KUMAR SANATAN

ROLL NO – 2211AI24

CS 564

Foundations of Machine Learning

ASSIGMENT 4:

INDIAN INSTITUTE OF TECHNOLOGY
PATNA

Date: 16th Nov 2022 **Deadline:** 30th Nov 2022

OBJECTIVE

Design and implement a Feed Forward Neural Network (FFNN) and a Recurrent Neural Network (RNN) for the task of image classification on the CIFAR-10 dataset.

Result:

a. Loss and accuracy for training phase (on validation set) of FFNN and RNN
ANSWER:

FFNN:

Epoch 1/50
704/704 - 32s - loss: 382.1806 - accuracy: 0.2369 - val_loss: 11.5990 - val_accuracy: 0.2098 - 32s/epoch - 45ms/step
Epoch 2/50
704/704 - 42s - loss: 382.3374 - accuracy: 0.2323 - val_loss: 13.3805 - val_accuracy: 0.2296 - 42s/epoch - 60ms/step

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Epoch 3/50
704/704 - 28s - loss: 5.6969 - accuracy: 0.2684 - val_loss: 4.4212 -
val_accuracy: 0.2374 - 28s/epoch - 40ms/step
Epoch 4/50
704/704 - 25s - loss: 2.9444 - accuracy: 0.2914 - val_loss: 2.7488 -
val_accuracy: 0.2962 - 25s/epoch - 35ms/step
Epoch 5/50
704/704 - 25s - loss: 2.4403 - accuracy: 0.3050 - val_loss: 2.7022 -
val_accuracy: 0.2844 - 25s/epoch - 35ms/step
Epoch 6/50
704/704 - 25s - loss: 2.3435 - accuracy: 0.3110 - val_loss: 4.5962 -
val_accuracy: 0.1712 - 25s/epoch - 36ms/step
Epoch 7/50
704/704 - 25s - loss: 3125.3899 - accuracy: 0.2236 - val_loss: 18.3583 -
val_accuracy: 0.2994 - 25s/epoch - 36ms/step
Epoch 8/50
704/704 - 25s - loss: 11.9006 - accuracy: 0.2680 - val_loss: 9.4926 -
val_accuracy: 0.2476 - 25s/epoch - 36ms/step
Epoch 9/50
704/704 - 25s - loss: 6.1908 - accuracy: 0.2742 - val_loss: 5.3801 -
val_accuracy: 0.2414 - 25s/epoch - 35ms/step
Epoch 10/50
704/704 - 25s - loss: 4.0877 - accuracy: 0.2799 - val_loss: 4.0850 -
val_accuracy: 0.2678 - 25s/epoch - 35ms/step
Epoch 11/50
704/704 - 25s - loss: 3.1546 - accuracy: 0.2904 - val_loss: 4.5448 -
val_accuracy: 0.2308 - 25s/epoch - 35ms/step
Epoch 12/50
704/704 - 25s - loss: 2.9036 - accuracy: 0.2996 - val_loss: 2.7532 -
val_accuracy: 0.2614 - 25s/epoch - 35ms/step
```

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Epoch 13/50
704/704 - 25s - loss: 458.8902 - accuracy: 0.2515 - val_loss: 4.1875 -
val_accuracy: 0.2800 - 25s/epoch - 35ms/step
Epoch 14/50
704/704 - 25s - loss: 3.2682 - accuracy: 0.2911 - val_loss: 3.4541 -
val_accuracy: 0.2180 - 25s/epoch - 35ms/step
Epoch 15/50
704/704 - 25s - loss: 2.3581 - accuracy: 0.3199 - val_loss: 2.5163 -
val_accuracy: 0.3104 - 25s/epoch - 35ms/step
Epoch 16/50
704/704 - 25s - loss: 2.1495 - accuracy: 0.3336 - val_loss: 2.1175 -
val_accuracy: 0.3194 - 25s/epoch - 35ms/step
Epoch 17/50
704/704 - 25s - loss: 2.0626 - accuracy: 0.3369 - val_loss: 2.2632 -
val_accuracy: 0.2870 - 25s/epoch - 35ms/step
Epoch 18/50
704/704 - 25s - loss: 2.0574 - accuracy: 0.3354 - val_loss: 4.5663 -
val_accuracy: 0.2372 - 25s/epoch - 35ms/step
Epoch 19/50
704/704 - 25s - loss: 1082.5310 - accuracy: 0.2388 - val_loss: 5.5870 -
val_accuracy: 0.2382 - 25s/epoch - 35ms/step
Epoch 20/50
704/704 - 25s - loss: 4.2518 - accuracy: 0.2864 - val_loss: 4.6809 -
val_accuracy: 0.2450 - 25s/epoch - 35ms/step
Epoch 21/50
704/704 - 25s - loss: 2.8884 - accuracy: 0.3040 - val_loss: 2.6360 -
val_accuracy: 0.3036 - 25s/epoch - 35ms/step
Epoch 22/50
704/704 - 25s - loss: 2.3594 - accuracy: 0.3220 - val_loss: 2.6378 -
val_accuracy: 0.2882 - 25s/epoch - 35ms/step
```

