University College Dublin
An Coláiste Ollscoile, Baile Átha Cliath

SPRING, 21/22 TRIMESTER EXAMINATIONS

COMP47590

Advanced Machine Learning

Module Coordinator: Assoc Professor Brian Mac Namee

Student Number

Seat Number

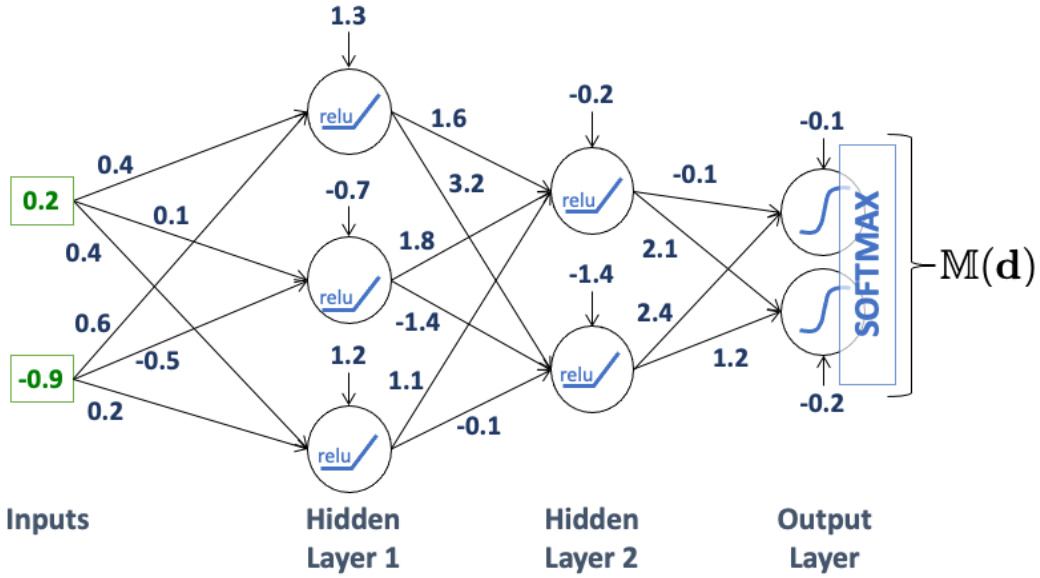
Time Allowed: 120 minutes

Materials Permitted in the Exam Venue:
Non-programmable or scientific calculator
Programmable calculator

Materials to be Supplied to Students:
8 Page Answer Booklets
New Cambridge Statistical Tables

Instructions to Students:
Answer any three out of four questions. All questions carry equal marks. Total marks available 90. The value of each part of each question is shown in brackets next to it.

1. **(a)** The image below shows a *feed forward artificial network*. The computational units in the two hidden layers use *rectified linear* (*relu*) activation functions and the output layer unit uses a *softmax* activation function. The *weights* and *biases* are shown along the links in the network.



(i) Perform a **forward propagation** through the network using an input feature vector of [0.2, -0.9]. Show your workings.

[12 marks]

(ii) If the target feature vector for the current input vector is [1.0, 0.0], calculate the **loss** associated with this training instance using **cross entropy loss**.

[2 marks]

(b) **Gradient descent with momentum**, **RMSprop**, and **adam** are three common adaptations to the basic gradient descent algorithm used to train neural networks. Explain how these approaches improve upon basic gradient descent and how they differ from each other.

