CS2109s - Tutorial 7

Eric Han (TG12-TG15)

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Annoucements

1. Attendance is taken at the end of the lesson via a QR code
    1.1 You will rate yourself ie. tutorial completeness etc.
    1.2 You will rate your buddy also [Groups of 2/3 in Breakout rooms]
    1.3 Exp is awared based on the declaration.
2. Group/Buddy discussion is with your buddy
    2.1 Q1 and Q4 are discussion questions [5 mins ea]
3. Class discussion is when you are answering to me
4. Bonus qns is applicable only to my (TG12-TG15) students.
5. [@] qns are advanced, extra questions that I may ask (limited to 1 answer per qn)

Question 1 [G]

ID	x_1	x_2	AND	OR	XOR
0	0	0	0	0	0
1	0	1	0	1	1
2	1	0	0	1	1
3	1	1	1	1	0

x	NOT
0	1
1	0

a. Determine a function that can be used to model the decision boundaries of the logical NOT, OR, and AND gates. What are the weights and bias?
b. Is it possible to model the XOR function using a single Perceptron? [@] Proof.
c. Model XOR using a number of NOT, OR, and AND perceptrons.
d. If data samples are reordered, will the model converges to a different model?
e. Does your proposed models (AND, OR, NOT) have high bias and high variance?

Recap

What is a Perceptron and what is the Perceptron Update Rule?

Answer 1a

$y = X \cdot w^T + w_0$

AND Gate - 4 iters, 11 updates

```
iter=0 idx=0 w=[-0.1  0.   0. ]
iter=0 idx=3 w=[0.  0.1 0.1]
iter=1 idx=0 w=[-0.1  0.1  0.1]
iter=1 idx=1 w=[-0.2  0.1  0. ]
iter=1 idx=3 w=[-0.1  0.2  0.1]
iter=2 idx=1 w=[-0.2  0.2  0. ]
iter=2 idx=2 w=[-0.3  0.1  0. ]
iter=2 idx=3 w=[-0.2  0.2  0.1]
iter=3 idx=2 w=[-0.3  0.1  0.1]
iter=3 idx=3 w=[-0.2  0.2  0.2]
iter=4 idx=1 w=[-0.3  0.2  0.1]
```

OR Gate - 2 iters, 5 updates

```
iter=0 idx=0 w=[-0.1  0.   0. ]
iter=0 idx=1 w=[0.  0.  0.1]
iter=1 idx=0 w=[-0.1  0.   0.1]
iter=1 idx=2 w=[0.  0.1 0.1]
iter=2 idx=0 w=[-0.1  0.1  0.1]
```

NOT Gate - 1 iters, 2 updates

```
iter=0 idx=1 w=[-0.1 -0.1]
iter=1 idx=0 w=[ 0.  -0.1]
```

Answer 1b

XOR gate is not linearly separable

Answer 1c

$$XOR(x_1, x_2) = AND(NOT(AND(x_1, x_2)), OR(x_1, x_2))$$

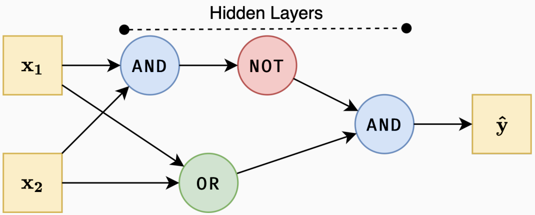

Figure 1: Layers are important to generalize better complex data.

Answer 1d

Ordering	Iterations	No. of Updates	Weight	No. of Correct
[0, 1, 2, 3]	4	11	[-0.3 0.2 0.1]	4
[0, 2, 3, 1]	4	13	[-0.3 0.2 0.1]	4
[0, 2, 1, 3]	4	11	[-0.3 0.1 0.2]	4

- Reordering can help model converge faster
- Reordering can change the optimum point found - potentially many local optimas.

Answer 1e

The proposed model has low bias and low variance; They all classify correctly.

