In [1]:
```
%matplotlib inline
```

In [2]:
```
import torch
import torchvision
import torchvision.transforms as transforms
from torch.utils.data.sampler import SubsetRandomSampler
import matplotlib.pyplot as plt
import numpy as np
import torch.nn as nn
import torch.nn.functional as F
import torch.optim as optim

import pandas as pd
```

HW_04_Problem 1

MLP

- Pseudocode:
  1. Load CIFAR Data
     - Show an image
  2. Build two MLP models
     - Multiple layer sizes
     - Use regularization
  3. For each model
     A. Train a multi-layer perceptron (MLP) on the CIFAR10 data set
        - Report error on training data
          - w/ regularization
          - w/o regularization
        - include report of hyperparameters (epochs, regularization, learning rate)

     B. Test a multi-layer perceptron (MLP) on the CIFAR10 data set
        - Report error on testing data
          - w/ regularization
          - w/o regularization
        - include report of hyperparameters (epochs, regularization, learning rate)

1. Load CIFAR Dataset

In [4]:
```
# # number of subprocesses to use for data loading
# num_workers = 0
# how many samples per batch to load
batch_size = 12
# # percentage of training set to use as validation
# valid_size = 0.2

# convert data to torch.FloatTensor
transform = transforms.Compose(
    [transforms.ToTensor(),
     transforms.Normalize((0.5, 0.5, 0.5), (0.5, 0.5, 0.5))])
```

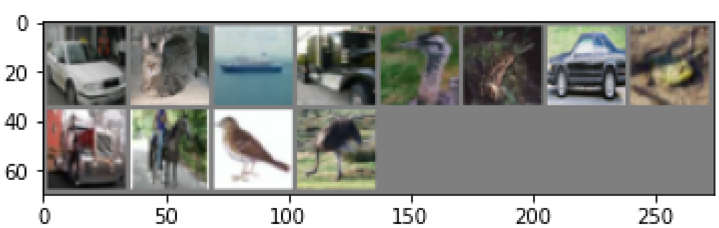
```
# choose the training and testing datasets
train_data = torchvision.datasets.CIFAR10(root = './data', train = True, downloa
test_data = torchvision.datasets.CIFAR10(root = './data', train = False, downloa

train_loader = torch.utils.data.DataLoader(train_data, batch_size=batch_size,
                                          shuffle=True, num_workers=0)
test_loader = torch.utils.data.DataLoader(test_data, batch_size=batch_size,
                                         shuffle=False, num_workers=0)
```

```
Files already downloaded and verified
Files already downloaded and verified
```

Show an Image

In [5]:

```
classes = ('plane', 'car', 'bird', 'cat',
           'deer', 'dog', 'frog', 'horse', 'ship', 'truck')

# functions to show an image
def imshow(img):
    img = img / 2 + 0.5     # unnormalize
    npimg = img.numpy()
    plt.imshow(np.transpose(npimg, (1, 2, 0)))
    plt.show()


# get some random training images
dataiter = iter(train_loader)
images, labels = dataiter.next()

# show images
imshow(torchvision.utils.make_grid(images))
# print labels
print(' '.join('%5s' % classes[labels[j]] for j in range(batch_size)))
```




```
  car   cat  ship truck  bird  frog   car  frog truck horse  bird  bird
```

