

Artificial Intelligence and Machine Learning

Homework 2

Matteo Stoisa – s265542

Introduction

The aim of the homework is to experiment, evaluate and optimize the functioning of AlexNet, a deep convolutional neural network specialized in image classification.

I implemented code in Python 3 mainly using PyTorch library and ran in Colab environment using GPU which guarantees faster computation (each train-validation-test run takes from about 7 up to 15 minutes).

The Architecture

AlexNet is a CNN (convolutional neural network) composed by eight learnig layers: five convolutional layers (*feautures 0, 3, 6, 8, 10*) and three fully-connected layers (*classifier 1, 4, 6*), followed by non-linear ReLu and maxpool layers.

```
AlexNet(  
  (features): Sequential(  
    (0): Conv2d(3, 64, kernel_size=(11, 11), stride=(4, 4), padding=(2, 2))  
    (1): ReLU(inplace=True)  
    (2): MaxPool2d(kernel_size=3, stride=2, padding=0, dilation=1, ceil_mode=False)  
    (3): Conv2d(64, 192, kernel_size=(5, 5), stride=(1, 1), padding=(2, 2))  
    (4): ReLU(inplace=True)  
    (5): MaxPool2d(kernel_size=3, stride=2, padding=0, dilation=1, ceil_mode=False)  
    (6): Conv2d(192, 384, kernel_size=(3, 3), stride=(1, 1), padding=(1, 1))  
    (7): ReLU(inplace=True)  
    (8): Conv2d(384, 256, kernel_size=(3, 3), stride=(1, 1), padding=(1, 1))  
    (9): ReLU(inplace=True)  
    (10): Conv2d(256, 256, kernel_size=(3, 3), stride=(1, 1), padding=(1, 1))  
    (11): ReLU(inplace=True)  
    (12): MaxPool2d(kernel_size=3, stride=2, padding=0, dilation=1, ceil_mode=False)  
  )  
  (avgpool): AdaptiveAvgPool2d(output_size=(6, 6))  
  (classifier): Sequential(  
    (0): Dropout(p=0.5, inplace=False)  
    (1): Linear(in_features=9216, out_features=4096, bias=True)  
    (2): ReLU(inplace=True)  
    (3): Dropout(p=0.5, inplace=False)  
    (4): Linear(in_features=4096, out_features=4096, bias=True)  
    (5): ReLU(inplace=True)  
    (6): Linear(in_features=4096, out_features=101, bias=True)  
  )  
)
```

The Dataset

The dataset used is Caltech-101, It contains about 8600 pictures of 101 different categories, with about 50 (or more) images per each category.

I split It into train-set, validation-set and test-set in three equal parts. Initially, the blank network has been trained with the only Caltech-101 dataset, as results will show 8000 images are not enough so that the accuracy scores up to 50%. In a second time I used the network pretrained on ImageNet dataset that counts about five hundred images per category, the train procedure has been performed in different ways just to adjust and optimize the pretrained parameters of the network.

1. Data Preparation

Images and labels are processed and stored into data structures using a custom class in order to filter an unneeded class (underground). The custom dataset object (Caltech) offers a length function (that returns the number of couple) and a getter function that returns a couple image-label by index. This lets the dataset be used by PyTorch Dataloader that iterates over the dataset during the train, validation and test procedures. The getter function performs a set of PyTorch Transformation on the image if specified during the dataset instantiation, in the first part transformations applied are resize, center crop and normalization in order to uniform images of different types.

2. Training from Scratch

The whole Caltech dataset is split into train-set, validation-set and test-set in equal parts using the PyTorch Subset function wondering that different classes have the same distribution in the three sets. The validation process is performed at the end of each train epoch in order to log the evolution of the network accuracy so that only the best model will be used to perform the final test on the test-set.

The network uses the SGD optimizer with momentum with the following weight update rule:

$$\begin{aligned}\Delta w &:= \mu \Delta w + \epsilon \left(\left\langle \frac{\partial E}{\partial w} \right\rangle_i - \omega w \right) \\ w &:= w + \Delta w\end{aligned}$$

where ω is the coefficient of weight decay, μ is the momentum, ϵ is the learning rate and $\langle \partial E / \partial w \rangle_i$ denotes the expectation of the weight gradient for a batch i .

The following parameters are kept constant during all tests:

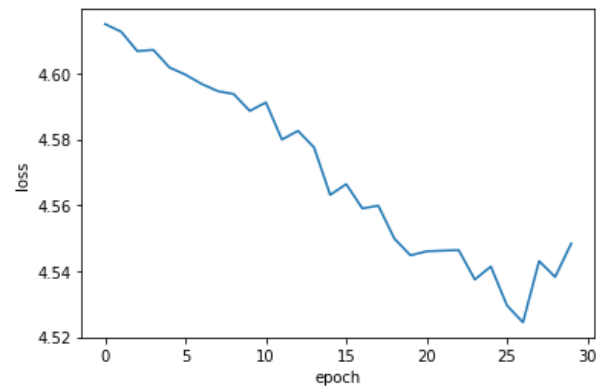
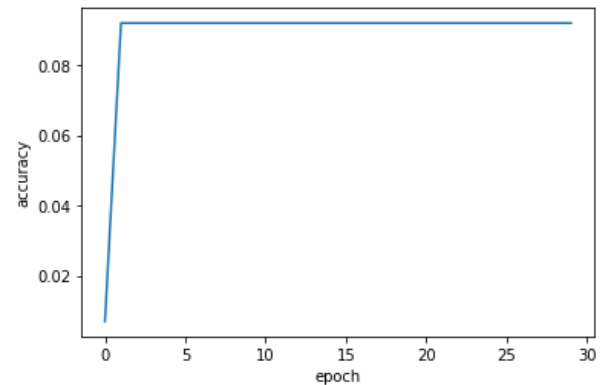
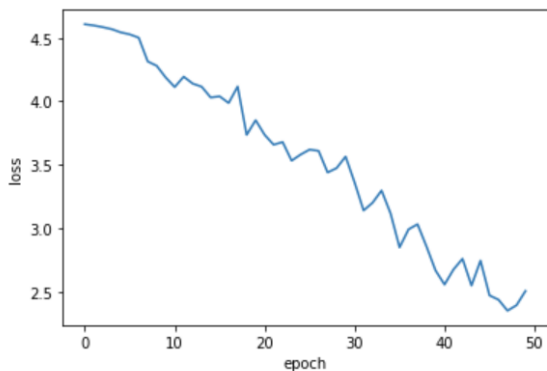
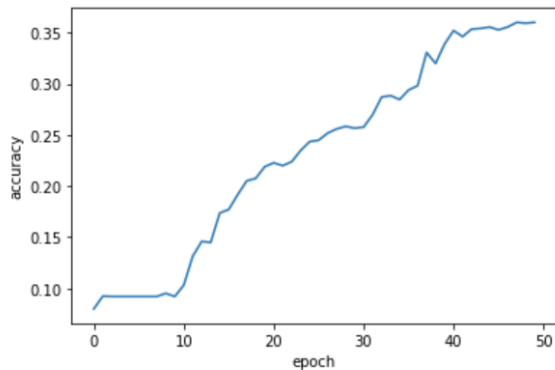
- BATCH_SIZE: 256 (number of images taken from the train-set each train iteration)
- MOMENTUM: 0.9
- WEIGHT_DECAY: $5e-5$
- GAMMA: 0.1

On the other hand this three parameters are tuned in each test in order to find the best results:

- LR (learning rate)
- NUM_EPOCH (number of epochs of training)
- STEP_SIZE (number of epochs after that the learning rate is decreased of a 10 factor)

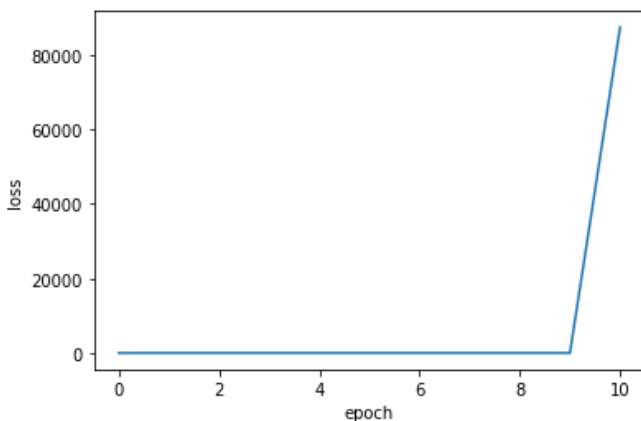
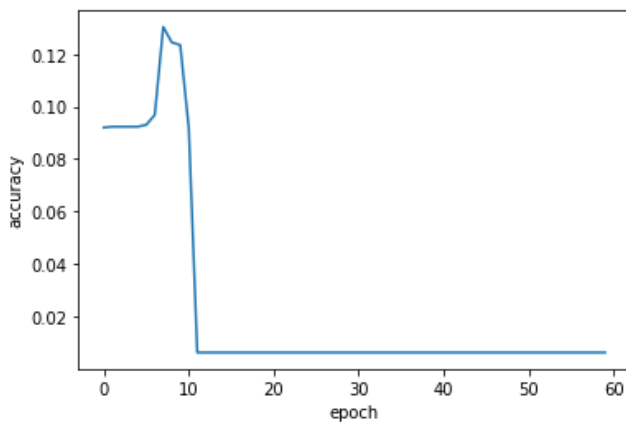
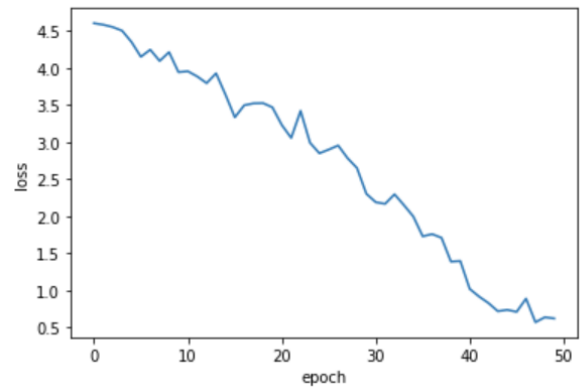
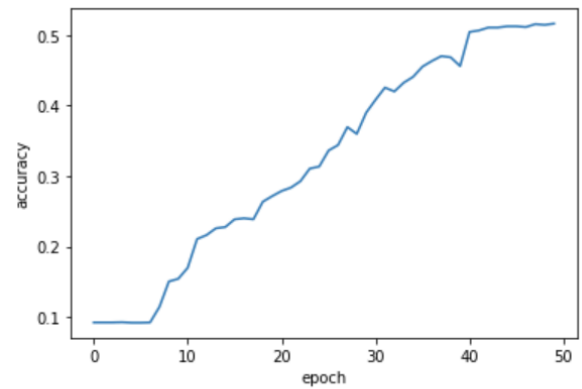
Following graphs show the trend of accuracy and loss during the epochs calculated on the validation-set, less relevant score logs are also reported in appendix for completeness.