Q1 Visualization

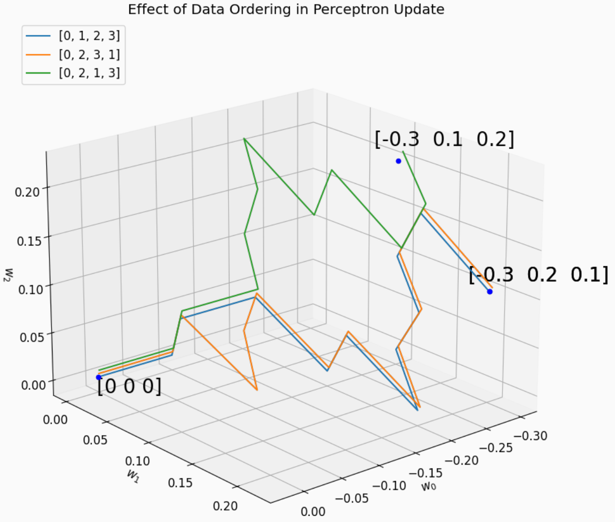

Figure 2: Q1 Viz

Question 2

Perceptron	MSE Train	MSE Validation
Single	1000	2000
Multi	800	1200

a. Why the difference in performance?
b. How to improve Single's performance? What are the advantages / disadvantages?
c. How to improve the performance of the multi-layer perceptron?

Recap

What does adding layers do?

Answer 2

a. Complexity needed to classify dataset is likely non-linear boundary
    - Single-layer: Less Complex, linear classifier
    - Multi-layer: More Complex, non-linear classifier

b. Feature Engineering, to ‘transform’ the space
    - Add polynomial terms
    - Add interaction terms

c. Improve. . . ?
    - Performance: Increase complexity, add hidden layer
    - Reduce overfitting: Regualization

Question 3

Neural Network with 2D input, one hidden layer, with bias, using ReLU, MSE.

$$\boldsymbol{W}^{[1]} = \begin{bmatrix} 0.1 & 0.1 \\ -0.1 & 0.2 \\ 0.3 & -0.4 \end{bmatrix}, \boldsymbol{W}^{[2]} = \begin{bmatrix} 0.1 & 0.1 \\ 0.5 & -0.6 \\ 0.7 & -0.8 \end{bmatrix}, b = 1, X = [2, 3], y = [.1, .9]$$

Calculate the following values after the forward propagation: $\mathbf{a}^{[1]}$, $\mathbf{y}^{[2]}$ and $L(\mathbf{y}^{[2]}, \mathbf{y})$.

Recap

- How to do forward pass?
- What is Loss/MSE?
- What is ReLU?

Answer 3

Layer 1:

$$\mathbf{a}^{[1]\,T} = ReLU\left(\boldsymbol{W}^{[1]\,T} \times X^T\right) = ReLU\left(\begin{bmatrix} 0.1 & -0.1 & 0.3 \\ 0.1 & 0.2 & -0.4 \end{bmatrix} \times \begin{bmatrix} 1 \\ 2 \\ 3 \end{bmatrix}\right) = \begin{bmatrix} 0.8 \\ 0 \end{bmatrix}$$

Layer 2:

$$\mathbf{y}^{[2]\,T} = ReLU\left(\boldsymbol{W}^{[2]\,T} \times \mathbf{a}^{[1]\,T}\right) = ReLU\left(\begin{bmatrix} 0.1 & 0.5 & 0.7 \\ 0.1 & -0.6 & -0.8 \end{bmatrix} \times \begin{bmatrix} 1 \\ 0.8 \\ 0 \end{bmatrix}\right) = \begin{bmatrix} 0.5 \\ 0 \end{bmatrix}$$

Loss:

$$L(\mathbf{y}^{[2]}, \mathbf{y}) = 0.5||\mathbf{y}^{[2]} - \mathbf{y}||_2 = 0.5 \times ((0.5-0.1)^2 + (0-0.9)^2) = 0.5 \times (0.16 + 0.81) = 0.485$$

Question 4 [G]

$$\hat{y} = g(\mathbf{W^{[L]}}^{\mathsf{T}} \ldots g(\mathbf{W^{[2]}}^{\mathsf{T}} \cdot g(\mathbf{W^{[1]}}^{\mathsf{T}} x)))$$

where $\mathbf{W}^{[l] \in \{1, \cdots, L\}}$ is a weight matrix. You're given the following weight matrices:

$$\mathbf{W^{[3]}} = \begin{bmatrix} 1.2 & -2.2 \\ 1.2 & 1.3 \end{bmatrix}, \mathbf{W^{[2]}} = \begin{bmatrix} 2.1 & -0.5 \\ 0.7 & 1.9 \end{bmatrix}, \mathbf{W^{[1]}} = \begin{bmatrix} 1.4 & 0.6 \\ 0.8 & 0.6 \end{bmatrix}$$

You are given $g(z) = \mathrm{SiLU}(z) = \frac{z}{1+e^{-z}}$ between all layers *except the last layer*.

a. Is it possible to replace the whole neural network with just one matrix in both cases **with** and **without** non-linear activations $g(z)$?
b. What does this signify about the importance of the non-linear activation?