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Epoch 23/50
704/704 - 25s - loss: 2.1593 - accuracy: 0.3344 - val_loss: 2.2592 -
val_accuracy: 0.3180 - 25s/epoch - 35ms/step
Epoch 24/50
704/704 - 25s - loss: 2.0510 - accuracy: 0.3373 - val_loss: 2.1008 -
val_accuracy: 0.3126 - 25s/epoch - 35ms/step
Epoch 25/50
704/704 - 25s - loss: 652.0171 - accuracy: 0.2847 - val_loss: 9.1639 -
val_accuracy: 0.2294 - 25s/epoch - 35ms/step
Epoch 26/50
704/704 - 25s - loss: 4.7819 - accuracy: 0.2806 - val_loss: 4.0411 -
val_accuracy: 0.2554 - 25s/epoch - 35ms/step
Epoch 27/50
704/704 - 25s - loss: 2.8362 - accuracy: 0.3026 - val_loss: 3.1788 -
val_accuracy: 0.2826 - 25s/epoch - 35ms/step
Epoch 28/50
704/704 - 25s - loss: 2.3691 - accuracy: 0.3234 - val_loss: 2.1418 -
val_accuracy: 0.3206 - 25s/epoch - 35ms/step
Epoch 29/50
704/704 - 25s - loss: 2.1139 - accuracy: 0.3379 - val_loss: 2.0584 -
val_accuracy: 0.3230 - 25s/epoch - 35ms/step
Epoch 30/50
704/704 - 25s - loss: 2.0115 - accuracy: 0.3452 - val_loss: 2.1814 -
val_accuracy: 0.3208 - 25s/epoch - 35ms/step
Epoch 31/50
704/704 - 25s - loss: 2.0326 - accuracy: 0.3430 - val_loss: 3.6790 -
val_accuracy: 0.2270 - 25s/epoch - 35ms/step
Epoch 32/50
704/704 - 25s - loss: 538.7697 - accuracy: 0.2505 - val_loss: 5.3122 -
val_accuracy: 0.2768 - 25s/epoch - 35ms/step
```

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Epoch 33/50
704/704 - 25s - loss: 2.9790 - accuracy: 0.3003 - val_loss: 2.5023 -
val_accuracy: 0.2970 - 25s/epoch - 35ms/step
Epoch 34/50
704/704 - 25s - loss: 2.3441 - accuracy: 0.3248 - val_loss: 2.4832 -
val_accuracy: 0.2896 - 25s/epoch - 35ms/step
Epoch 35/50
704/704 - 25s - loss: 2.0754 - accuracy: 0.3434 - val_loss: 2.2538 -
val_accuracy: 0.3102 - 25s/epoch - 35ms/step
Epoch 36/50
704/704 - 25s - loss: 1.9811 - accuracy: 0.3499 - val_loss: 2.0168 -
val_accuracy: 0.3626 - 25s/epoch - 35ms/step
Epoch 37/50
704/704 - 25s - loss: 1.9280 - accuracy: 0.3532 - val_loss: 2.0551 -
val_accuracy: 0.3356 - 25s/epoch - 35ms/step
Epoch 38/50
704/704 - 25s - loss: 1.9461 - accuracy: 0.3542 - val_loss: 2.3041 -
val_accuracy: 0.2626 - 25s/epoch - 35ms/step
Epoch 39/50
704/704 - 25s - loss: 226.2200 - accuracy: 0.2693 - val_loss: 2.5522 -
val_accuracy: 0.3026 - 25s/epoch - 35ms/step
Epoch 40/50
704/704 - 25s - loss: 2.2249 - accuracy: 0.3294 - val_loss: 2.1475 -
val_accuracy: 0.3144 - 25s/epoch - 35ms/step
Epoch 41/50
704/704 - 25s - loss: 1.9870 - accuracy: 0.3541 - val_loss: 1.9956 -
val_accuracy: 0.3388 - 25s/epoch - 35ms/step
Epoch 42/50
704/704 - 25s - loss: 1.8634 - accuracy: 0.3702 - val_loss: 2.0271 -
val_accuracy: 0.3332 - 25s/epoch - 35ms/step
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Epoch 43/50
704/704 - 25s - loss: 1.8267 - accuracy: 0.3770 - val_loss: 1.9227 - val_accuracy: 0.3440 - 25s/epoch - 35ms/step
Epoch 44/50
704/704 - 25s - loss: 1.8254 - accuracy: 0.3741 - val_loss: 1.9125 - val_accuracy: 0.3476 - 25s/epoch - 35ms/step
Epoch 45/50
704/704 - 25s - loss: 1.8187 - accuracy: 0.3762 - val_loss: 1.8413 - val_accuracy: 0.3556 - 25s/epoch - 35ms/step
Epoch 46/50
704/704 - 25s - loss: 1.8582 - accuracy: 0.3625 - val_loss: 1.9232 - val_accuracy: 0.3260 - 25s/epoch - 35ms/step
Epoch 47/50
704/704 - 25s - loss: 365.0070 - accuracy: 0.2606 - val_loss: 3.9005 - val_accuracy: 0.2628 - 25s/epoch - 35ms/step
Epoch 48/50
704/704 - 25s - loss: 2.4611 - accuracy: 0.3192 - val_loss: 2.6621 - val_accuracy: 0.2976 - 25s/epoch - 35ms/step
Epoch 49/50
704/704 - 25s - loss: 2.0763 - accuracy: 0.3469 - val_loss: 2.1307 - val_accuracy: 0.3270 - 25s/epoch - 35ms/step
Epoch 50/50
704/704 - 25s - loss: 1.9269 - accuracy: 0.3649 - val_loss: 2.0645 - val_accuracy: 0.3144 - 25s/epoch - 35ms/step

RNN:

Epoch 1/50
704/704 - 32s - loss: 382.1806 - accuracy: 0.2369 - val_loss: 11.5990 - val_accuracy: 0.2098 - 32s/epoch - 45ms/step