- In the first try using LR 0.001, NUM_EPOCH 30 and STEP_SIZE 20 [2C-1] the accuracy remains under the 10% though the loss slightly decreases, obviously the learning rate is too small. The test-set scores the same accuracy.



- Increasing to LR 0.005, NUM_EPOCH 50 and STEP_SIZE 40 [2C-5] the accuracy arrives to 35% in the validation and in the test too

- Increasing LR 0.01, NUM_EPOCH 50 and STEP_SIZE 40 [2C-4] the network scores the best accuracy score of 51% on the validation-set and 52% on the test-set.



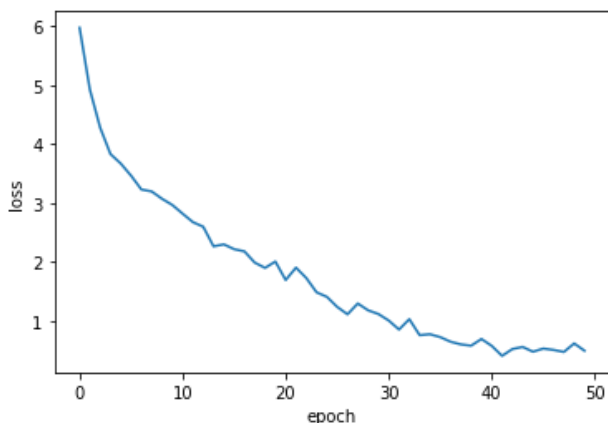
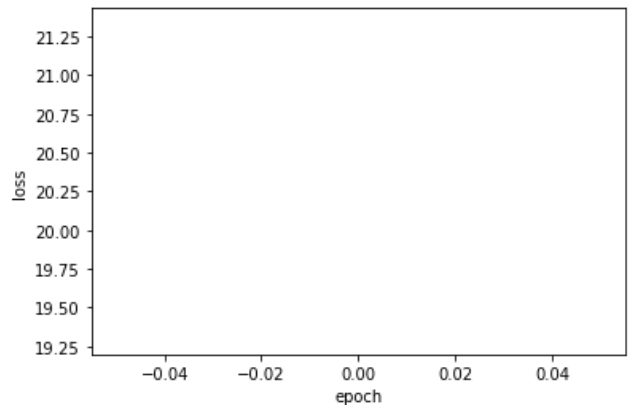
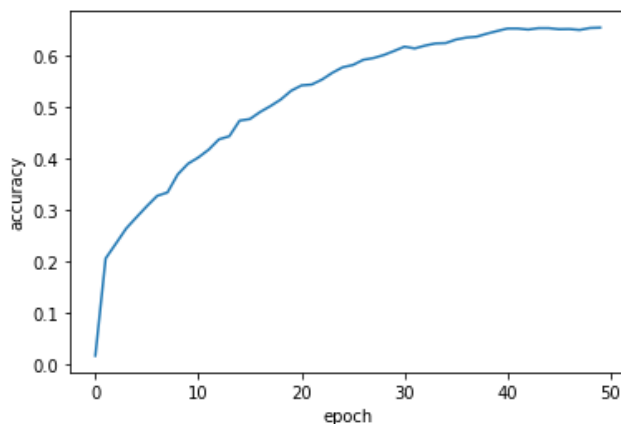
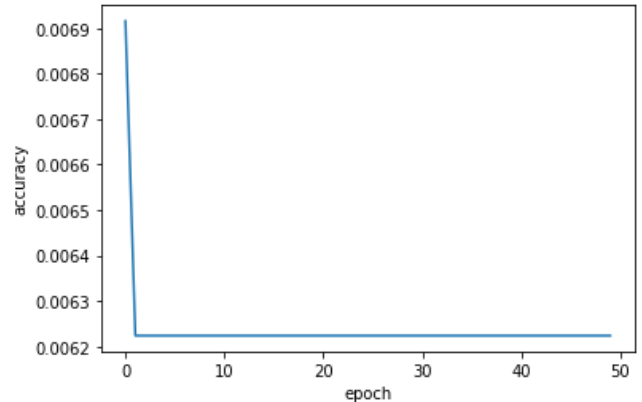
- Tring to increase LR 0.1 with higher NUM_EPOCH 60 and a low STEP_SIZE 20 [2C-7] the network diverges, accuracy stays under 10% and the loss becomes too large after only 10 epochs so that It can't even be logged.

- As appendix logs show, keeping LR 0.01 and varying NUM_EPOCH and STEP_SIZE 40-20 [2C-2], 40-30 [2C-3], 50-20 [2C-8], 70-20 [2C-9] the accuracy score remains between 40% and 50%.

3. Transfer Learning

Using the technique of transfer learning, I imported AlexNet pretrained on ImageNet dataset. Weights of the network are already tuned on this big number of images and the further train on Caltech-101 slightly improve them.

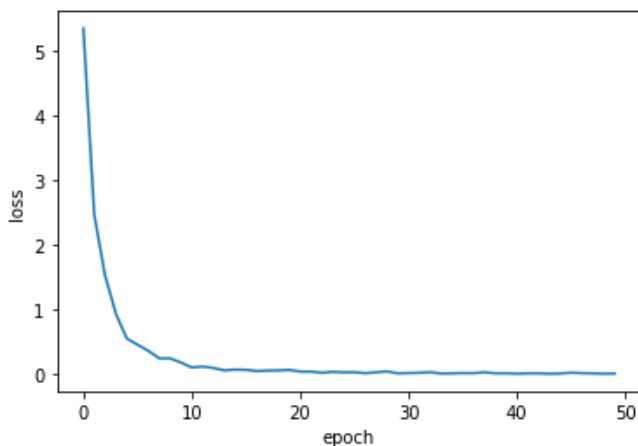
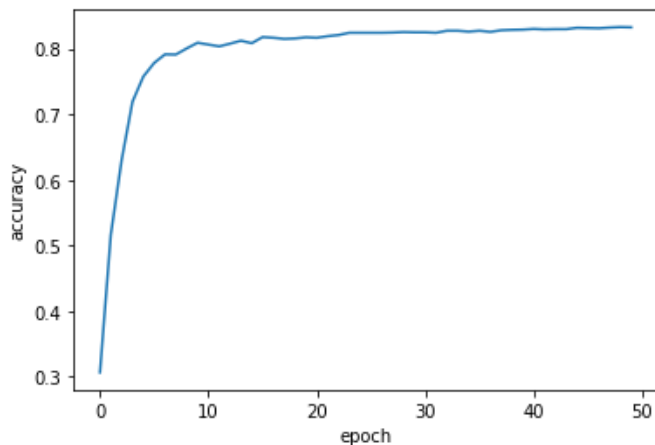
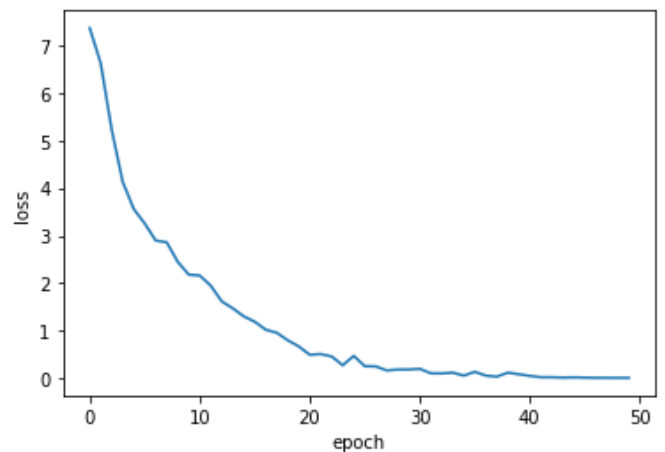
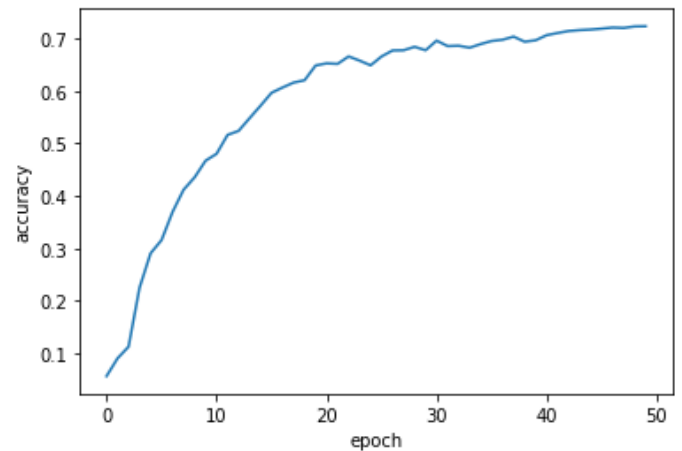
- Predictably, using the parameters LR 0.01, NUM_EPOCH 50 and STEP_SIZE 40 [3C-1] that previously gave the best result, the network diverges. This happens because the learning rate is too big applied on yet tuned weights.



- Decreasing to LR 0.001, NUM_EPOCHS 50 and STEP_SIZE 40 [3C-2] the accuracy reaches 65% on the validation and on the test-set

- Tuning the LR 0.005, NUM_EPOCHS 50 and STEP_SIZE 40 [3C-5] the network achieves the best score of 72% on the validation and 71% on the test-set.

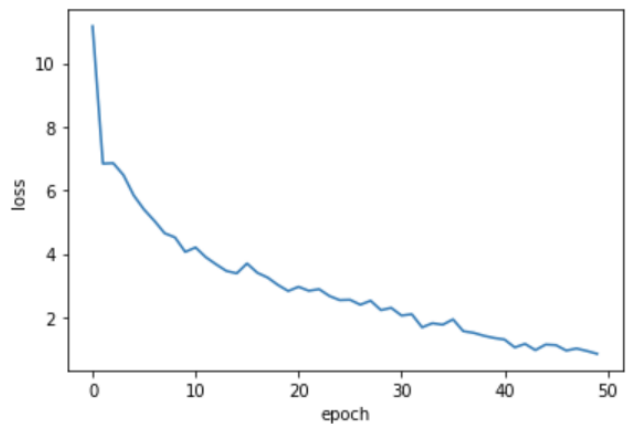
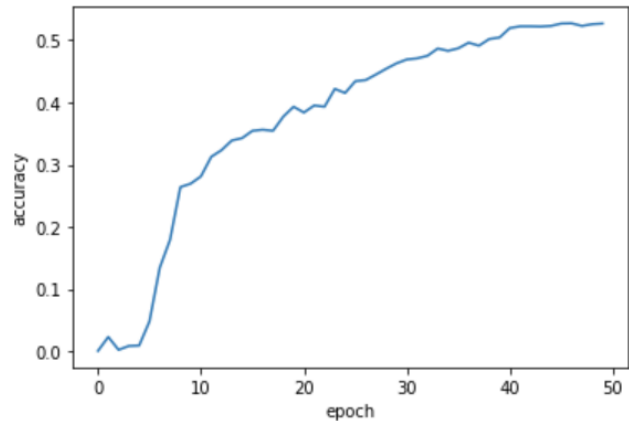
Using LR 0.001 [3C-3] and 0.005 [3C-4] I also tried to tune NUM_EPOCHS 60 and STEP_SIZE 20, results are similarly, slightly lower as the appendix logs show.



