DD2437 Artificial Neural Networks and Deep Architectures (annda23VT)

Exam 2023-03-14 at 8:00-11:00

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 (grading details are available on the course website).

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 DD2437 course (unless you are a PhD student, in which case you should write that you follow FDD3437 course)!

Good luck!

Pawel and Erik

Question 1 (11p)

In the context of a car manufacturing process you have been requested to help design a neural network based approach to diagnosis of dampers (part of car's suspension system) based on the visual and audio signals. In particular, dampers are photographed from three different angles and they are subject to the stress test by inducing different vibrations and measuring their sound response in the frequency domain. So, as a result, for each damper there are three rather low-resolution (512x512 pixels) images and a power spectrum of their audio responses in 1024 frequency bins (a vector of 1024 components, each corresponding to the power of the corresponding frequency bin - subband). The data are collected at different manufacturing sites across Europe that all produce dampers for different car types ranging from small cars to large vans (these annotations are available). The main task for the diagnosis is to assess the quality of each damper (whether it is technically flawless and can be mounted in a car) and identify potential flaws. So far this process has been sluggish and based solely on human expertise that is hardly verbalised, somehow it is elusive. For obvious reasons there is an expectation that a machine learning solution could offer a more sustainable, objective and scalable solution to the diagnostic problem. Your objective is to propose neural network solutions that can serve diagnostic purposes and can be used to explore multiple quality control questions:

A) Based on the available data develop a simplistic diagnostic system geared towards individual manufacturing sites (using their local data and manufacturing specificity). At this point it suffices to distinguish good from flawed dampers. The manufacturer also wonders if one network could be used to produce a reliable diagnostic output for all car types. Finally, they would also like to investigate if it suffices to rely only on the frequency response (sound domain) data without images as they are costly to collect and store. How would you help them clarify this?

B) In the next step you are asked to make an attempt at cross-site diagnostic system, still with dichotomous output – good vs flawed damper (with separate or the same network for every car type depending on the result of your tests and conclusions in A). How would you assess the feasibility of a single system with cross-site generalisation?

C) This time the focus is on flawed dampers – there are no annotations about different categories of technical flaws but according to technical stuff there should be clear distinctions. Please propose a neural network approach that now can expand and group flawed clusters (or test if such groupings are distinctive and clear). At this point you are asked about the visualisation of the output in 3D space (where dampers can be placed/grouped depending on their condition). How would you test how well good dampers fit that visualisation space, i.e. get placed far away from flawed ones? How would you examine which group of flawed dampers is most similar to good dampers? How would you test the compatibility of these technical flaw groupings between different sites as well as across different car types?

D) Assuming that distinct groups of flawed dampers can be identified and interpreted by human experts (and named/labelled), how would you extend your approach in A (individually for each manufacturing site) to examine the diagnostic performance for good dampers and multiple flawed damper categories?

Please describe your approach (neural network systems architecture, names of learning algorithms, data usage for training/validation and/or testing) and how with the proposed method you could address every task, concern and question listed above (how your method should be used including the visualisation output). What key challenges and risks do you expect? You can be brief in your descriptions, focus on the conceptual/design aspects, motivate your choices and, as mentioned, highlight your concerns or potential risks that you perceive.

Question 2 (4p)

A) Show that $\boldsymbol{p}$ = [-1 1 1 -1 -1 1] is a noisy version of a stored pattern in the Hopfield network with the following weight matrix:

$$\mathbf{W} = \begin{bmatrix} 0 & 1 & 1 & 0 & -1 & 0 \\ 1 & 0 & 1 & 0 & -1 & 0 \\ 1 & 1 & 0 & 0 & -1 & 0 \\ 0 & 0 & 0 & 0 & 0 & -1 \\ -1 & -1 & -1 & 0 & 0 & 0 \\ 0 & 0 & 0 & -1 & 0 & 0 \end{bmatrix}$$

using sequential update. Nodes are {-1, 1} and output is 1 for sum >=0.

B) The nodes in the Boltzmann machine are said to be “stochastic”. Explain how they are constructed to get this property. Explain also what role the stochastic nature plays in the function of the network.

Question 3 (10p)

In each case below, what type of problem/processing is this? Propose a neural network approach to address it. For your solution, give algorithm name, network topology, describe input and output (what kind of data, how many nodes etc), how training is done etc.

A) In the game industry, physical modelling is frequently used to obtain realistic games, such as simulating the bio-mechanical movement of one of the agents in the game. However, some physical processes are so complex and time consuming to simulate that it is not feasible given the performance of home computers and the demand for real time. One example might be to simulate the water movement of a river, with its swirls and waves. However, there are alternatives to using detailed mechanistic models, where one starts with a set of descriptors of the system and computes the resulting state of the system. In the example of the river, input could be a set of variables describing water depth, slope of the ground, smoothness of the river bottom and output could be water speed, number of waves per unit area, size of waves, number of vortices per unit area, size of vortices etc. Propose how you can employ a neural network approach to minimise the need to rely on detailed mechanistic models.

