# CS 523 – Deep Learning

# Exam

# Summer 2021

***Instructions:***

1- Share your video and audio
2- Set an alarm for 2:45pm EST. You have 1 hour and 40 minutes to solve the exam
3- Solve the exam using paper and pen
4- Print your name and BU ID clearly on the top right of the first page (the page that will have the solution to Problem 1)
5- Start a new page for each question
6- Stop solving at 2:45pm EST
7- Take photos of your solutions in order using your phone
8- Convert the photos into a single pdf
9- Submit your pdf file on GradeScope
10- You will receive a confirmation message from us that we received your submission. **<u>It is your responsibility to make sure the file contains solutions to all the problems you solved.</u>**

***Notes:***

** There are six questions. The last page has some common formulas*
** If you have any inquiries during the exam please message us in the zoom chat in 40mins after raising your hand or using a zoom reaction.*
** You may turn the speakers off, but please keep your chat open*
** We are only able to grade what we can read*
** Total points: 64*

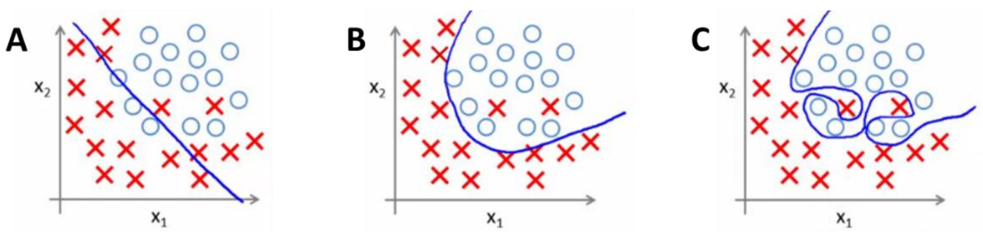
## Good luck ☺

# Q1. [8 points] Overfitting and Regularization

Suppose you want to fit a Logistic Regression model to predict whether an email is spam ($y = 1$) or not spam ($y = 0$) based on the frequency of the words "buy" (feature $x_1$) and "click" (feature $x_2$). You decide to use polynomial basis functions to represent the input features and to apply regularization. You have fit three models by minimizing the regularized Logistic Regression cost function

$$J(\theta) = \frac{1}{m}\sum_{i=1}^{m}[-y^{(i)}\log\left(h_\theta(x^{(i)})\right) - (1-y^{(i)})\log\left(1-h_\theta(x^{(i)})\right)] + \frac{\lambda}{2m}\sum_{j=2}^{n}\theta_j^2$$

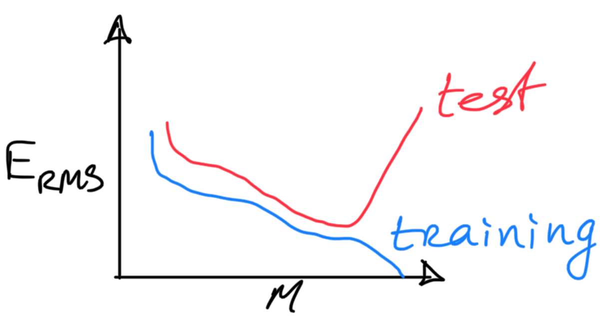
for $\lambda = 10^{-2}, 10^{0}, 10^{2}$. The following are sketches of the resulting decision boundaries.




a) [3 points] Which value of λ goes with each of the plots?

**A:** $10^2$ **B:** $10^0$ **C:** $10^{-2}$

b) [3 points] You plot model complexity *M* (number of polynomials) versus the cost function, computed on the test data, and a similar curve for the training data. Explain how you can use these curves to detect when the model is overfitting and draw and example to illustrate.




As the model becomes complex, the gap between training and test error grows large, which signals overfitting

c) [2 points] Name the regularization technique specifically designed for Deep Neural networks and briefly describe how it achieves such regularization.

Dropout. Model averaging

## Q2. [12 points] Training Strategies

a) [2 points] Alice decides to use Principal Component Analysis to implement image compression. Briefly explain how she should train the algorithm and how she should use it to compress a new image. What parameter controls the amount of compression?

PCA on pixel colour features
Parameter
↳ The number of principal

b) [2 points] Suppose you have trained an anomaly detection system for intruder detection in a security camera, and your system flags anomalies when p(x) is less than ε. You find on the cross-validation set that it is missing many intruder events. What should you do?

c) [2 points] Describe K-fold cross-validation.

d) [2 points ] Describe the goal of an autoencoder, incorporating how that goal is achieved through the design of the loss function.

e) [2 points] What are the benefits of fine-tuning a pre-trained network?

f) [2 points] What is a minibatch? List an advantage of using a minibatch.

## Q3. [10 points] Design Questions

a) [4 points] For the tasks of de-noising/inpainting an input image using an auto-encoder:

i) What is the input?

ii) What is the ground-truth?

iii) What is the loss function?

iv) Sketch the entire pipeline

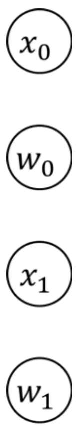
b) [3 points] How would you design a deep learning model that computes the temporal regions where an advertisement makes audience laugh/smile while watching it online, and how can you contrast that with regions where an advertisement is meant to be funny?

c) [3 points] Sketch a pipeline for unsupervised domain adaptation, where the source data has class labels but the target data does not, and formulate and explain the associated loss/cost function.