- Using the best parameters found (LR 0.005, NUM_EPOCHS 50, STEP_SIZE 40) [3D-1] I set the optimizer to work only on the fully connected layers. Without changes on the convolutional layers, the network achieves an accuracy score of 83% in validation and test. Transfer learning starting from the ImageNet pretrain with only fully connected layers fine train on Caltech-101 leads to the best result.

- Conversely, performing the train only on the convolutional layers (again with LR 0.005, NUM_EPOCHS 50, STEP_SIZE 40) [3E-1] leads to a lower result of 53%.

Thinking this poor result were caused by the too high learning rate I tried with LR 0.001 [3E-2] but accuracy got worse to 40%

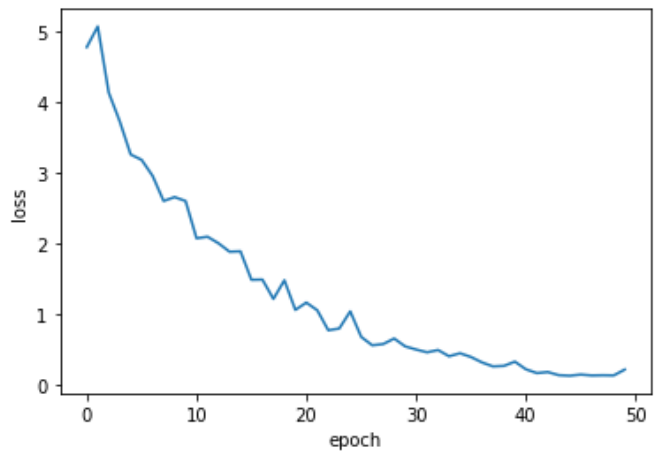
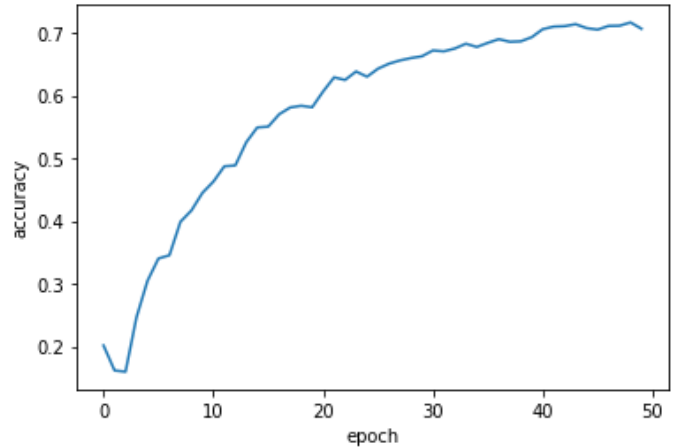


4. Data Augmentation

In order to increase the amount of image and their difference while maintaining the characteristics of the label, I applied different transformations that modifies images used in the train procedure. Transformations are applied randomly (with set probability) when the image is taken from the train-set by the Dataloader so that each epoch different images are randomly slightly modified. I used again best parameters found previously (LR 0.005, NUM_EPOCHS 50, STEP_SIZE 40) .

- [4A-1] Applying an horizontal flip and a vertical flip, both with a 0.5 probability, the network achieves an accuracy score on the validation and on the test of 70%, similarly to [3C-5]. There seems to be no difference with or without using this kind of transformation.
- [4A-2] Modifying the image color to grayscale, with probability 0.1, the accuracy on the validation remains near 70% but the score on the test-set achieves only 60%. This negative result is probably related to the fact that images of the test-set are not in gray scale so the network falls in over-fit.

- [4A-3] Applying bot horizontal flip, vertical flip and grayscale color (with same probability) the result is similar to [4A-2] so that prevails the problem of absence of grayscale images in the test-set.



Appendix (2)

[2C-1] (LR 0.001, NUM_EPOCHS 30, STEP_SIZE 20)

VALIDATION Final Results (epoch, accuracy, loss):
(0, 0.006915629322268326, 4.6149702072143555)
(1, 0.09197786998616875, 4.612652778625488)
(2, 0.09197786998616875, 4.606773853302002)
(3, 0.09197786998616875, 4.607143402099609)
(4, 0.09197786998616875, 4.601810455322266)
(5, 0.09197786998616875, 4.599611759185791)
(6, 0.09197786998616875, 4.596821308135986)
(7, 0.09197786998616875, 4.594636917114258)
(8, 0.09197786998616875, 4.593742847442627)
(9, 0.09197786998616875, 4.588617324829102)
(10, 0.09197786998616875, 4.591211795806885)
(11, 0.09197786998616875, 4.57993745803833)
(12, 0.09197786998616875, 4.582572937011719)
(13, 0.09197786998616875, 4.577535152435303)
(14, 0.09197786998616875, 4.563137054443359)
(15, 0.09197786998616875, 4.5664167404174805)
(16, 0.09197786998616875, 4.55905294418335)
(17, 0.09197786998616875, 4.559854984283447)
(18, 0.09197786998616875, 4.549836158752441)
(19, 0.09197786998616875, 4.544792175292969)
(20, 0.09197786998616875, 4.546023368835449)
(21, 0.09197786998616875, 4.546219825744629)
(22, 0.09197786998616875, 4.546366214752197)

(23, 0.09197786998616875, 4.5374627113342285)
(24, 0.09197786998616875, 4.541413307189941)
(25, 0.09197786998616875, 4.529598236083984)
(26, 0.09197786998616875, 4.524450778961182)
(27, 0.09197786998616875, 4.543066501617432)
(28, 0.09197786998616875, 4.538241386413574)
(29, 0.09197786998616875, 4.548398494720459)

Best model accuracy: 0.09197786998616875

TEST Accuracy Final Result: 0.09194607673695127

[2C-2] (LR 0.01, NUM_EPOCHS 40, STEP_SIZE 20)

VALIDATION Final Results (epoch, accuracy, loss):
(0, 0.09197786998616875, 4.602643966674805)
(1, 0.09197786998616875, 4.57694149017334)
(2, 0.09197786998616875, 4.558826446533203)
(3, 0.09197786998616875, 4.497818470001221)
(4, 0.09197786998616875, 4.2119550704956055)
(5, 0.09197786998616875, 4.171655654907227)
(6, 0.11860304287690179, 4.225765228271484)
(7, 0.10926694329183956, 4.089466571807861)
(8, 0.14764868603042877, 4.057936668395996)
(9, 0.15802213001383125, 4.0990309715271)
(10, 0.19813278008298754, 4.094510555267334)
(11, 0.18672199170124482, 3.9655990600585938)
(12, 0.2202627939142462, 3.626392364501953)

(13, 0.22475795297372061, 3.7142438888549805)
(14, 0.2181881051175657, 3.535285472869873)
(15, 0.23098201936376211, 3.5982604026794434)
(16, 0.23858921161825727, 3.488229274749756)
(17, 0.24688796680497926, 3.4304096698760986)
(18, 0.2524204702627939, 3.3996102809906006)
(19, 0.2648686030428769, 3.3333113193511963)
(20, 0.262448132780083, 3.4742259979248047)
(21, 0.27005532503457813, 3.319077730178833)
(22, 0.27351313969571234, 3.0282435417175293)
(23, 0.27005532503457813, 3.286785125732422)
(24, 0.27247579529737204, 3.099599599838257)
(25, 0.2752420470262794, 3.184931993484497)
(26, 0.2818118948824343, 3.2669365406036377)
(27, 0.2797372060857538, 3.2618205547332764)
(28, 0.279045643153527, 3.1083757877349854)
(29, 0.2835408022130014, 3.259258508682251)
(30, 0.28319502074688796, 2.922548770904541)
(31, 0.28250345781466113, 3.0402681827545166)
(32, 0.28734439834024894, 2.976297378540039)
(33, 0.2925311203319502, 3.1016016006469727)
(34, 0.29149377593361, 3.21102237701416)
(35, 0.2897648686030429, 2.8251240253448486)
(36, 0.2942600276625173, 2.9829511642456055)
(37, 0.2966804979253112, 3.052229404449463)
(38, 0.29495159059474413, 2.9825637340545654)
(39, 0.29806362378976486, 2.914339065551758)

Best model accuracy: 0.29806362378976486

TEST Accuracy Final Result: 0.2976149325959212

[2C-3] (LR 0.01, NUM_EPOCHS 40, STEP_SIZE 30)

VALIDATION Final Results (epoch, accuracy, loss):
(0, 0.09232365145228216, 4.605880260467529)
(1, 0.09232365145228216, 4.577836513519287)
(2, 0.15836791147994467, 4.560397624969482)
(3, 0.09197786998616875, 4.477816104888916)
(4, 0.15110650069156292, 4.284994125366211)
(5, 0.09197786998616875, 4.231678009033203)
(6, 0.1037344398340249, 4.243941783905029)
(7, 0.1078838174273859, 4.062342643737793)
(8, 0.15179806362378975, 4.294162273406982)
(9, 0.19536652835408022, 3.9222147464752197)
(10, 0.21092669432918396, 3.9500792026519775)
(11, 0.2140387275242047, 3.792290210723877)
(12, 0.22406639004149378, 3.4661941528320312)
(13, 0.22337482710926695, 3.7279694080352783)
(14, 0.2306362378976487, 3.6893739700317383)
(15, 0.2351313969571231, 3.623199701309204)
(16, 0.2392807745504841, 3.5090935230255127)
(17, 0.2503457814661134, 3.441349983215332)
(18, 0.25864453665283543, 3.429628610610962)
(19, 0.2645228215767635, 3.5335195064544678)
(20, 0.2693637621023513, 3.410433053970337)
(21, 0.2866528354080221, 3.204057455062866)
(22, 0.2991009681881051, 2.9337284564971924)
(23, 0.28042876901798064, 3.1086902618408203)
(24, 0.3029045643153527, 2.967963218688965)
(25, 0.30532503457814664, 2.8084158897399902)
(26, 0.3350622406639004, 2.83646297454834)
(27, 0.35096818810511754, 2.7698354721069336)
(28, 0.37413554633471646, 2.7029435634613037)
(29, 0.3599585062240664, 2.492480516433716)
(30, 0.3824343015214384, 2.3626248836517334)
(31, 0.3962655601659751, 2.295086622238159)
(32, 0.39730290456431533, 2.0530776977539062)
(33, 0.4017980636237898, 2.1981630325317383)
(34, 0.40352697095435686, 1.9346150159835815)
(35, 0.40318118948824344, 2.206629991531372)
(36, 0.41217150760719223, 2.2269232273101807)

(37, 0.41044260027662516, 1.906809687614441)
(38, 0.4135546334716459, 2.033097267150879)
(39, 0.42012448132780084, 1.916806936264038)

Best model accuracy: 0.42012448132780084

TEST Accuracy Final Result: 0.41513999308676114

[2C-4] (LR 0.01, NUM_EPOCHS 50, STEP_SIZE 40)