B) Truck manufacturers attempt to better understand the exploitation patterns of their products. This becomes feasible with the growing number of sensors their trucks are equipped with and enhanced data collection and management systems. One of the key motivating factor to study such data is to gain insights into mechanisms that underlie most common failures as this would enable the manufacturers to predict them and warn the user in advance. The data are usually logged on a regular basis to facilitate monitoring process and when selected variables cross predefined thresholds, a warning signal is issued. It turns out however that this approach has a very high false positive rate. There is a hypothesis that rather than readouts from individual sensors one should detect co-occurring patterns of activities reported by multiple sensors (multivariate patterns). In addition, it is expected that not specific states but rather their sequence is a robust predictor of the oncoming failure. In this task you are asked to propose a neural network approach to the problem of failure detection. What aspect(s) of such data could pose a serious challenge to the process of training your network? Apart from identifying a suitable neural network architecture and learning algorithm, please describe briefly how you would test the aforementioned hypotheses.

Question 4 (3p)

Recurrent neural networks suffer from the vanishing gradients problem caused by the way the network processes temporal data. Describe the problem, explain how it arises and how it can be avoided. Furthermore, when we take actions to avoid this problem, state what is typically done and discuss the consequences of this solution on the function of the network (for instance, exemplify a capability we want the network to have that is affected by this solution).

Question 5 (10p)

You work for a travel agency as a local host. Among many duties you are supposed to take care of guests at arrival and departure, which is essentially to transport guests from the airport when a full plane of guests arrives and take each one of them to their hotel, and on departure to do the opposite. Hotels are distributed over a fairly large area. The travel agency has contract with a total of 134 hotels, but on a specific arrival/departure only a subset of hotels will have guests. Even if the bus drivers generally are very experienced and drive guests fairly effectively by taking a route which is as short as possible in driving time, you see a problem. In only 2-3 years, most of the experienced drivers will retire while the new inexperienced drivers rely on the GPS navigation and have little knowledge of driving time between most of the relevant hotels. The machine learning expert in you see a golden opportunity. You download lots of data from the GPS system of the buses, especially those driven by the experienced drivers. From this data, you put together a table of driving time between all pairs of hotels (median driving time, you save this in a 134 x 134 matrix where rows are "starting hotel" and columns are "ending hotel"). *[As a side note, your intuition that the travel time between hotel A and hotel B would not necessarily be the same in both directions as some hotels are up in the mountains and some down at the sea level turns out to be unsubstantiated, and in fact the two travel times are almost the same (totally within the accuracy of using medians) for all hotel pairs. Your guess is that the condition of the road sets the speed and not elevation.]*

After the data has been collected, the next step is to implement a machine learning system that can give you the optimised driving plan considered to be as short as possible in time. Every time a group of guests have to be transported from the airport, your idea is to compile the list of their hotels and generate the quickest travel route with a computational method exploiting your matrix of pairwise travelling times.

What type of problem does the company want to address with this method? Accordingly, propose a neural network solution (method) in your design assignment. In particular, motivate the choice of a 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 6 (8p)

In healthcare there is a growing interest in decision support systems, particularly for triaging purposes (assigning different levels of priority for treatment depending on the severity of patients' conditions). The objective is to design a neural network based method that will help doctors to decide on the priorities for patients in an emergency unit. To train your network you have a dataset containing 400 cases each labelled with one of five triage categories. Each case is characterised by single patient's responses to 56 questions, a mix of yes/no and multiple choice questions. It turns out that 7 questions have only been answered by 20 patients (incidentally, belonging to the lowest priority triage category), and 9 questions have only been answered by 12 patients who make up for 50% of all of the available highest priority patients. Importantly, from doctors' perspective it is vital that particularly severe cases (the highest triage category) are correctly identified. Please propose a solution by addressing the following points (provide reasoning and motivation for your answers):

- Propose a network architecture, name a learning algorithm, list key hyperparameters and describe briefly how you would optimise their values (model selection). How would you minimise the risk of overfitting? Is it really a serious concern?

- How should a doctor interpret the network's output? How do you measure performance and how can you account for the doctor's special care for the top priority cases, what are the associated challenges?

- Describe how you would treat the data, e.g. pre-processing, encoding, splitting into subsets. Are there any concerns regarding the available dataset, extra challenges?

- If there was a suggestion that new extended questionnaires (e.g., with 50 more questions) should be designed, what implications would it have for your network design? In addition, if you could have more data collected from another set of patients, which patient category would you consider most relevant and why?