```
Epoch 2/50
704/704 - 42s - loss: 382.3374 - accuracy: 0.2323 - val_loss: 13.3805 -
val_accuracy: 0.2296 - 42s/epoch - 60ms/step
Epoch 3/50
704/704 - 28s - loss: 5.6969 - accuracy: 0.2684 - val_loss: 4.4212 -
val_accuracy: 0.2374 - 28s/epoch - 40ms/step
Epoch 4/50
704/704 - 25s - loss: 2.9444 - accuracy: 0.2914 - val_loss: 2.7488 -
val_accuracy: 0.2962 - 25s/epoch - 35ms/step
Epoch 5/50
704/704 - 25s - loss: 2.4403 - accuracy: 0.3050 - val_loss: 2.7022 -
val_accuracy: 0.2844 - 25s/epoch - 35ms/step
Epoch 6/50
704/704 - 25s - loss: 2.3435 - accuracy: 0.3110 - val_loss: 4.5962 -
val_accuracy: 0.1712 - 25s/epoch - 36ms/step
Epoch 7/50
704/704 - 25s - loss: 3125.3899 - accuracy: 0.2236 - val_loss: 18.3583 -
val_accuracy: 0.2994 - 25s/epoch - 36ms/step
Epoch 8/50
704/704 - 25s - loss: 11.9006 - accuracy: 0.2680 - val_loss: 9.4926 -
val_accuracy: 0.2476 - 25s/epoch - 36ms/step
Epoch 9/50
704/704 - 25s - loss: 6.1908 - accuracy: 0.2742 - val_loss: 5.3801 -
val_accuracy: 0.2414 - 25s/epoch - 35ms/step
Epoch 10/50
704/704 - 25s - loss: 4.0877 - accuracy: 0.2799 - val_loss: 4.0850 -
val_accuracy: 0.2678 - 25s/epoch - 35ms/step
Epoch 11/50
704/704 - 25s - loss: 3.1546 - accuracy: 0.2904 - val_loss: 4.5448 -
val_accuracy: 0.2308 - 25s/epoch - 35ms/step
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Epoch 12/50
704/704 - 25s - loss: 2.9036 - accuracy: 0.2996 - val_loss: 2.7532 -
val_accuracy: 0.2614 - 25s/epoch - 35ms/step
Epoch 13/50
704/704 - 25s - loss: 458.8902 - accuracy: 0.2515 - val_loss: 4.1875 -
val_accuracy: 0.2800 - 25s/epoch - 35ms/step
Epoch 14/50
704/704 - 25s - loss: 3.2682 - accuracy: 0.2911 - val_loss: 3.4541 -
val_accuracy: 0.2180 - 25s/epoch - 35ms/step
Epoch 15/50
704/704 - 25s - loss: 2.3581 - accuracy: 0.3199 - val_loss: 2.5163 -
val_accuracy: 0.3104 - 25s/epoch - 35ms/step
Epoch 16/50
704/704 - 25s - loss: 2.1495 - accuracy: 0.3336 - val_loss: 2.1175 -
val_accuracy: 0.3194 - 25s/epoch - 35ms/step
Epoch 17/50
704/704 - 25s - loss: 2.0626 - accuracy: 0.3369 - val_loss: 2.2632 -
val_accuracy: 0.2870 - 25s/epoch - 35ms/step
Epoch 18/50
704/704 - 25s - loss: 2.0574 - accuracy: 0.3354 - val_loss: 4.5663 -
val_accuracy: 0.2372 - 25s/epoch - 35ms/step
Epoch 19/50
704/704 - 25s - loss: 1082.5310 - accuracy: 0.2388 - val_loss: 5.5870 -
val_accuracy: 0.2382 - 25s/epoch - 35ms/step
Epoch 20/50
704/704 - 25s - loss: 4.2518 - accuracy: 0.2864 - val_loss: 4.6809 -
val_accuracy: 0.2450 - 25s/epoch - 35ms/step
Epoch 21/50
704/704 - 25s - loss: 2.8884 - accuracy: 0.3040 - val_loss: 2.6360 -
val_accuracy: 0.3036 - 25s/epoch - 35ms/step
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Epoch 22/50
704/704 - 25s - loss: 2.3594 - accuracy: 0.3220 - val_loss: 2.6378 -
val_accuracy: 0.2882 - 25s/epoch - 35ms/step
Epoch 23/50
704/704 - 25s - loss: 2.1593 - accuracy: 0.3344 - val_loss: 2.2592 -
val_accuracy: 0.3180 - 25s/epoch - 35ms/step
Epoch 24/50
704/704 - 25s - loss: 2.0510 - accuracy: 0.3373 - val_loss: 2.1008 -
val_accuracy: 0.3126 - 25s/epoch - 35ms/step
Epoch 25/50
704/704 - 25s - loss: 652.0171 - accuracy: 0.2847 - val_loss: 9.1639 -
val_accuracy: 0.2294 - 25s/epoch - 35ms/step
Epoch 26/50
704/704 - 25s - loss: 4.7819 - accuracy: 0.2806 - val_loss: 4.0411 -
val_accuracy: 0.2554 - 25s/epoch - 35ms/step
Epoch 27/50
704/704 - 25s - loss: 2.8362 - accuracy: 0.3026 - val_loss: 3.1788 -
val_accuracy: 0.2826 - 25s/epoch - 35ms/step
Epoch 28/50
704/704 - 25s - loss: 2.3691 - accuracy: 0.3234 - val_loss: 2.1418 -
val_accuracy: 0.3206 - 25s/epoch - 35ms/step
Epoch 29/50
704/704 - 25s - loss: 2.1139 - accuracy: 0.3379 - val_loss: 2.0584 -
val_accuracy: 0.3230 - 25s/epoch - 35ms/step
Epoch 30/50
704/704 - 25s - loss: 2.0115 - accuracy: 0.3452 - val_loss: 2.1814 -
val_accuracy: 0.3208 - 25s/epoch - 35ms/step
Epoch 31/50
704/704 - 25s - loss: 2.0326 - accuracy: 0.3430 - val_loss: 3.6790 -
val_accuracy: 0.2270 - 25s/epoch - 35ms/step
```