VALIDATION Final Results (epoch, accuracy, loss):
(0, 0.09232365145228216, 4.602494239807129)
(1, 0.09232365145228216, 4.5822343826293945)
(2, 0.09232365145228216, 4.550873279571533)
(3, 0.09266943291839558, 4.50163459777832)
(4, 0.09197786998616875, 4.349424362182617)
(5, 0.09197786998616875, 4.149726867675781)
(6, 0.09232365145228216, 4.245110511779785)
(7, 0.1144536652835408, 4.092945098876953)
(8, 0.1504149377593361, 4.212347030639648)
(9, 0.1542185338865837, 3.941973924636841)
(10, 0.16977869986168742, 3.9537785053253174)
(11, 0.21058091286307054, 3.8835251331329346)
(12, 0.2161134163208852, 3.7933177947998047)
(13, 0.22579529737206086, 3.9262287616729736)
(14, 0.22752420470262794, 3.6392810344696045)
(15, 0.23858921161825727, 3.33247971534729)
(16, 0.23997233748271093, 3.495296001434326)
(17, 0.23858921161825727, 3.5210235118865967)
(18, 0.26348547717842324, 3.524085521697998)
(19, 0.2714384508990318, 3.467210292816162)
(20, 0.27869986168741356, 3.229203224182129)
(21, 0.2835408022130014, 3.0544593334198)
(22, 0.2925311203319502, 3.419711112976074)
(23, 0.31051175656984786, 2.9897544384002686)
(24, 0.3132780082987552, 2.8470466136932373)
(25, 0.3360995850622407, 2.897463083267212)
(26, 0.3437067773167358, 2.952746629714966)
(27, 0.36929460580912865, 2.7810757160186768)
(28, 0.359612724757953, 2.648627042770387)
(29, 0.3896957123098202, 2.3009331226348877)
(30, 0.40802213001383125, 2.186551332473755)
(31, 0.42531120331950206, 2.1646676063537598)
(32, 0.4197786998616874, 2.2935800552368164)
(33, 0.4322268326417704, 2.1474835872650146)
(34, 0.4405255878284924, 1.9939594268798828)
(35, 0.45504840940525587, 1.7264134883880615)
(36, 0.4630013831258645, 1.7563265562057495)
(37, 0.4699170124481328, 1.706920862197876)
(38, 0.4681881051175657, 1.385825753211975)
(39, 0.4557399723374827, 1.393351674079895)
(40, 0.504149377593361, 1.016473650932312)
(41, 0.5062240663900415, 0.9130882024765015)
(42, 0.5103734439834025, 0.8250301480293274)
(43, 0.5103734439834025, 0.7153604030609131)
(44, 0.5121023513139695, 0.7339391708374023)
(45, 0.5121023513139695, 0.7068967223167419)
(46, 0.5110650069156293, 0.8859679102897644)
(47, 0.5152143845089903, 0.5667560696601868)
(48, 0.51417704011065, 0.6341248750686646)
(49, 0.5159059474412172, 0.6176919341087341)

Best model accuracy: 0.5159059474412172

TEST Accuracy Final Result: 0.5219495333563775

[2C-5] (LR 0.005, NUM_EPOCHS 50, STEP_SIZE 40)

VALIDATION Final Results (epoch, accuracy, loss):
(0, 0.07987551867219916, 4.608321666717529)
(1, 0.09232365145228216, 4.598754405975342)

(2, 0.09197786998616875, 4.585377216339111)
(3, 0.09197786998616875, 4.569484710693359)
(4, 0.09197786998616875, 4.544224739074707)
(5, 0.09197786998616875, 4.5282745361328125)
(6, 0.09197786998616875, 4.502050399780273)
(7, 0.09197786998616875, 4.314676284790039)
(8, 0.09508990318118948, 4.280320167541504)
(9, 0.09197786998616875, 4.1880998611450195)
(10, 0.10304287690179806, 4.112736701965332)
(11, 0.1313969571230982, 4.194580078125)
(12, 0.1459197786998617, 4.140118598937988)
(13, 0.14488243430152145, 4.115397930145264)
(14, 0.173582295988935, 4.030635356903076)
(15, 0.17704011065006917, 4.039276123046875)
(16, 0.1915629322683266, 3.9868290424346924)
(17, 0.20504840940525587, 4.117069244384766)
(18, 0.2074688796680498, 3.735490560531616)
(19, 0.21887966804979253, 3.8513243198394775)
(20, 0.22268326417704012, 3.735705852508545)
(21, 0.21991701244813278, 3.6579253673553467)
(22, 0.22372060857538037, 3.6790266036987305)
(23, 0.23478561549100968, 3.5320472717285156)
(24, 0.24343015214384509, 3.5802273750305176)
(25, 0.24481327800829875, 3.61956787109375)
(26, 0.2517289073305671, 3.6091811656951904)
(27, 0.25587828492392806, 3.4389922618865967)
(28, 0.258298755186722, 3.47331953044870605)
(29, 0.2565698478561549, 3.5646612644195557)
(30, 0.25760719225449513, 3.3603837490081787)
(31, 0.2697095435684647, 3.139172077178955)
(32, 0.2869986168741355, 3.200249433517456)
(33, 0.2883817427385892, 3.2968082427978516)
(34, 0.2845781466113416, 3.115852117538452)
(35, 0.2939142461964039, 2.848116397857666)
(36, 0.29806362378976486, 2.9904582500457764)
(37, 0.330567081604426, 3.030683755874634)
(38, 0.31984785615491007, 2.85427188873291)
(39, 0.338865836791148, 2.666139841079712)
(40, 0.35200553250345784, 2.5547006130218506)
(41, 0.34612724757952973, 2.6739706993103027)
(42, 0.3533886583679115, 2.7584316730499268)
(43, 0.35408022130013833, 2.5468902587890625)
(44, 0.355463347164592, 2.7435643672943115)
(45, 0.35269709543568467, 2.469059705734253)
(46, 0.355463347164592, 2.4354922771453857)
(47, 0.3599585062240664, 2.3486249446868896)
(48, 0.35926694329183956, 2.3915345668792725)
(49, 0.3599585062240664, 2.5040805339813232)

Best model accuracy: 0.3599585062240664

TEST Accuracy Final Result: 0.3643276875216039

[2C-6] (LR 0.05, NUM_EPOCHS 50, STEP_SIZE 20)

VALIDATION Final Results (epoch, accuracy, loss):

(0, 0.09612724757952974, 4.563028812408447)
(1, 0.09232365145228216, 4.324764728546143)
(2, 0.09232365145228216, 4.235649108886719)
(3, 0.09197786998616875, 4.370594024658203)
(4, 0.09232365145228216, 4.190117359161377)
(5, 0.09197786998616875, 4.1983819007873535)
(6, 0.16009681881051174, 4.1469855308532715)
(7, 0.17669432918395575, 4.0413899421691895)
(8, 0.19986168741355465, 3.8424932956695557)
(9, 0.22821576763485477, 3.751800060272217)
(10, 0.22821576763485477, 3.56296968460083)
(11, 0.3087828492392808, 3.049593448638916)
(12, 0.05013831258644537, 4.4248480796813965)
(13, 0.09197786998616875, 4.247037410736084)
(14, 0.09197786998616875, 4.131260871887207)
(15, 0.15871369294605808, 4.217735290527344)

(16, 0.09232365145228216, 4.1217122077941895)
(17, 0.1338174273858921, 4.1433587074279785)
(18, 0.19017980636237897, 3.9191384315490723)
(19, 0.21161825726141079, 3.8594017028808594)
(20, 0.22164591977869985, 3.7463796138763428)
(21, 0.23201936376210236, 3.8074398040771484)
(22, 0.24100968188105118, 3.6436820030212402)
(23, 0.2527662517289073, 3.441620349884033)
(24, 0.26141078838174275, 3.6193032264709473)
(25, 0.262448132780083, 3.27597975730896)
(26, 0.2766251728907331, 3.1691768169403076)
(27, 0.2887275242047026, 3.2530906200408936)
(28, 0.29149377593361, 3.087158441543579)
(29, 0.2901106500691563, 3.169311761856079)
(30, 0.3008298755186722, 3.011049509048462)
(31, 0.3032503457814661, 2.98829984664917)
(32, 0.3284923928077455, 2.897587776184082)
(33, 0.3212309820193638, 2.7745416164398193)
(34, 0.3177731673582296, 2.8961312770843506)
(35, 0.32468879668049794, 2.65904852781494)
(36, 0.3454356846473029, 2.7270121574401855)
(37, 0.34889349930843705, 2.6794612407684326)
(38, 0.3651452282157676, 2.5317022800445557)
(39, 0.3551175656984786, 2.479985475540161)
(40, 0.3668741355463347, 2.279317855834961)
(41, 0.36964038727524207, 2.376512050628662)
(42, 0.3744813278008299, 2.288670301437378)
(43, 0.37586445366528354, 2.065084218978882)
(44, 0.3775933609958506, 2.109952926635742)
(45, 0.37655601659751037, 2.205705404281616)
(46, 0.3800138312586445, 2.315049648284912)
(47, 0.3755186721991701, 2.094773530960083)
(48, 0.37863070539419086, 1.910776972770691)
(49, 0.38381742738589214, 1.7759859561920166)

Best model accuracy: 0.38381742738589214

TEST Accuracy Final Result: 0.4044244728655375

[2C-7] (LR 0.1, NUM_EPOCHS 60, STEP_SIZE 20)

VALIDATION Final Results (epoch, accuracy, loss):

(0, 0.09197786998616875, 4.436728477478027)
(1, 0.09232365145228216, 4.467409133911133)
(2, 0.09232365145228216, 4.343264102935791)
(3, 0.09232365145228216, 4.235462188720703)
(4, 0.09232365145228216, 4.201386451721191)
(5, 0.09301521438450899, 4.316862106323242)
(6, 0.09681881051175657, 4.17860603325195)
(7, 0.13035961272475796, 4.0677571296691895)
(8, 0.12448132780082988, 4.198368549346924)
(9, 0.12344398340248963, 4.149363994598389)
(10, 0.09197786998616875, 87390.6953125)
(11, 0.006224066390041493, nan)
(12, 0.006224066390041493, nan)
(13, 0.006224066390041493, nan)
(14, 0.006224066390041493, nan)
(15, 0.006224066390041493, nan)
(16, 0.006224066390041493, nan)
(17, 0.006224066390041493, nan)
(18, 0.006224066390041493, nan)
(19, 0.006224066390041493, nan)
(20, 0.006224066390041493, nan)
(21, 0.006224066390041493, nan)
(22, 0.006224066390041493, nan)
(23, 0.006224066390041493, nan)
(24, 0.006224066390041493, nan)
(25, 0.006224066390041493, nan)
(26, 0.006224066390041493, nan)
(27, 0.006224066390041493, nan)
(28, 0.006224066390041493, nan)
(29, 0.006224066390041493, nan)