Data Preparation

2. Build an MLP model

In [6]:

```
# from pytorch tutorial (see resources)
class Net(nn.Module):
    def __init__(self):
        super(Net, self).__init__()
        self.conv1 = nn.Conv2d(3, 6, 5)
        self.pool = nn.MaxPool2d(2, 2)
        self.conv2 = nn.Conv2d(6, 16, 5)
        self.fc1 = nn.Linear(16 * 5 * 5, 120)
        self.fc2 = nn.Linear(120, 84)
        self.fc3 = nn.Linear(84, 10)
```

```
    def forward(self, x):
        x = self.pool(F.relu(self.conv1(x)))
        x = self.pool(F.relu(self.conv2(x)))
        x = x.view(-1, 16 * 5 * 5)
        x = F.relu(self.fc1(x))
        x = F.relu(self.fc2(x))
        x = self.fc3(x)
        return x

# modified from Net2 in medium article (see resources)
class Net3(nn.Module):
    '''a two-layer linear model
      dropout: with default dropout = True
      do_const: with default dropout countant = 0.2
      hidden: with a default hidden dimension = 100
    '''

    def __init__(self, hidden=100, dropout=True, do_const=0.2):
        super(Net3,self).__init__()

        # characteristics of input
        dim_1 = 32 # x dimensions of the figure
        dim_2 = 32 # y dimensions of the figure
        num_classes = 10 # number of output classes
        num_col = 3 # since color images, for greyscale = 1

        # number of hidden nodes in each layer
        self.hidden_1  = hidden # hidden layer dimension (user defined)
        self.hidden_2  = hidden # hidden layer dimension (user defined)

        # dropout
        self.dropout = dropout
        self.do_const = do_const

        # linear layer (num_col*dim_1 * dim_2 -> hidden_1) *NOTE Adding num_col
        self.fc1 = nn.Linear(3*32*32, self.hidden_1)
        # linear layer (n_hidden -> hidden_2)
        self.fc2 = nn.Linear(self.hidden_1,self.hidden_2)
        # linear layer (n_hidden -> num_classes)
        self.fc3 = nn.Linear(self.hidden_2,10)

        # optional dropout
        if self.dropout:
          # dropout layer (p=self.do_const)
          # dropout prevents overfitting of data
          self.droput = nn.Dropout(p=self.do_const)
        else:
          self.droput = nn.Dropout(p=0)

    def forward(self,x):
        # print(x.shape)
        # flatten image input (-1, num_col*dim_1*dim_2) *NOTE Adding num_col ver
        x = x.view(-1,3*32*32)
        # print(x.shape)
        # add hidden layer, with relu activation function
        x = F.relu(self.fc1(x))
        # add dropout layer
        x = self.droput(x)
         # add hidden layer, with relu activation function
        x = F.relu(self.fc2(x))
```

```
        # optional dropout
        if self.dropout:
          # add dropout layer
          x = self.dropout(x)
        else:
          x = self.dropout(x)

        # add output layer
        x = self.fc3(x)
        return x
```

3. Train each model

- Prelim - Create a pandas array to store all the information re: training and testing
- Prelim - Define a loss function and optimizer

1. First, train the simplest neural net
    - with regularization
    - without regularization
2. Then, test the more complicated neural net (with convolution)
    - with regularization
    - without regularization
3. Save the data

In [7]:
```
# Prelim - Create a pandas array to store all the information re: training and t
model_df = pd.DataFrame(columns=['model_name', 'net', 'train_err', 'test_error',
```

Prelim

In [53]:
```
# Prelim define loss function, optimizer, and other hyperparameters
lr = 0.001
momentum = 0.9
n_epochs = 5

# L2
L2_penalty = True # the L2 penalty is par tof the optimizer
L2_constant = 1e-2 # some L2 constant > 0

# dropout
dropout=False
do_const=0.5

# hidden layers
hidden = 50

# set up net
net_in = Net3(hidden=hidden, dropout=dropout, do_const=do_const)
print(net_in)

# controls optimization
criterion = nn.CrossEntropyLoss()
if L2_penalty: # add regularization if desired
  optimizer = optim.SGD(net_in.parameters(), lr=0.001, momentum=0.9, weight_deca
else:
  optimizer = optim.SGD(net_in.parameters(), lr=0.001, momentum=0.9, weight_deca
```

```
# assembles list of loss for plotting
loss_list = []

# creates model name
model_name = str(hidden)+'HLN+'+'L2='+str(L2_penalty)
print(model_name)
```

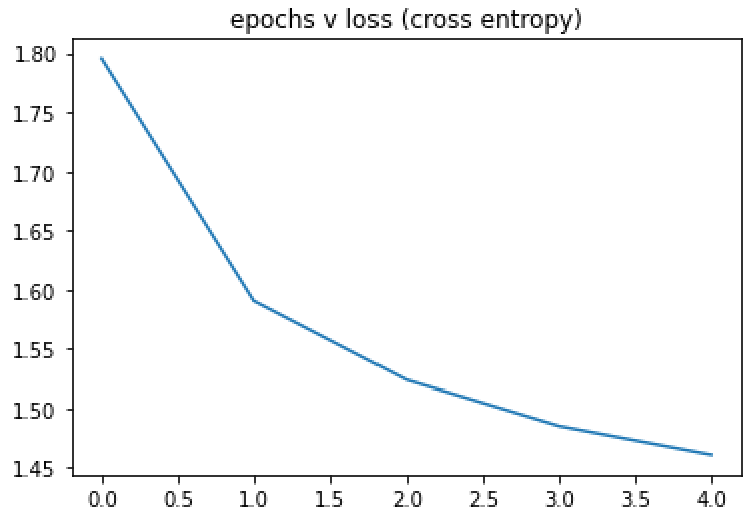
```
Net3(
  (fc1): Linear(in_features=3072, out_features=50, bias=True)
  (fc2): Linear(in_features=50, out_features=50, bias=True)
  (fc3): Linear(in_features=50, out_features=10, bias=True)
  (dropout): Dropout(p=0, inplace=False)
)
50HLN+L2=True
```