Answer 4a

without non-linear activations:

$$
\begin{aligned}
M^T &= \begin{bmatrix} 1.2 & -2.2 \\ 1.2 & 1.3 \end{bmatrix}^T \begin{bmatrix} 2.1 & -0.5 \\ 0.7 & 1.9 \end{bmatrix}^T \begin{bmatrix} 1.4 & 0.6 \\ 0.8 & 0.6 \end{bmatrix}^T \\
&= \begin{bmatrix} 4.56 & 3.408 \\ -6.82 & -3.658 \end{bmatrix}
\end{aligned}
$$

with non-linear activations: suppose $x_1 = [1, 0]$ and $x_2 = [2, 0]$:

$$
\begin{aligned}
[\hat{y_1}, \hat{y_2}] &= \begin{bmatrix} 1.2 & -2.2 \\ 1.2 & 1.3 \end{bmatrix}^T g\left(\begin{bmatrix} 2.1 & -0.5 \\ 0.7 & 1.9 \end{bmatrix}^T g\left(\begin{bmatrix} 1.4 & 0.6 \\ 0.8 & 0.6 \end{bmatrix}^T \begin{bmatrix} 1, 2 \\ 0, 0 \end{bmatrix} \right)\right) \\
&= \begin{bmatrix} 3.0571, 7.7257 \\ -5.2727, -13.2458 \end{bmatrix}
\end{aligned}
$$

Assume $\mathbf{M^T}$ exist:

- $x_2 = 2x_1$
- $\mathbf{M^T} x_2 = 2\mathbf{M^T} x_1 \implies \hat{y_2} = 2\hat{y_1}$ by linearity of $\mathbf{M^T}$.
- But, $\hat{y_2} \neq 2\hat{y_1}$, thus there exist no such $\mathbf{M^T}$.

Answer 4b

$$\begin{aligned}\hat{y} &= \mathbf{W}^{[\mathbf{L}]\mathbf{T}} \dots \mathbf{W}^{[\mathbf{2}]\mathbf{T}} \mathbf{W}^{[\mathbf{1}]\mathbf{T}} x \\ &= \mathbf{A}x, \quad \text{where } \mathbf{A} = \mathbf{W}^{[\mathbf{L}]\mathbf{T}} \dots \mathbf{W}^{[\mathbf{2}]\mathbf{T}} \mathbf{W}^{[\mathbf{1}]\mathbf{T}} \text{ by matrix multiplication}\end{aligned}$$

- Without non-linear activations, the entire network **collapses to a simple linear model**; adding layers is futile.
- With non-linear activation functions let the network model non-linear relationships.

The non-linear activation gives the Neural Network its representation power - without which the parameters in the network behave the same way.

Question 5

Takes in grayscale images of size 32×32 and outputs 4 classes, with 3 layers, assuming batch size is 1.

- What are the dimensions of the input vector, the weight matrix, and the output vector of the three linear layers?
- [@] How would this look like for a CNN? Compare with the setup here.

Recap

- How does one layer interact with the next?

Answer

layer	Input dim	Weight Matrix dim	Output dim
Linear layer 1	1024×1	1024×512	512×1
Linear layer 2	512×1	512×128	128×1
Linear layer 3	128×1	128×4	4×1

Bonus Qn

To help you further your understanding, not compulsory; Work for Snack/EXP!

Tasks

1. Implement the missing code for `FconLayer`, `NNetwork` and `M` in the boilerplate code given to answer Q3, Q4
2. You must use Matrix operations where possible.
3. You must use `reduce` where possible. (Prompts in the code)
4. `FconLayer` should work properly with/without bias.

Buddy Attendance Taking

1. [@] and Bonus declaration is to be done here; You should show bonus to Eric.
2. Attempted tutorial should come with proof (sketches, workings etc. . .)
3. Guest students must inform Eric and also register the attendance.

Figure 3: Buddy Attendance: https://forms.gle/jsGfFyfo9PTgWxib6