(30, 0.006224066390041493, nan)
(31, 0.006224066390041493, nan)
(32, 0.006224066390041493, nan)
(33, 0.006224066390041493, nan)
(34, 0.006224066390041493, nan)
(35, 0.006224066390041493, nan)
(36, 0.006224066390041493, nan)
(37, 0.006224066390041493, nan)
(38, 0.006224066390041493, nan)
(39, 0.006224066390041493, nan)
(40, 0.006224066390041493, nan)
(41, 0.006224066390041493, nan)
(42, 0.006224066390041493, nan)
(43, 0.006224066390041493, nan)
(44, 0.006224066390041493, nan)
(45, 0.006224066390041493, nan)
(46, 0.006224066390041493, nan)
(47, 0.006224066390041493, nan)
(48, 0.006224066390041493, nan)
(49, 0.006224066390041493, nan)
(50, 0.006224066390041493, nan)
(51, 0.006224066390041493, nan)
(52, 0.006224066390041493, nan)
(53, 0.006224066390041493, nan)
(54, 0.006224066390041493, nan)
(55, 0.006224066390041493, nan)
(56, 0.006224066390041493, nan)
(57, 0.006224066390041493, nan)
(58, 0.006224066390041493, nan)
(59, 0.006224066390041493, nan)

Best model accuracy: 0.13035961272475796

TEST Accuracy Final Result: 0.006567576909782233

[2C-8] (LR 0.01, NUM_EPOCHS 50, STEP_SIZE 20)

VALIDATION Final Results (epoch, accuracy, loss):

(0, 0.09197786998616875, 4.60373067855835)
(1, 0.09197786998616875, 4.578423500061035)
(2, 0.09197786998616875, 4.540865898132324)
(3, 0.09197786998616875, 4.340523719787598)
(4, 0.09232365145228216, 4.221375942230225)
(5, 0.09197786998616875, 4.268529891967773)
(6, 0.14073305670816044, 4.219630718231201)
(7, 0.13658367911479943, 4.011722564697266)
(8, 0.1607883817427386, 4.01336669921875)
(9, 0.20020746887966806, 4.061745643615723)
(10, 0.21127247579529737, 3.9577507972717285)
(11, 0.2157676348547718, 3.9289064407348633)
(12, 0.22199170124481327, 3.6272740364074707)
(13, 0.22856154910096818, 3.7745203971862793)
(14, 0.23478561549100968, 3.8284401893615723)
(15, 0.229253112033195, 3.528254747390747)
(16, 0.2520746887966805, 3.535402774810791)
(17, 0.258298755186722, 3.386030912399292)
(18, 0.2745504840940526, 3.2075466183166504)
(19, 0.2690179806362379, 3.381005048751831)
(20, 0.2814661134163209, 3.1653330326080322)
(21, 0.2883817427385892, 3.218538284301758)
(22, 0.29564315352697096, 3.069260597229004)
(23, 0.29771784232365145, 3.0782642364501953)
(24, 0.29737206085753803, 2.981215476989746)
(25, 0.30048409405255877, 3.0335254669189453)
(26, 0.30463347164591975, 3.1285412311553955)
(27, 0.30428769017980634, 2.8067073822021484)
(28, 0.3115491009681881, 2.871396541595459)
(29, 0.3115491009681881, 2.8951971530914307)
(30, 0.3118948824343015, 2.9545576572418213)
(31, 0.31673582295988933, 2.808366060256958)
(32, 0.32226832641770403, 2.8339381217956543)
(33, 0.31673582295988933, 2.6838512420654297)

(34, 0.32676348547717843, 2.8278260231018066)
(35, 0.32745504840940526, 2.7444803714752197)
(36, 0.33402489626556015, 2.803929328918457)
(37, 0.32987551867219916, 2.8565046787261963)
(38, 0.3312586445366528, 2.799224853515625)
(39, 0.3385200553250346, 2.5609233379364014)
(40, 0.3381742738589212, 2.786968469619751)
(41, 0.3354080221300138, 2.6779367923736572)
(42, 0.3367911479944675, 2.7498819828033447)
(43, 0.3392116182572614, 2.7308506965637207)
(44, 0.33955739972337484, 2.598623514175415)
(45, 0.33990318118948826, 2.8575758934020996)
(46, 0.3405947441217151, 2.6949148178100586)
(47, 0.34163208852005533, 2.6881842613220215)
(48, 0.343015214384509, 2.633721113204955)
(49, 0.3409405255878285, 2.7869718074798584)

Best model accuracy: 0.343015214384509

TEST Accuracy Final Result: 0.3394400276529554

[2C-9] (LR 0.01, NUM_EPOCHS 70, STEP_SIZE 20)

VALIDATION Final Results (epoch, accuracy, loss):

(0, 0.09197786998616875, 4.605137348175049)
(1, 0.09197786998616875, 4.58706521987915)
(2, 0.09197786998616875, 4.56015157699585)
(3, 0.09197786998616875, 4.464719295501709)
(4, 0.09232365145228216, 4.221573829650879)
(5, 0.09197786998616875, 4.150157451629639)
(6, 0.11929460580912864, 4.244040489196777)
(7, 0.09197786998616875, 4.20583963394165)
(8, 0.1507607192254495, 4.096395015716553)
(9, 0.1566390041493776, 4.1289143562316895)
(10, 0.20470262793914246, 4.051076889038086)
(11, 0.20643153526970953, 3.9565675258636475)
(12, 0.22199170124481327, 3.7034106254577637)
(13, 0.21369294605809128, 3.7321832180023193)
(14, 0.21334716459197786, 3.7430953979492188)
(15, 0.23409405255878285, 3.5851755142211914)
(16, 0.23824343015214383, 3.3873629570007324)
(17, 0.23409405255878285, 3.1266236305236816)
(18, 0.2475795297372061, 3.559631109237671)
(19, 0.26383125864453666, 3.2962803840637207)
(20, 0.26625172890733056, 3.3170547485351562)
(21, 0.2693637621023513, 3.185260057449341)
(22, 0.26832641770401106, 3.1089203357696533)
(23, 0.27869986168741356, 3.378100633621216)
(24, 0.2745504840940526, 3.2022602558135986)
(25, 0.2800829875518672, 3.348595380783081)
(26, 0.28077455048409405, 3.112349510192871)
(27, 0.2838865836791148, 3.1431784629821777)
(28, 0.2821576763485477, 3.1612846851348877)
(29, 0.2894190871369295, 3.1603097915649414)
(30, 0.2942600276625173, 2.9370672702789307)
(31, 0.29149377593361, 3.0187296867370605)
(32, 0.2970262793914246, 3.0317115783691406)
(33, 0.2984094052558783, 2.8766579627990723)
(34, 0.29979253112033194, 2.9829792976379395)
(35, 0.3063623789764869, 2.9747653007507324)
(36, 0.3029045643153527, 2.90294694905127)
(37, 0.30428769017980634, 2.948528289794922)
(38, 0.3094744121715076, 2.953641414642334)
(39, 0.3094744121715076, 2.911541700363159)
(40, 0.3087828492392808, 2.926013469696045)
(41, 0.31016597510373445, 2.855862617492676)
(42, 0.31016597510373445, 2.862689971923828)
(43, 0.3118948824343015, 3.0436484813690186)
(44, 0.31016597510373445, 2.8180246353149414)
(45, 0.3136237897648686, 2.76577091217041)
(46, 0.3108575380359613, 2.990347146987915)
(47, 0.3118948824343015, 2.745936155319214)

(48, 0.3108575380359613, 2.892432689666748)
(49, 0.3136237897648686, 2.866467237472534)
(50, 0.3132780082987552, 2.8864080905914307)
(51, 0.3153526970954357, 2.8906636238098145)
(52, 0.3118948824343015, 2.8954274654388428)
(53, 0.31431535269709543, 2.9362359046936035)
(54, 0.31500691562932226, 3.0558531284332275)
(55, 0.313969571230982, 2.753582239151001)
(56, 0.31431535269709543, 2.8799993991851807)
(57, 0.3115491009681881, 2.841796636581421)
(58, 0.31500691562932226, 2.926602840423584)
(59, 0.31466113416320884, 2.9629523754119873)
(60, 0.31500691562932226, 2.961254119873047)
(61, 0.31500691562932226, 2.8615036010742188)
(62, 0.31500691562932226, 2.6031272411346436)
(63, 0.3160442600276625, 2.861069679260254)
(64, 0.3160442600276625, 2.9079439640045166)
(65, 0.3163900414937759, 2.640597105026245)
(66, 0.3160442600276625, 2.787245273590088)
(67, 0.3160442600276625, 2.8935964107513428)
(68, 0.3156984785615491, 2.829183340072632)
(69, 0.3153526970954357, 2.710942268371582)

Best model accuracy: 0.3163900414937759

TEST Accuracy Final Result: 0.3207742827514691

Appendix (3)

[3C-1] (LR 0.01, NUM_EPOCHS 50, STEP_SIZE 40)

VALIDATION Final Results (epoch, accuracy, loss):

(0, 0.006915629322268326, 20.31509780883789)
(1, 0.006224066390041493, nan)
(2, 0.006224066390041493, nan)
(3, 0.006224066390041493, nan)
(4, 0.006224066390041493, nan)
(5, 0.006224066390041493, nan)
(6, 0.006224066390041493, nan)
(7, 0.006224066390041493, nan)
(8, 0.006224066390041493, nan)
(9, 0.006224066390041493, nan)
(10, 0.006224066390041493, nan)
(11, 0.006224066390041493, nan)
(12, 0.006224066390041493, nan)
(13, 0.006224066390041493, nan)
(14, 0.006224066390041493, nan)
(15, 0.006224066390041493, nan)
(16, 0.006224066390041493, nan)
(17, 0.006224066390041493, nan)
(18, 0.006224066390041493, nan)
(19, 0.006224066390041493, nan)
(20, 0.006224066390041493, nan)
(21, 0.006224066390041493, nan)
(22, 0.006224066390041493, nan)
(23, 0.006224066390041493, nan)
(24, 0.006224066390041493, nan)
(25, 0.006224066390041493, nan)
(26, 0.006224066390041493, nan)
(27, 0.006224066390041493, nan)
(28, 0.006224066390041493, nan)
(29, 0.006224066390041493, nan)
(30, 0.006224066390041493, nan)
(31, 0.006224066390041493, nan)
(32, 0.006224066390041493, nan)
(33, 0.006224066390041493, nan)
(34, 0.006224066390041493, nan)
(35, 0.006224066390041493, nan)
(36, 0.006224066390041493, nan)
(37, 0.006224066390041493, nan)
(38, 0.006224066390041493, nan)

(39, 0.006224066390041493, nan)
(40, 0.006224066390041493, nan)
(41, 0.006224066390041493, nan)
(42, 0.006224066390041493, nan)
(43, 0.006224066390041493, nan)
(44, 0.006224066390041493, nan)
(45, 0.006224066390041493, nan)
(46, 0.006224066390041493, nan)
(47, 0.006224066390041493, nan)
(48, 0.006224066390041493, nan)
(49, 0.006224066390041493, nan)