[8 marks]

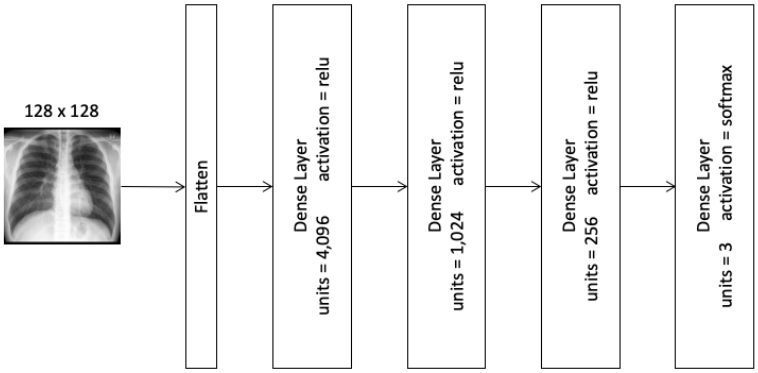
(c) Regularisation can be defined as "*any modification we make to a learning algorithm that is intended to reduce its generalization error but not its training error*" (Goodfellow et al, 2016).

Describe **two** regularisation approaches that can be used when training deep neural networks and explain who they help to reduce generalisation error.

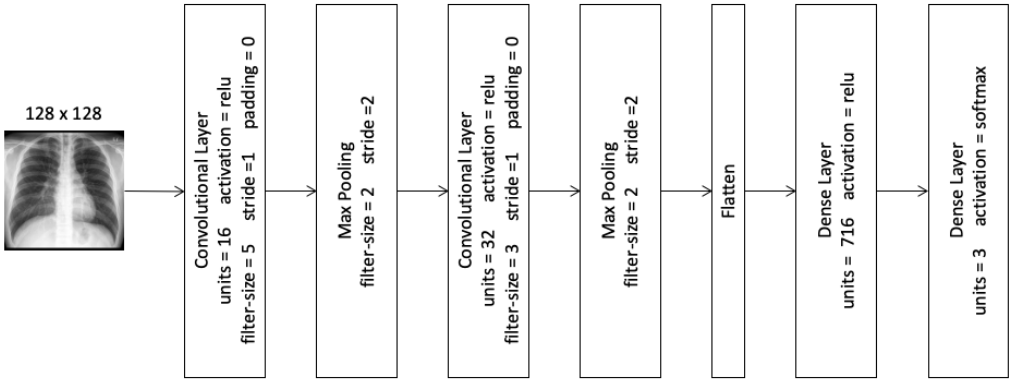
[8 marks]

2. **(a)** You have been tasked with training a neural network to diagnose pneumonia from chest x-rays. The model should produce diagnoses on a three-point scale: *grade-0* = no pneumonia, *grade-1* = mild pneumonia, *grade-2* = severe pneumonia. The only input to the model is a 128 pixel by 128 pixel greyscale image of a chest x-ray.

Image (a) shows the architecture of a multi-layer perceptron neural network designed for this problem. Image (b) shows the architecture of a convolutional neural network designed for this problem. Both architectures are composed of four layers.