```
Epoch 32/50
704/704 - 25s - loss: 538.7697 - accuracy: 0.2505 - val_loss: 5.3122 -
val_accuracy: 0.2768 - 25s/epoch - 35ms/step
Epoch 33/50
704/704 - 25s - loss: 2.9790 - accuracy: 0.3003 - val_loss: 2.5023 -
val_accuracy: 0.2970 - 25s/epoch - 35ms/step
Epoch 34/50
704/704 - 25s - loss: 2.3441 - accuracy: 0.3248 - val_loss: 2.4832 -
val_accuracy: 0.2896 - 25s/epoch - 35ms/step
Epoch 35/50
704/704 - 25s - loss: 2.0754 - accuracy: 0.3434 - val_loss: 2.2538 -
val_accuracy: 0.3102 - 25s/epoch - 35ms/step
Epoch 36/50
704/704 - 25s - loss: 1.9811 - accuracy: 0.3499 - val_loss: 2.0168 -
val_accuracy: 0.3626 - 25s/epoch - 35ms/step
Epoch 37/50
704/704 - 25s - loss: 1.9280 - accuracy: 0.3532 - val_loss: 2.0551 -
val_accuracy: 0.3356 - 25s/epoch - 35ms/step
Epoch 38/50
704/704 - 25s - loss: 1.9461 - accuracy: 0.3542 - val_loss: 2.3041 -
val_accuracy: 0.2626 - 25s/epoch - 35ms/step
Epoch 39/50
704/704 - 25s - loss: 226.2200 - accuracy: 0.2693 - val_loss: 2.5522 -
val_accuracy: 0.3026 - 25s/epoch - 35ms/step
Epoch 40/50
704/704 - 25s - loss: 2.2249 - accuracy: 0.3294 - val_loss: 2.1475 -
val_accuracy: 0.3144 - 25s/epoch - 35ms/step
Epoch 41/50
704/704 - 25s - loss: 1.9870 - accuracy: 0.3541 - val_loss: 1.9956 -
val_accuracy: 0.3388 - 25s/epoch - 35ms/step
```