Best model accuracy: 0.006915629322268326

TEST Accuracy Final Result: 0.006567576909782233

[3C-2] (LR 0.001, NUM_EPOCHS 50, STEP_SIZE 40)

VALIDATION Final Results (epoch, accuracy, loss):

(0, 0.016597510373443983, 5.97486686706543)
(1, 0.2057399723374827, 4.9254865646362305)
(2, 0.23478561549100968, 4.278190612792969)
(3, 0.2641770401106501, 3.8307247161865234)
(4, 0.2859612724757953, 3.6698107719421387)
(5, 0.3073997233748271, 3.4640567302703857)
(6, 0.32745504840940526, 3.2299230098724365)
(7, 0.33402489626556015, 3.197077751159668)
(8, 0.36929460580912865, 3.072399139404297)
(9, 0.3900414937759336, 2.9676926136016846)
(10, 0.4021438450899032, 2.8199098110198975)
(11, 0.4173582295988935, 2.676210880279541)
(12, 0.43741355463347165, 2.597935438156128)
(13, 0.4432918395573997, 2.2658848762512207)
(14, 0.47372060857538034, 2.298875093460083)
(15, 0.47683264177040113, 2.217359781265259)
(16, 0.49066390041493774, 2.1797866821289062)
(17, 0.5020746887966805, 1.9893908500671387)
(18, 0.5148686030428768, 1.8992455005645752)
(19, 0.5318118948824343, 2.0077767372131348)
(20, 0.5421853388658368, 1.6939520835876465)
(21, 0.5439142461964038, 1.9039087295532227)
(22, 0.5535961272475796, 1.7281277179718018)
(23, 0.5667358229598893, 1.485351324081421)
(24, 0.5774550484094052, 1.4086205959320068)
(25, 0.5819502074688797, 1.2378840446472168)
(26, 0.5919778699861687, 1.1121885776519775)
(27, 0.5954356846473029, 1.2960171699523926)
(28, 0.601313969571231, 1.1799654960632324)
(29, 0.6092669432918395, 1.1170214414596558)
(30, 0.6175656984785616, 1.0066280364990234)
(31, 0.6141078838174274, 0.8537322878837585)
(32, 0.6196403872752421, 1.029923439025879)
(33, 0.623789764868603, 0.7583782076835632)
(34, 0.6244813278008299, 0.7740246057510376)
(35, 0.6313969571230982, 0.7252016663551331)
(36, 0.6352005532503457, 0.6470445394515991)
(37, 0.6369294605809128, 0.6016724109649658)
(38, 0.642807745504841, 0.5799550414085388)
(39, 0.6479944674965422, 0.6932010054588318)
(40, 0.65283540802213, 0.5761263370513916)
(41, 0.65283540802213, 0.40712350606918335)
(42, 0.6507607192254495, 0.5226714611053467)
(43, 0.6535269709543569, 0.558639407157898)
(44, 0.6535269709543569, 0.4770742952823639)
(45, 0.6514522821576764, 0.5310466289520264)
(46, 0.6517980636237898, 0.5076252818107605)
(47, 0.6500691562932227, 0.4733797609806061)
(48, 0.6538727524204703, 0.6182546615600586)
(49, 0.6545643153526971, 0.4939025640487671)

Best model accuracy: 0.6545643153526971

TEST Accuracy Final Result: 0.6564120290356031

[3C-3] (LR 0.001, NUM_EPOCHS 60, STEP_SIZE 20)

VALIDATION Final Results (epoch, accuracy, loss):

(0, 0.016597510373443983, 6.137425422668457)
(1, 0.21507607192254496, 4.822393417358398)
(2, 0.2437759336099585, 4.18969202041626)
(3, 0.26590594744121715, 3.8290092945098877)
(4, 0.2793914246196404, 3.5683064460754395)
(5, 0.2970262793914246, 3.689789056777954)
(6, 0.3357538035961272, 3.3472609519958496)
(7, 0.3502766251728907, 2.9653334617614746)
(8, 0.3703319502074689, 2.7544355392456055)
(9, 0.3938450899031812, 2.882842540740967)
(10, 0.40076071922544954, 2.717744827270508)
(11, 0.4215076071922545, 2.7883801460266113)
(12, 0.43533886583679116, 2.508028984069824)
(13, 0.4581604426002766, 2.3838794231414795)
(14, 0.4778699861687414, 2.1167821884155273)
(15, 0.504149377593361, 1.9699418544769287)
(16, 0.5034578146611342, 1.923825979232788)
(17, 0.5238589211618258, 1.957592248916626)
(18, 0.5366528354080221, 1.8684157133102417)
(19, 0.5397648686030428, 1.6848034858703613)
(20, 0.5466804979253111, 1.554010272026062)
(21, 0.5501383125864454, 1.692199945449829)
(22, 0.5535961272475796, 1.6445943117141724)
(23, 0.5542876901798064, 1.5997424125671387)
(24, 0.55567081604426, 1.4269150495529175)
(25, 0.55567081604426, 1.744206190109253)
(26, 0.5591286307053942, 1.3695385456085205)
(27, 0.5591286307053942, 1.6294981241226196)
(28, 0.559820193637621, 1.559914231300354)
(29, 0.5646611341632088, 1.604506254196167)
(30, 0.5629322268326418, 1.5789564847946167)
(31, 0.563969571230982, 1.6466094255447388)
(32, 0.5663900414937759, 1.6448992490768433)
(33, 0.5650069156293223, 1.4264334440231323)
(34, 0.5646611341632088, 1.5709807872772217)
(35, 0.5712309820193637, 1.2905770540237427)
(36, 0.5698478561549101, 1.563819408416748)
(37, 0.572268326417704, 1.4994760751724243)
(38, 0.5726141078838174, 1.3527182340621948)
(39, 0.5695020746887967, 1.4320935010910034)
(40, 0.5715767634854771, 1.4526783227920532)
(41, 0.5701936376210235, 1.4786497354507446)
(42, 0.572268326417704, 1.2963088750839233)
(43, 0.5712309820193637, 1.4201301336288452)
(44, 0.5733056708160442, 1.4048192501068115)
(45, 0.5719225449515906, 1.2913670539855957)
(46, 0.5729598893499308, 1.3743407726287842)
(47, 0.5733056708160442, 1.4345539808273315)
(48, 0.5729598893499308, 1.5035457611083984)
(49, 0.572268326417704, 1.4606525897979736)
(50, 0.5729598893499308, 1.6835767030715942)
(51, 0.5726141078838174, 1.3645994663238525)
(52, 0.5729598893499308, 1.230972409248352)
(53, 0.5726141078838174, 1.3477990627288818)
(54, 0.5712309820193637, 1.3563556671142578)
(55, 0.5736514522821576, 1.1785082817077637)
(56, 0.5733056708160442, 1.4791265726089478)
(57, 0.5746887966804979, 1.407923698425293)
(58, 0.5750345781466113, 1.4309285879135132)
(59, 0.5729598893499308, 1.290323257446289)

Best model accuracy: 0.5750345781466113

TEST Accuracy Final Result: 0.5793294158313169

[3C-4] (LR 0.005, NUM_EPOCHS 60, STEP_SIZE 20)

VALIDATION Final Results (epoch, accuracy, loss):

(0, 0.17911479944674966, 5.670609474182129)
(1, 0.08852005532503458, 8.241596221923828)
(2, 0.11825726141078838, 6.0582475662231445)
(3, 0.18775933609958506, 4.511292934417725)
(4, 0.22268326417704012, 3.784499168395996)
(5, 0.27420470262793917, 3.545097827911377)
(6, 0.3495850622406639, 3.291064739227295)
(7, 0.3879668049792531, 2.8132176399230957)
(8, 0.4256569847856155, 2.5022499561309814)
(9, 0.45885200553250344, 2.2645888328552246)
(10, 0.48132780082987553, 2.2474141120910645)
(11, 0.5079529737206085, 1.9720396995544434)
(12, 0.5373443983402489, 1.6540826559066772)
(13, 0.5511756569847857, 1.461517095565796)
(14, 0.5822959889349931, 1.2365453243255615)
(15, 0.5819502074688797, 0.9445226788520813)
(16, 0.6099585062240664, 0.8716464042663574)
(17, 0.6203319502074689, 0.8116912245750427)
(18, 0.6317427385892116, 0.801740288734436)
(19, 0.6341632088520055, 0.6018902659416199)
(20, 0.6614799446749654, 0.4285018742084503)
(21, 0.6763485477178424, 0.423822283744812)
(22, 0.6787690179806363, 0.29255110025405884)
(23, 0.6798063623789765, 0.3650147318840027)
(24, 0.6749654218533887, 0.3376768231391907)
(25, 0.677731673582296, 0.3562435805797577)
(26, 0.6791147994467497, 0.2933444678783417)
(27, 0.6780774550484094, 0.27235329151153564)
(28, 0.6825726141078838, 0.29623785614967346)
(29, 0.6808437067773168, 0.26138561964035034)
(30, 0.6791147994467497, 0.3170282244682312)
(31, 0.6763485477178424, 0.24922966957092285)
(32, 0.6863762102351314, 0.33004817366600037)
(33, 0.6853388658367912, 0.2854127287864685)
(34, 0.6822268326417704, 0.2622225880622864)
(35, 0.6825726141078838, 0.21736647188663483)
(36, 0.6825726141078838, 0.23753874003887177)
(37, 0.686030428769018, 0.19261693954467773)
(38, 0.6849930843706777, 0.24436189234256744)
(39, 0.6853388658367912, 0.21281850337982178)
(40, 0.6856846473029046, 0.20505976676940918)
(41, 0.6853388658367912, 0.1814039647579193)
(42, 0.6867219917012448, 0.20694118738174438)
(43, 0.6870677731673582, 0.24826662242412567)
(44, 0.6863762102351314, 0.22186967730522156)
(45, 0.686030428769018, 0.2075885832309723)
(46, 0.686030428769018, 0.1979677975177765)
(47, 0.6877593360995851, 0.15977856516838074)
(48, 0.6874135546334716, 0.19567075371742249)
(49, 0.6853388658367912, 0.20002290606498718)
(50, 0.6863762102351314, 0.22582006454467773)
(51, 0.6877593360995851, 0.24103039503097534)
(52, 0.6881051175656985, 0.20430992543697357)
(53, 0.6881051175656985, 0.1699337363243103)
(54, 0.6881051175656985, 0.1510235071182251)
(55, 0.6884508990318119, 0.20128941535949707)
(56, 0.6881051175656985, 0.18922358751296997)
(57, 0.6898340248962656, 0.17826318740844727)
(58, 0.690179806362379, 0.214180588722229)
(59, 0.6891424619640387, 0.189200758934021)

Best model accuracy: 0.690179806362379

TEST Accuracy Final Result: 0.67646042170757

[3C-5] (LR 0.005, NUM_EPOCHS 50, STEP_SIZE 40)

VALIDATION Final Results (epoch, accuracy, loss):

(0, 0.05705394190871369, 7.359565734863281)
(1, 0.09094052558782849, 6.617340087890625)