4. Train the neural Net

In [54]:

```
# training
for epoch in range(n_epochs):  # loop over the dataset multiple times

    running_loss = 0.0 # keep track of loss within each epoch

    for i, data in enumerate(train_loader, 0): # loop through batches in train

        # get the inputs; data is a list of [inputs, labels]
        inputs, labels = data

        # zero the parameter gradients
        optimizer.zero_grad()

        # forward + backward + optimize
        outputs = net_in(inputs)
        loss = criterion(outputs, labels)
        loss.backward()
        optimizer.step()

        # update loss statistics
        running_loss += loss.item()

    # print and save loss statistics
    print(running_loss / i)
    loss_list.append(running_loss / i)
    running_loss = 0.0


# final things
print('Finished Training')

# save some results

# plot
plt.plot(np.arange(0,len(loss_list)), loss_list)
plt.title('epochs v loss (cross entropy)')
plt.show()
```

```
1.7955943031260673
1.5903667818309593
1.5236713025384492
1.4848844187081118
1.4606699741808085
Finished Training
```



5. test and

6. save

In [55]:

```
# train
correct = 0
total = 0
with torch.no_grad():
    for data in train_loader:
        images, labels = data
        outputs = net_in(images)
        _, predicted = torch.max(outputs.data, 1)
        total += labels.size(0)
        correct += (predicted == labels).sum().item()

# create train error, where train error is the percent mis-identified (expressed
train_err = 1 - (correct / total)

# test
correct = 0
total = 0
with torch.no_grad():
    for data in test_loader:
        images, labels = data
        outputs = net_in(images)
        _, predicted = torch.max(outputs.data, 1)
        total += labels.size(0)
        correct += (predicted == labels).sum().item()

# create test error, where test error is the percent mis-identified (expressed a
test_err = 1 - (correct / total)
```

In [58]:

```
model_df = model_df.append({'model_name': model_name, 'net': net_in,
                            'train_err': train_err, 'test_error': test_err, 'mod
```

PLOT

In [80]:

```
model_df[['model_name', 'train_err', 'test_error', 'L2_penalty', 'num_nodes', '
```

Out[80]:

model_name	train_err	test_error	L2_penalty	num_nodes	num_layers

	model_name	train_err	test_error	L2_penalty	num_nodes	num_layers
1	200HLN+L2=False	0.39780	0.4666	0.00	200	2
2	200HLN+L2=True	0.47864	0.5067	0.01	200	2
3	200HLN+L2=True	0.90000	0.9000	0.50	200	2
4	50HLN+L2=False	0.45254	0.4956	0.00	50	2
5	50HLN+L2=True	0.49738	0.5181	0.01	50	2
6	50HLN+L2=True	0.90000	0.9000	0.50	50	2
7	50HLN+L2=True	0.90000	0.9000	0.50	50	2
8	5HLN+L2=False	0.65572	0.6646	0.00	5	2