(a) A multi-layer perceptron network for diabetes diagnosis

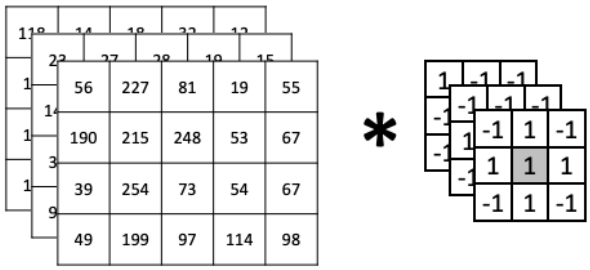


(b) A convolutional neural network for diabetes diagnosis

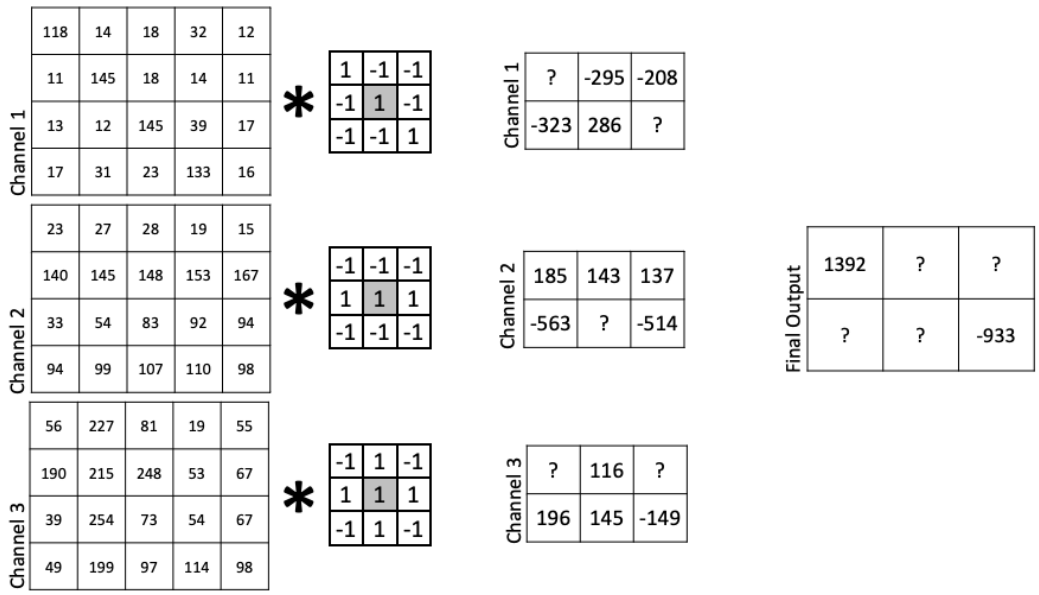
Calculate the number of parameters (weights and biases) that need to be learned for each network architecture.

[12 marks]

(b) The image below shows a 3 channel input that is being convolved (cross correlated) with a 3 channel kernel.



The image below expands the three-channel input and three-channel kernel so that all values can be seen and shows the intermediate convolution result for each channel as well as the final output. Calculate the values marked with a **?** in the intermediate convolution results and the final output.



[7 marks]

(c) The ability of convolutional networks to learn accurate models with many fewer weights than multi-layer perceptrons of similar depth is often attributed to **shared weights** and **sparse connections**. Explain the meaning of these two terms.

[5 marks]

(d) **Transfer learning** using pre-trained weights has become a standard approach to training large convolutional neural networks for image classification. Explain what this means, and how it is helpful for training convolutional neural networks with small datasets.

[6 marks]

3. **(a)** Describe the concept of **discounted return** that is frequently used in reinforcement learning.

[4 marks]

(b) An intelligent agent trained to play a video game completes an episode and receives the following sequence of rewards over six timesteps:

$\{r_0 = -33, r_1 = -11, r_2 = -12, r_3 = 27, r_4 = 87, r_5 = 156\}$

Compare the discounted returns calculated at time $t = 0$ based on this reward sequence when discounting factors of 0.72 and 0.22 are used.

[6 marks]

(c) As part of a project to develop a farm simulator, the behaviour of a cow has been observed over a day. During the day the cow can REST, GRAZE grass, PLAY with other cows, or enter the milking parlour to MILK. The behaviour of the cow over the course of a day is captured in the table below (with time flowing down through the columns and left to right).

1	REST	13	PLAY	25	PLAY	37	MILK	49	REST	61	REST
2	GRAZE	14	REST	26	REST	38	MILK	50	GRAZE	62	REST
3	REST	15	REST	27	REST	39	MILK	51	GRAZE	63	PLAY
4	REST	16	GRAZE	28	REST	40	REST	52	GRAZE	64	PLAY
5	REST	17	GRAZE	29	REST	41	REST	53	REST	65	PLAY
6	GRAZE	18	REST	30	MILK	42	REST	54	REST	66	GRAZE
7	GRAZE	19	PLAY	31	MILK	43	REST	55	GRAZE	67	GRAZE
8	GRAZE	20	GRAZE	32	MILK	44	REST	56	GRAZE	68	REST
9	REST	21	REST	33	MILK	45	REST	57	GRAZE	69	REST
10	REST	22	GRAZE	34	MILK	46	GRAZE	58	REST	70	REST
11	PLAY	23	GRAZE	35	MILK	47	GRAZE	59	GRAZE	71	REST
12	PLAY	24	PLAY	36	MILK	48	GRAZE	60	REST	72	REST