(2, 0.11307053941908714, 5.220590114593506)
(3, 0.22544951590594745, 4.127058029174805)
(4, 0.29080221300138315, 3.5597848892211914)
(5, 0.3160442600276625, 3.253392457962036)
(6, 0.36964038727524207, 2.896334648132324)
(7, 0.4118257261410788, 2.858912229537964)
(8, 0.43533886583679116, 2.449186325073242)
(9, 0.46715076071922546, 2.1798996925354004)
(10, 0.4802904564315353, 2.1618144512176514)
(11, 0.5162517289073306, 1.9476569890975952)
(12, 0.5238589211618258, 1.6192212104797363)
(13, 0.5480636237897649, 1.4724979400634766)
(14, 0.5719225449515906, 1.3037594556808472)
(15, 0.5964730290456431, 1.190701961517334)
(16, 0.6065006915629322, 1.022757887840271)
(17, 0.6158367911479945, 0.959364116191864)
(18, 0.6203319502074689, 0.8011096715927124)
(19, 0.6483402489626556, 0.6730209589004517)
(20, 0.6524896265560166, 0.4967942535877228)
(21, 0.6514522821576764, 0.512720644740295)
(22, 0.6656293222683264, 0.46016114950180054)
(23, 0.6576763485477178, 0.27585774660110474)
(24, 0.648686030428769, 0.4741614758968353)
(25, 0.6656293222683264, 0.2562925815582754)
(26, 0.6770401106500692, 0.2525748908519745)
(27, 0.6773858921161826, 0.16751539707183838)
(28, 0.6839557399723375, 0.18676215410232544)
(29, 0.6773858921161826, 0.18727201223373413)
(30, 0.6957123098201936, 0.20132257044315338)
(31, 0.6853388658367912, 0.10757715255022049)
(32, 0.686030428769018, 0.10534271597862244)
(33, 0.6822268326417704, 0.12122011184692383)
(34, 0.6891424619640387, 0.05859825015068054)
(35, 0.6950207468879668, 0.13940578699111938)
(36, 0.6974412171507607, 0.05893810838460922)
(37, 0.7033195020746889, 0.03642949461936951)
(38, 0.6936376210235131, 0.12177496403455734)
(39, 0.6964038727524204, 0.08753684163093567)
(40, 0.7060857538035962, 0.05420093238353729)
(41, 0.7102351313969572, 0.025921449065208435)
(42, 0.7140387275242047, 0.025414831936359406)
(43, 0.7157676348547718, 0.01760459691286087)
(44, 0.716804979253112, 0.02269481122493744)
(45, 0.7185338865836791, 0.01758445054292679)
(46, 0.7206085753803596, 0.012238584458827972)
(47, 0.7199170124481328, 0.012635886669158936)
(48, 0.7226832641770401, 0.011731699109077454)
(49, 0.7230290456431535, 0.011137649416923523)

Best model accuracy: 0.7230290456431535

TEST Accuracy Final Result: 0.7120636017974421

[3D-1] (LR 0.005, NUM_EPOCHS 50, STEP_SIZE 40)

VALIDATION Final Results (epoch, accuracy, loss):

(0, 0.3063623789764869, 5.353875160217285)
(1, 0.5162517289073306, 2.4753849506378174)
(2, 0.6303596127247579, 1.529908299446106)
(3, 0.719225449515906, 0.9380613565444946)
(4, 0.7576071922544951, 0.5568947792053223)
(5, 0.7783540802213001, 0.4594956040382385)
(6, 0.7914937759336099, 0.3640190362930298)
(7, 0.7911479944674965, 0.24828192591667175)
(8, 0.8004840940525588, 0.24873627722263336)
(9, 0.8091286307053942, 0.18390928208827972)
(10, 0.8063623789764869, 0.10823418200016022)
(11, 0.8035961272475796, 0.12237371504306793)
(12, 0.8077455048409405, 0.09958138316869736)
(13, 0.8122406639004149, 0.063590407371521)
(14, 0.8084370677731674, 0.07543925940990448)
(15, 0.8177731673582296, 0.07156536728143692)

(16, 0.8167358229598893, 0.05217311158776283)
(17, 0.8150069156293223, 0.06031520292162895)
(18, 0.8156984785615491, 0.06271344423294067)
(19, 0.8174273858921162, 0.06964503228664398)
(20, 0.8167358229598893, 0.04495865851640701)
(21, 0.8191562932226832, 0.0438428670167923)
(22, 0.8208852005532503, 0.025355249643325806)
(23, 0.8243430152143845, 0.04054166376590729)
(24, 0.8243430152143845, 0.03216496482491493)
(25, 0.8243430152143845, 0.03400802239775658)
(26, 0.8243430152143845, 0.0190143845975399)
(27, 0.8246887966804979, 0.032773710787296295)
(28, 0.8253803596127247, 0.04782852157950401)
(29, 0.8250345781466113, 0.01724451407790184)
(30, 0.8250345781466113, 0.02169424667954445)
(31, 0.8243430152143845, 0.025687165558338165)
(32, 0.8274550484094052, 0.03418193385004997)
(33, 0.8274550484094052, 0.014856915920972824)
(34, 0.8260719225449515, 0.01710023730993271)
(35, 0.8274550484094052, 0.021534442901611328)
(36, 0.8257261410788381, 0.020118996500968933)
(37, 0.8281466113416321, 0.03302275016903877)
(38, 0.828838174273859, 0.017952963709831238)
(39, 0.8291839557399724, 0.01867714151740074)
(40, 0.8302213001383126, 0.01227351650595665)
(41, 0.8295297372060858, 0.016642525792121887)
(42, 0.8298755186721992, 0.01738644391289294)
(43, 0.8298755186721992, 0.010701265186071396)
(44, 0.8319502074688797, 0.015317093580961227)
(45, 0.8316044260027663, 0.02725672721862793)
(46, 0.8312586445366529, 0.02050359919667244)
(47, 0.8322959889349931, 0.016472503542900085)
(48, 0.83298755186722, 0.012211229652166367)
(49, 0.8326417704011065, 0.014253709465265274)

Best model accuracy: 0.83298755186722

TEST Accuracy Final Result: 0.8396128586242655

[3E-1] (LR 0.005, NUM_EPOCHS 50, STEP_SIZE 40)

VALIDATION Final Results (epoch, accuracy, loss):

(0, 0.00034578146611341634, 11.160593032836914)
(1, 0.022821576763485476, 6.838382244110107)
(2, 0.002074688796680498, 6.854372024536133)
(3, 0.008298755186721992, 6.477596759796143)
(4, 0.008990318118948824, 5.836972713470459)
(5, 0.04771784232365145, 5.39240837097168)
(6, 0.13416320885200553, 5.039538860321045)
(7, 0.17911479944674966, 4.647604465484619)
(8, 0.26383125864453666, 4.518416881561279)
(9, 0.2693637621023513, 4.059633731842041)
(10, 0.28112033195020747, 4.201109409332275)
(11, 0.31258644536652835, 3.8935582637786865)
(12, 0.3233056708160443, 3.6680619716644287)
(13, 0.338865836791148, 3.4601478576660156)
(14, 0.3426694329183956, 3.3855912685394287)
(15, 0.35442600276625175, 3.696965456008911)
(16, 0.3561549100968188, 3.403576612472534)
(17, 0.35442600276625175, 3.2539007663726807)
(18, 0.3772475795297372, 3.0204644203186035)
(19, 0.39315352697095435, 2.8294811248779297)
(20, 0.38381742738589214, 2.9624509811401367)
(21, 0.39522821576763484, 2.837106704711914)
(22, 0.39315352697095435, 2.887871742248535)
(23, 0.4218533886583679, 2.6733450889587402)
(24, 0.415283540802213, 2.5441455841064453)
(25, 0.4343015214384509, 2.5543582439422607)
(26, 0.436030428769018, 2.398282051086426)
(27, 0.4450207468879668, 2.5252037048339844)
(28, 0.45435684647302904, 2.2293574810028076)
(29, 0.4630013831258645, 2.3002545833587646)

(30, 0.46922544951590595, 2.0591490268707275)
(31, 0.470954356846473, 2.100492238998413)
(32, 0.475103734439834, 1.6870975494384766)
(33, 0.48686030428769017, 1.8171221017837524)
(34, 0.4830567081604426, 1.7694776058197021)
(35, 0.4872060857538036, 1.9384351968765259)
(36, 0.49619640387275243, 1.5666594505310059)
(37, 0.49135546334716457, 1.5146905183792114)
(38, 0.5020746887966805, 1.4219014644622803)
(39, 0.5044951590594744, 1.35189950466156)
(40, 0.5197095435684648, 1.3044198751449585)
(41, 0.5224757952973721, 1.0556350946426392)
(42, 0.5224757952973721, 1.1674312353134155)
(43, 0.5221300138312587, 0.9697062969207764)
(44, 0.5231673582295989, 1.1467158794403076)
(45, 0.5269709543568465, 1.1271065473556519)
(46, 0.5273167358229599, 0.9564487934112549)
(47, 0.5231673582295989, 1.0217950344085693)
(48, 0.5259336099585062, 0.9438039064407349)
(49, 0.5269709543568465, 0.8551754951477051)

Best model accuracy: 0.5273167358229599

TEST Accuracy Final Result: 0.5357760110611821

[3E-2] (LR 0.001, NUM_EPOCHS 50, STEP_SIZE 40)

VALIDATION Final Results (epoch, accuracy, loss):
(0, 0.004840940525587829, 6.55710506439209)
(1, 0.035961272475795295, 5.433020114898682)
(2, 0.060511756569847856, 5.353227615356445)
(3, 0.06673582295988935, 4.874050617218018)
(4, 0.15975103734439833, 4.624469757080078)
(5, 0.19329183955739973, 4.5603156089782715)
(6, 0.2392807745504841, 4.395915508270264)
(7, 0.24965421853388658, 4.128351211547852)
(8, 0.262448132780083, 4.330151081085205)
(9, 0.2752420470262794, 3.993180751800537)
(10, 0.28561549100968187, 3.8260693550109863)
(11, 0.2925311203319502, 3.694399118423462)
(12, 0.2963347164591978, 4.267098903656006)
(13, 0.301521438450899, 3.6592934131622314)
(14, 0.30532503457814664, 3.5526793003082275)
(15, 0.31016597510373445, 3.86014723777771)
(16, 0.3160442600276625, 3.5121865272521973)
(17, 0.3212309820193638, 3.6184277534484863)
(18, 0.3212309820193638, 3.874525547027588)
(19, 0.3257261410788382, 3.4841551780700684)
(20, 0.32676348547717843, 3.4611973762512207)
(21, 0.3412863070539419, 3.4973831176757812)
(22, 0.3454356846473029, 3.4697372913360596)
(23, 0.34647302904564314, 3.54034423828125)
(24, 0.3457814661134163, 3.2139792442321777)
(25, 0.3533886583679115, 3.3271756172180176)
(26, 0.3561549100968188, 3.236142635345459)
(27, 0.35684647302904565, 3.27085280418396)
(28, 0.36410788381742737, 3.4426887035369873)
(29, 0.3730982019363762, 3.185537338256836)
(30, 0.36894882434301524, 2.8780016899108887)
(31, 0.3668741355463347, 3.2620458602905273)
(32, 0.3813969571230982, 3.1133065223693848)
(33, 0.37378976486860305, 2.8023664951324463)
(34, 0.3831258644536653, 2.745201587677002)
(35, 0.3824343015214384, 2.93234920501709)
(36, 0.3755186721991701, 2.95577073097229)
(37, 0.3852005532503458, 2.974501609802246)
(38, 0.38450899031811897, 2.8847436904907227)
(39, 0.3966113416320885, 2.634305715560913)
(40, 0.3962655601659751, 2.8243637084960938)
(41, 0.39522821576763484, 3.0325565338134766)
(42, 0.4004149377593361, 2.66579270362854)
(43, 0.40145228215767637, 2.8651137351989746)
(44, 0.39868603042876904, 2.923882246017456)

