modelling specification please answer briefly the following questions about the proposed Hopfield net based memory model:

a) What learning rule would you adopt for your memory model? What are its most defining characteristics? What is the mechanism of encoding a memory (learning a pattern), what does it correspond to, what does learning a pattern imply or what effect does it have on the network (through the weights modified by the learning rule)?

b) Given that the sensory input is a combination of an image (vision), sound (auditory input) etc., how would you interface it with the Hopfield memory model, i.e. what would you feed directly to the Hopfield model? What representations would be particularly desirable and how would you extract them? Please illustrate the overall architecture from the raw sensory input up to the associative memory model.

c) What parameters and characteristics would determine the capacity of your memory model? How would you test the storage capacity in simulations? What would happen if you your memory model was fed sensory inputs to remember beyond its storage capacity?

d) Would your Hopfield model manage to recall a past (stored) memory based on only a partial sensory input, say only visual input without any auditory or olfactory cues, and why? What does it depend on?

Question 2 (4p)

The temperature parameter is one of the key parameters in a Boltzmann machine. Describe what component of the network it is part of and explain what role it plays during the running of the network. In particular, describe what important consequence the parameter and the function it is involved in has on the state of the network. Also, what values does it take during running of the network and what is this kind of procedure of varying the parameter called?

Question 3 (9p)

Your company is manufacturing equipment for analysis of air and, in particular, the presence of solid particles (dust) in the air. Customers are government agencies and companies with the role of monitoring and reporting environmental factors, including cleanliness of air. The air processed by the equipment is fed through a camera-based microscope, which takes images at high resolution. Using a particle detection and image-processing software, each particle detected is measured along a number of features (area, roundness, aspect ratio, solidity, etc, a total of 14 different features). The company has been running this system over the world in a multitude of locations (a total of 1375834 measurements have been stored for 124 locations where each location has a minimum of 10000 measurements). For each measurement that takes 24 hours to complete, each of the 14 features are estimated from the average value over all collected particles. In addition, the total particle count is also added to the feature set. The idea is to provide environment agencies with a tool that can group geographical locations according to how they are similar in terms of air particles. Your company now wants to build a system that can group locations based on similarity of air particle content. The system output should enable the user to see which locations are similar to each other in terms of air particles. They can thereby discuss common factors of pollution or compare the results of air cleaning efforts.

What type of problem does the company want to address? Accordingly, propose a neural network solution in your design assignment. In particular, motivate the choice of your network type, briefly characterise its topology clearly indicating the inputs and outputs, and describe how the network should be trained – how the data should be used and what learning algorithm you recommend. Please, explain also how you would optimise and estimate the generalization capacity. Finally, identify key challenges and potential difficulties/risks concerning the problem and your approach to effectively solving it.

Question 4 (6p)

Please describe and motivate briefly how you would approach the following problems linked to the deployment of a neural network based solution:

a) There is relatively little data available (fortunately, the available pictures are assigned labels) for building from scratch a convolutional neural network (CNN) for classifying different species of animals living in a remote exotic country. You are still convinced that a CNN approach is worth pursuing – how do you go about developing it?

b) This time you develop a similar approach but in the geographical context where a large number of images of different species are available but only a tiny portion of them is labelled (fortunately with a rather even distribution of labels per species to recognise). How do you train your network to perform this recognition task?

c) Finally, all available images of different species have been taken with the same camera with animals placed in the same part of the photo preserving the same scale (of animal size) and taken at the same light intensity though with relatively high noise. How would you train a CNN that would be capable to classify images taken with various cameras in different lightning conditions etc.(unavailable during the training process).

Question 5 (10p)

You have been asked to consult on the development of a neural network approach to medical diagnostic support system in early dementia with the help of brain imaging. In other words, you are asked to use available 2D brain imaging scans, typically recorded in three planes per patient: sagittal, coronal and horizontal (three 2D planes to describe 3D brain volume), along with the available clinical assessment of the risk of developing dementia on the continuous scale between 0 (no risk) and 5 (very high risk). This 0-5 score has been obtained by averaging individual assessments performed in the preliminary stage by a few clinicians with rather low experience. So, your task is to examine whether automated analysis/interpretation of brain scans with artificial neural networks could replace this preliminary stage and generate the 0-5 risk score based on available images. If yes, your platform could save a lot of time typically taken by the younger and rather inexperienced clinicians and offer direct support for senior clinicians in the more advanced aspects of the diagnostic process.

Please address this question/objective by considering the three following case studies: a)-c). In particular, propose and motivate a suitable *network architecture(s)* (network type, input/output dimensionality, key hyperparameters, activation functions etc.), *training/validation pipeline* (algorithm, loss function, data split, regularisation technique etc.), and *evaluation approach*. Also, what types of pattern recognition problem are they?

a) There are 900 patients, each offering a set of three images (one per plane, i.e. sagittal, horizontal and coronal), and the average risk scores rather uniformly distributed between 0 and 5. As mentioned, your neural network should match the available scoring labels. Propose how you would show the results of this match to the clinical staff.

b) How would you modify your approach to suit another request by senior clinicians to generate a discrete label at two crude levels of the risk score: low (for the cases with the original score between 0 and 1.5) and high risk (the original score above 3.5)? This time for evaluation purposes only you are given access to data from another 100 patients with such dichotomous labels: low / high risk. How would you evaluate your modified neural network based solution to appeal to the clinicians?

c) The clinicians would like to test another hypothesis as to whether the diagnostic support can be improved for patient cases with multiple images taken longitudinally over time (typically 10-12 images collected over 5-6 years). For that purpose they have identified 600 new patients, each with a dichotomous assessment (low or high risk) made by clinicians based on a sequence of available images. The request for you is to develop a neural network based solution that would use such image sequences to provide the diagnostic support and, ultimately, to examine if using such longitudinal data (over time) offers any extra diagnostic value in comparison to the analysis of the single most recent image (the last in the sequence). Please describe your design leveraging as much as possible your efforts in case b) – focus on a general architecture rather than details and briefly describe how you would train/validate and evaluate your networks to answer the clinicians' question about the diagnostic usefulness of brain image sequences.

Question 6 (9p)

Please design an empirical study to resolve a question as to which neural network approaches are suitable for forecasting retail sales in the sector of Swedish clothing industry. Please bear in mind that the focus is on prediction horizon up to 2 months ahead. There are 10 large companies that provided data for your study – they range from 2 to 18 years' cumulative sale reports (weekly sales within 4 largest garment categories – 4 values per time point) made every week. Most large seasonality trends have been removed and there is only remaining monthly periodicity (similarity between consecutive months). When describing your experimental study please keep the following questions/issues in mind:

a) What could be candidate neural network types for your comparative study? What configurations would you consider worth testing (how would you go about parameter settings and what parameters)? What would you consider a fair comparison in terms of network configurations?

b) How would you suggest using your data, how would you use/divide samples from different companies to ensure reliable training, validation and testing?

c) What would you feed to the networks, what would be inputs and outputs? You could support your short description with suitable illustrations.

d) What would be the criterion/criteria for your comparison (what would you measure)? How would you ensure that your findings account for stochastic nature of training neural networks so that generalizable conclusion could be drawn (rather than being an unreliable product of random effects)? What kind of generalisation would you aim for and how would you test/evaluate it?