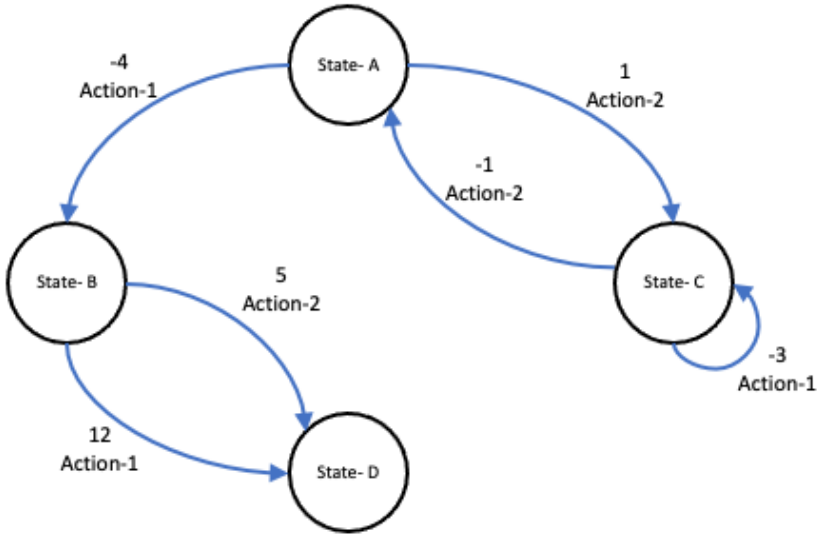
(i) Based on this behaviour sequence, calculate a **transition matrix** that gives the probability of moving between the four states.

[8 marks]

(ii) Draw a **Markov process diagram** to capture the behaviour of the cow as described by the transition matrix.

[3 marks]

(d) The following image shows a simple state transition diagram for a domain in which an agent can occupy one of four states and has two actions available to it.



Actions that connect states are shown above the arrows in the diagram. This environment is fully deterministic (actions always lead to the states shown in the diagram above). The rewards associated with each state transition are shown in the diagram above the name of the action taken to complete the state transition.

The action-value-function-table for this environment is shown in the table below.

State	Action	Value
State-A	Action-1	3.24
State-A	Action-2	-1.24
State-B	Action-1	6.78
State-B	Action-2	4.56
State-C	Action-1	-12.56
State-C	Action-2	-2.87
State-D	Action-1	0
State-D	Action-2	0

(i) If the agent begins in State-C which action will it select following a **greedy action selection strategy**?

[3 marks]

(ii) What state would the agent occupy after taking the action selected in Part (a) of this question and what reward would the agent receive after taking the action.

[3 marks]

(iii) Assuming that **Q-learning** is being used, update the entry in the action value table above for State-C and the action selected in Part (a) of this question. In your calculations assume that $\alpha = 0.1$ and that $\gamma = 0.9$.

[3 marks]

4. **(a)** Machine learning algorithms face a constant struggle between **over-fitting** and **under-fitting**. Explain what this means.

[10 marks]

(b) When developing a machine learning model that will be deployed to perform a task for a user, we can describe three different goals of evaluation:

1. to determine which model is the most suitable for a task
2. to estimate how the model will perform after deployment
3. to convince users that the model will meet their needs

Describe the differences between these goals, and how the evaluation methods used to achieve each of them can be different.

[10 marks]

(c) The following is a definition of machine learning:

The field of machine learning is concerned with the question of how to construct computer programs that automatically improve with experience.
- Tom Mitchell

Do you believe that this definition accurately defines machine learning? In your answer discuss the appropriateness of the definition, the scope of the definition, and any recommendations for improvements you would suggest.

[10 marks]

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