# Q4. [11 points] Backpropagation

Suppose we want to compute the gradients for the function $h(x) = q(w_0 x_0 + w_1 x_1)$, where $x = [x_0\ x_1]^T$ is the input vector, $w = [w_0\ w_1]^T$ is the parameter vector, and q is the *tanh* function: $\mathrm{q(u)} = \tanh(u) = (e^u - e^{-u})/(e^u + e^{-u})$. The *tanh* function is also plotted in the appendix.

a) [2 points] Complete the computational graph for this function below by adding two nodes $f_1(u, c) = c * u$ (multiplication), one node $f_2(u, c) = u + c$ (addition), and one node $f_3(u) = q(u)$. Label the nodes clearly with $f_1, f_2$ or $f_3$ and leave plenty of space between them.




b) [3 points] Write down the gradient $\frac{\partial f}{\partial u}$ for functions $f_1, f_2, f_3$. *Hint: note that* $tanh'(u) = 1 - tanh(u)^2$.

$\frac{\partial f_1}{\partial u} =$

$\frac{\partial f_2}{\partial u} =$

$\frac{\partial f_3}{\partial u} =$

c) [2 points] Perform a forward pass for $x = [5 \quad 5]^T$ and $w = [1 \quad -1]^T$, **writing values on top of the arrows** in your computational graph. What is the output of the forward pass, *i.e.* $h(x)$?

d) [4 points] Perform a backward pass for the example in (c), **writing values below the arrows** in the graph. What are the gradients of $h$ with respect to $x_0, x_1, w_0, w_1$?

$\frac{\partial h}{\partial x_0} =$ $\qquad$ $\frac{\partial h}{\partial x_1} =$ Type equation here.

$\frac{\partial h}{\partial w_0} =$ $\qquad$ $\frac{\partial h}{\partial w_1} =$

## Q5. [14 points] DL Architectures

Answer the following questions in brief one or two sentence answers.

a) [2 points] Is it recommended to do feature engineering first and then apply deep learning? Contrast deep learning with other machine learning algorithms in terms of feature engineering.

b) [2 points] Suppose we have a neural network with ReLU activation function. Let's say, we replace ReLu activations by linear activations. Would this new neural network be able to approximate a non-linear function? And why?

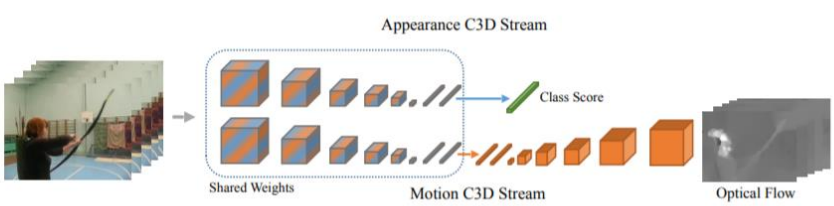
c) [2 points] Name an example of a data augmentation approach and explain how it helps improve model generalization.

d) [2 points] What is the main difference between a fully-connected and a convolutional network?

e) [2 points] List two ways to downsize feature maps in convolutional neural networks.

f) [2 points] Describe the benefit of using soft over hard targets in knowledge distillation.

g) [2 points] If the following is an action classification model, discuss the auxiliary task presented and how it can help the classification task.



## Q6. [9 points] Training Strategies

a) [3 points] Suppose you decide to use the loss $L(z) = exp(-2z - 1)$, where $z$ is a function of the weights $w$. Write down the gradient descent algorithm for minimizing this loss on a set of training examples $\{x_i, y_i\}, i = 1, \ldots, m$, using a squared L-2 norm regularizer $R(w) = ||w||^2$ on the parameter vector.

i) What is the cost function?

ii) Should it be minimized or maximized?

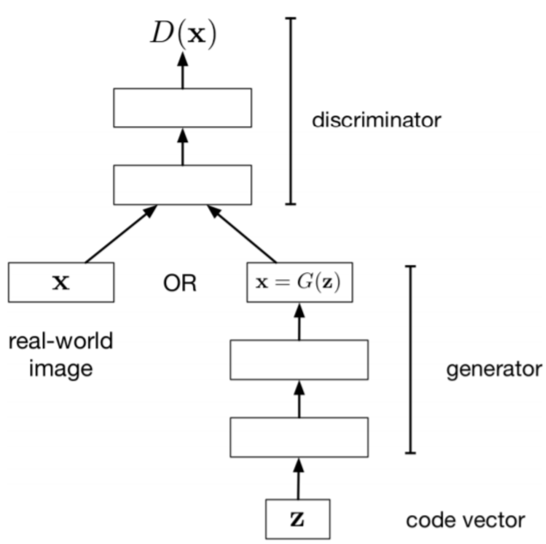
iii) What is the corresponding gradient descent update step for $w$?

b) [3 points] Explain the terms in the following equation and why they are needed, then list one application that would benefit from using this setup.

$$R_t = \sum_{i=t}^{\infty} \gamma^i r_i = \gamma^t r_t + \gamma^{t+1} r_{t+1} \ldots + \gamma^{t+n} r_{t+n} + \cdots$$

$\gamma$: discount factor; $0 < \gamma < 1$

c) [3 points] Describe how the discriminator and generator modules of this GAN are typically trained, *i.e.* how their parameters are updated.



# Appendix: Common Formulas

## Chain Rule

If z = f(y) and y = g(x), then $\frac{dz}{dx} = \frac{dz}{dy}\frac{dy}{dx} = f'\big(g(x)\big) * g'(x)$

## Hyperbolic Tangent Function (tanh)