```
Epoch 42/50
704/704 - 25s - loss: 1.8634 - accuracy: 0.3702 - val_loss: 2.0271 -
val_accuracy: 0.3332 - 25s/epoch - 35ms/step
Epoch 43/50
704/704 - 25s - loss: 1.8267 - accuracy: 0.3770 - val_loss: 1.9227 -
val_accuracy: 0.3440 - 25s/epoch - 35ms/step
Epoch 44/50
704/704 - 25s - loss: 1.8254 - accuracy: 0.3741 - val_loss: 1.9125 -
val_accuracy: 0.3476 - 25s/epoch - 35ms/step
Epoch 45/50
704/704 - 25s - loss: 1.8187 - accuracy: 0.3762 - val_loss: 1.8413 -
val_accuracy: 0.3556 - 25s/epoch - 35ms/step
Epoch 46/50
704/704 - 25s - loss: 1.8582 - accuracy: 0.3625 - val_loss: 1.9232 -
val_accuracy: 0.3260 - 25s/epoch - 35ms/step
Epoch 47/50
704/704 - 25s - loss: 365.0070 - accuracy: 0.2606 - val_loss: 3.9005 -
val_accuracy: 0.2628 - 25s/epoch - 35ms/step
Epoch 48/50
704/704 - 25s - loss: 2.4611 - accuracy: 0.3192 - val_loss: 2.6621 -
val_accuracy: 0.2976 - 25s/epoch - 35ms/step
Epoch 49/50
704/704 - 25s - loss: 2.0763 - accuracy: 0.3469 - val_loss: 2.1307 -
val_accuracy: 0.3270 - 25s/epoch - 35ms/step
Epoch 50/50
704/704 - 25s - loss: 1.9269 - accuracy: 0.3649 - val_loss: 2.0645 -
val_accuracy: 0.5144 - 25s/epoch - 35ms/step
```

b. Loss and accuracy for testing phase (on test set) of FFNN and RNN

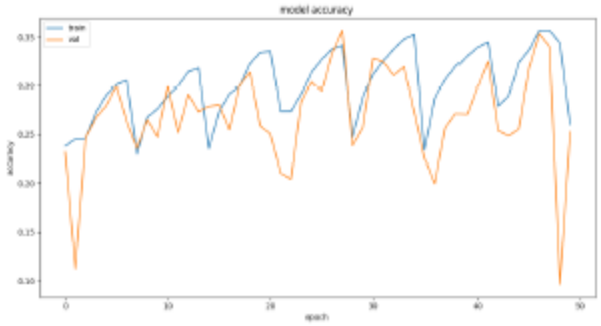
FFNN:

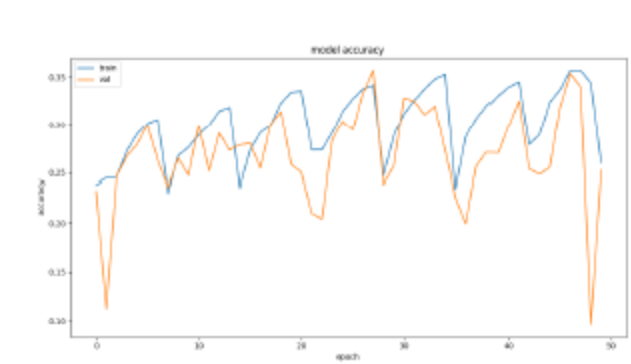
Test loss: 2.0304903984069824
Test accuracy: 0.314300000667572

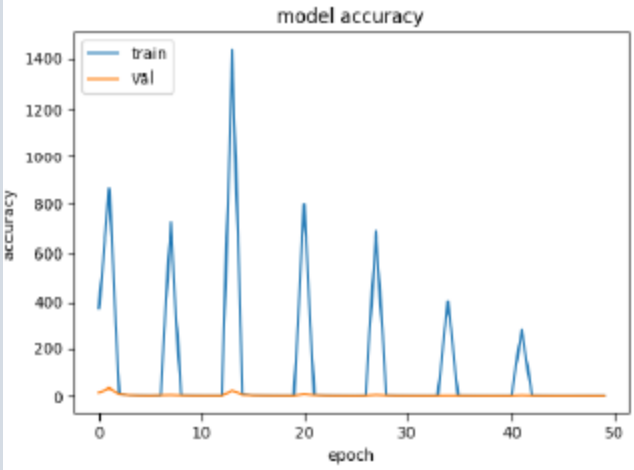
RNN:

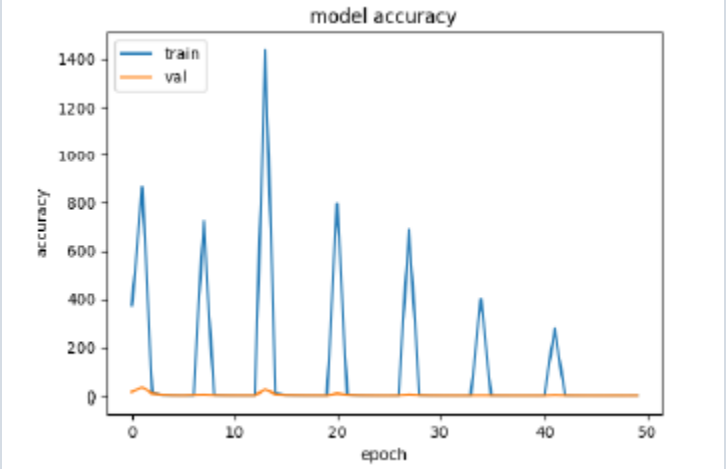
Test loss: 1.0501914998741123
Test accuracy: 0.614325000367177

c. Plot the loss and accuracy for both the cases above.




model accuracy
train
val
accuracy
epoch


model accuracy
train
val
1400
1200
1000
800
600
400
200
0
accuracy
0
10
20
30
40
50
epoch


model accuracy
train
val
1400
1200
1000
800
600
400
200
0
accuracy
0
10
20
30
40
50
epoch

d. **Write reasoning for why an RNN works better than FFNN in general.**

Simply put RNNs have memory while simple (like Perceptron) and not-so-simple (like CNNs) networks do not.

In any instance of a single operation (like classifying single image) feed-forward network has no information about what it did before, it always starts from whatever state it was trained to beforehand. No evolution after initial training.

RNNs on the other hand besides payload (like an image to describe) receive their own output from the previous application (and transitively from all previous applications). This way they can transfer some data to "future self" thus forming a sort of memory and evolving further from new instances of application.