(45, 0.40076071922544954, 2.6267898082733154)
(46, 0.4024896265560166, 2.7415502071380615)
(47, 0.4017980636237898, 2.760761022567749)
(48, 0.40318118948824344, 2.515712022781372)
(49, 0.40318118948824344, 2.6625378131866455)

Best model accuracy: 0.40318118948824344

TEST Accuracy Final Result: 0.4085724161769789

Appendix (4)

[4A-1] (LR 0.005, NUM_EPOCHS 50, STEP_SIZE 40)
horizontalFlip verticalFlip 0.5 0.5

VALIDATION Final Results (epoch, accuracy, loss):

(0, 0.08713692946058091, 5.831681251525879)
(1, 0.16217150760719226, 4.588322639465332)
(2, 0.22579529737206086, 3.874624252319336)
(3, 0.1950207468879668, 3.6753764152526855)
(4, 0.28077455048409405, 3.478196382522583)
(5, 0.3364453665283541, 3.020822048187256)
(6, 0.3582295988934993, 3.0756232738494873)
(7, 0.3962655601659751, 2.5505874156951904)
(8, 0.42081604426002767, 2.6291990280151367)
(9, 0.4346473029045643, 2.327176332473755)
(10, 0.4702627939142462, 2.3760905265808105)
(11, 0.47372060857538034, 2.0279176235198975)
(12, 0.5204011065006916, 1.8812289237976074)
(13, 0.5238589211618258, 1.7930970191955566)
(14, 0.5487551867219918, 1.6979014873504639)
(15, 0.5522130013831259, 1.620413899421692)
(16, 0.5608575380359613, 1.4212989807128906)
(17, 0.5809128630705395, 1.5484626293182373)
(18, 0.5892116182572614, 1.1954935789108276)
(19, 0.6068464730290456, 1.125062346458435)
(20, 0.6002766251728907, 1.1685312986373901)
(21, 0.6341632088520055, 0.9095383286476135)
(22, 0.6258644536652835, 0.8660642504692078)
(23, 0.6393499308437067, 0.8157479166984558)
(24, 0.6441908713692946, 0.8393873572349548)
(25, 0.6393499308437067, 0.6578114628791809)
(26, 0.6538727524204703, 0.6053130030632019)
(27, 0.6628630705394191, 0.5147048234939575)
(28, 0.6483402489626556, 0.6187628507614136)
(29, 0.6542185338865837, 0.63337242603302)
(30, 0.65283540802213, 0.44381916522979736)
(31, 0.6749654218533887, 0.4659865200519562)
(32, 0.6701244813278008, 0.3442453444004059)
(33, 0.671161825726141, 0.40204283595085144)
(34, 0.6749654218533887, 0.2898802161216736)
(35, 0.6791147994467497, 0.24178722500801086)
(36, 0.6863762102351314, 0.3438851237297058)
(37, 0.6849930843706777, 0.2923174798488617)
(38, 0.6881051175656985, 0.2506028413772583)
(39, 0.6915629322268326, 0.2415507733821869)
(40, 0.7012448132780082, 0.1670461893081665)
(41, 0.7053941908713693, 0.08137010782957077)
(42, 0.7029737206085753, 0.1235971450805664)
(43, 0.7008990318118948, 0.12118852138519287)
(44, 0.7008990318118948, 0.1381010264158249)
(45, 0.7057399723374828, 0.09627527743577957)
(46, 0.7102351313969572, 0.07315769046545029)
(47, 0.7071230982019364, 0.09010925143957138)
(48, 0.706777316735823, 0.08720820397138596)
(49, 0.7019363762102351, 0.09326042234897614)

Best model accuracy: 0.7102351313969572

TEST Accuracy Final Result: 0.6947805046664363

[4A-2] (LR 0.005, NUM_EPOCHS 50, STEP_SIZE 40)
grayScale 0.1

VALIDATION Final Results (epoch, accuracy, loss):

(0, 0.032157676348547715, 6.722440242767334)
(1, 0.03769017980636238, 6.022571563720703)
(2, 0.15975103734439833, 5.740679740905762)
(3, 0.13174273858921162, 7.839716911315918)
(4, 0.10511756569847856, 5.4568562507629395)
(5, 0.18568464730290457, 3.6722488403320312)
(6, 0.2607192254495159, 3.6677873134613037)
(7, 0.2697095435684647, 3.5253102779388428)
(8, 0.3288381742738589, 3.3996925354003906)
(9, 0.355463347164592, 3.093615770339966)
(10, 0.4083679114799467, 2.5338950157165527)
(11, 0.39591977869986167, 2.760416269302368)
(12, 0.45228215767634855, 2.283440589904785)
(13, 0.47441217150760717, 1.8899561166763306)
(14, 0.5020746887966805, 2.100471258163452)
(15, 0.5280082987551867, 1.7142151594161987)
(16, 0.5304287690179806, 1.5543767213821411)
(17, 0.5587828492392808, 1.4967385530471802)
(18, 0.5798755186721992, 1.3334368467330933)
(19, 0.5843706777316736, 1.3741830587387085)
(20, 0.6040802213001383, 1.0334563255310059)
(21, 0.6151452282157677, 0.8625975251197815)
(22, 0.6210235131396957, 0.8017573356628418)
(23, 0.6348547717842323, 0.7277262210845947)
(24, 0.6379668049792531, 0.7124180793762207)
(25, 0.6462655601659751, 0.5866100788116455)
(26, 0.6538727524204703, 0.4708325266838074)
(27, 0.6535269709543569, 0.46622103452682495)
(28, 0.6507607192254495, 0.28211450576782227)
(29, 0.6746196403872753, 0.3362331986427307)
(30, 0.66701244813278, 0.26692596077919006)
(31, 0.6642461964038727, 0.35628238320350647)
(32, 0.6801521438450899, 0.16356095671653748)
(33, 0.6739280774550485, 0.16609950363636017)
(34, 0.677731673582296, 0.272270530462265)
(35, 0.6746196403872753, 0.1771996021270752)
(36, 0.6811894882434302, 0.12697120010852814)
(37, 0.6614799446749654, 0.17830368876457214)
(38, 0.6846473029045643, 0.10778322070837021)
(39, 0.6742738589211619, 0.13306258618831635)
(40, 0.6922544951590595, 0.08583860099315643)
(41, 0.7057399723374828, 0.09704820066690445)
(42, 0.7040110650069157, 0.046617329120635986)
(43, 0.7015905947441217, 0.061256758868694305)
(44, 0.7026279391424619, 0.03469421714544296)
(45, 0.7085062240663901, 0.07812683284282684)
(46, 0.7095435684647303, 0.04419480264186859)
(47, 0.7029737206085753, 0.03417303040623665)
(48, 0.7047026279391425, 0.05232984572649002)
(49, 0.7091977869986169, 0.060695238411426544)

Best model accuracy: 0.7095435684647303

TEST Accuracy Final Result: 0.6035257518147252

[4A-3] (LR 0.005, NUM_EPOCHS 50, STEP_SIZE 40)
horizontalFlip verticalFlip grayScale 0.5 0.5 0.1

VALIDATION Final Results (epoch, accuracy, loss):

(0, 0.20159059474412172, 4.7840118408203125)
(1, 0.16182572614107885, 5.077057361602783)
(2, 0.15975103734439833, 4.138867378234863)
(3, 0.24654218533886585, 3.7329065799713135)
(4, 0.30463347164591975, 3.260969877243042)
(5, 0.34024896265560167, 3.1844866275787354)
(6, 0.3454356846473029, 2.956710577011084)
(7, 0.39868603042876904, 2.6012721061706543)
(8, 0.4166666666666667, 2.65659499168396)

(9, 0.44467496542185336, 2.6010448932647705)
(10, 0.46265560165975106, 2.0721356868743896)
(11, 0.4872060857538036, 2.0944650173187256)
(12, 0.48858921161825725, 2.001461982727051)
(13, 0.5255878284923928, 1.8823339939117432)
(14, 0.5491009681881052, 1.8877636194229126)
(15, 0.5504840940525588, 1.4835755825042725)
(16, 0.5701936376210235, 1.486703872680664)
(17, 0.5809128630705395, 1.2122156620025635)
(18, 0.5836791147994468, 1.476765751838684)
(19, 0.5812586445366529, 1.056651151474805)
(20, 0.6065006915629322, 1.1604397296905518)
(21, 0.6289764868603043, 1.050763726234436)
(22, 0.6248271092669433, 0.7679007053375244)
(23, 0.6383125864453665, 0.7925260663032532)
(24, 0.6300138312586445, 1.0355030298233032)
(25, 0.642807745504841, 0.673202395439148)
(26, 0.6507607192254495, 0.5549116134643555)
(27, 0.6559474412171508, 0.5721220374107361)
(28, 0.6597510373443983, 0.6503666639328003)
(29, 0.6625172890733056, 0.5393621921539307)
(30, 0.6718533886583679, 0.4943731427192688)
(31, 0.6704702627939142, 0.455255389213562)
(32, 0.6749654218533887, 0.4872770607471466)
(33, 0.6825726141078838, 0.39910560846328735)
(34, 0.6773858921161826, 0.4415501356124878)
(35, 0.6839557399723375, 0.38833072781562805)
(36, 0.6898340248962656, 0.3115880489349365)
(37, 0.6856846473029046, 0.2552001178264618)
(38, 0.6863762102351314, 0.26279231905937195)
(39, 0.6929460580912863, 0.32241174578666687)
(40, 0.7057399723374828, 0.2139887809753418)
(41, 0.7098893499308437, 0.16066813468933105)
(42, 0.7105809128630706, 0.17470477521419525)
(43, 0.7136929460580913, 0.13071224093437195)
(44, 0.7074688796680498, 0.12287493795156479)
(45, 0.7050484094052559, 0.13963322341442108)
(46, 0.710926694329184, 0.12651795148849487)
(47, 0.7112724757952974, 0.1293894350528717)
(48, 0.7164591977869986, 0.12718772888183594)
(49, 0.7064315352697096, 0.20999878644943237)

Best model accuracy: 0.7164591977869986

TEST Accuracy Final Result: 0.600069132388524