In [98]:

```
i = 0
for model in model_df['model_dict']:
  i = i + 1
  print('Model', i)
  for param_tensor in model:
      print(param_tensor, "\t", model[param_tensor].size())

  print()


i = 0
for optimizer in model_df['optim_dict']:
  i = i + 1
  print('Model', i)
  for var_name in optimizer:
      if var_name == 'state':
        a = 1
      else:
        print((var_name), "\t", optimizer[var_name])

  print()
```

```
Model 1
fc1.weight       torch.Size([200, 3072])
fc1.bias         torch.Size([200])
fc2.weight       torch.Size([200, 200])
fc2.bias         torch.Size([200])
fc3.weight       torch.Size([10, 200])
fc3.bias         torch.Size([10])

Model 2
fc1.weight       torch.Size([200, 3072])
fc1.bias         torch.Size([200])
fc2.weight       torch.Size([200, 200])
fc2.bias         torch.Size([200])
fc3.weight       torch.Size([10, 200])
fc3.bias         torch.Size([10])

Model 3
fc1.weight       torch.Size([200, 3072])
fc1.bias         torch.Size([200])
fc2.weight       torch.Size([200, 200])
fc2.bias         torch.Size([200])
fc3.weight       torch.Size([10, 200])
fc3.bias         torch.Size([10])
```

```
Model 4
fc1.weight       torch.Size([50, 3072])
fc1.bias         torch.Size([50])
fc2.weight       torch.Size([50, 50])
fc2.bias         torch.Size([50])
fc3.weight       torch.Size([10, 50])
fc3.bias         torch.Size([10])

Model 5
fc1.weight       torch.Size([50, 3072])
fc1.bias         torch.Size([50])
fc2.weight       torch.Size([50, 50])
fc2.bias         torch.Size([50])
fc3.weight       torch.Size([10, 50])
fc3.bias         torch.Size([10])

Model 6
fc1.weight       torch.Size([50, 3072])
fc1.bias         torch.Size([50])
fc2.weight       torch.Size([50, 50])
fc2.bias         torch.Size([50])
fc3.weight       torch.Size([10, 50])
fc3.bias         torch.Size([10])

Model 7
fc1.weight       torch.Size([50, 3072])
fc1.bias         torch.Size([50])
fc2.weight       torch.Size([50, 50])
fc2.bias         torch.Size([50])
fc3.weight       torch.Size([10, 50])
fc3.bias         torch.Size([10])

Model 8
fc1.weight       torch.Size([5, 3072])
fc1.bias         torch.Size([5])
fc2.weight       torch.Size([5, 5])
fc2.bias         torch.Size([5])
fc3.weight       torch.Size([10, 5])
fc3.bias         torch.Size([10])

Model 1
param_groups     [{'lr': 0.001, 'momentum': 0.9, 'dampening': 0, 'weight_decay':
0, 'nesterov': False, 'params': [0, 1, 2, 3, 4, 5]}]

Model 2
param_groups     [{'lr': 0.001, 'momentum': 0.9, 'dampening': 0, 'weight_decay':
0.01, 'nesterov': False, 'params': [0, 1, 2, 3, 4, 5]}]

Model 3
param_groups     [{'lr': 0.001, 'momentum': 0.9, 'dampening': 0, 'weight_decay':
0.5, 'nesterov': False, 'params': [0, 1, 2, 3, 4, 5]}]

Model 4
param_groups     [{'lr': 0.001, 'momentum': 0.9, 'dampening': 0, 'weight_decay':
0, 'nesterov': False, 'params': [0, 1, 2, 3, 4, 5]}]

Model 5
param_groups     [{'lr': 0.001, 'momentum': 0.9, 'dampening': 0, 'weight_decay':
0.01, 'nesterov': False, 'params': [0, 1, 2, 3, 4, 5]}]

Model 6
param_groups     [{'lr': 0.001, 'momentum': 0.9, 'dampening': 0, 'weight_decay':
0.5, 'nesterov': False, 'params': [0, 1, 2, 3, 4, 5]}]

Model 7
```

```
param_groups     [{'lr': 0.001, 'momentum': 0.9, 'dampening': 0, 'weight_decay':
0.5, 'nesterov': False, 'params': [0, 1, 2, 3, 4, 5]}]

Model 8
param_groups     [{'lr': 0.001, 'momentum': 0.9, 'dampening': 0, 'weight_decay':
0, 'nesterov': False, 'params': [0, 1, 2, 3, 4, 5]}]
```

BONUS. Fun extra tests

In [13]:

```
# # check that test data are set up
# dataiter = iter(test_loader)
# images, labels = dataiter.next()

# # print images
# imshow(torchvision.utils.make_grid(images))
# print('GroundTruth: ', ' '.join('%5s' % classes[labels[j]] for j in range(batc

# # preliminary check
# outputs = net_in(images)
# _, predicted = torch.max(outputs, 1)

# print('Predicted: ', ' '.join('%5s' % classes[predicted[j]]
#                               for j in range(batch_size)))

# # final check
# correct = 0
# total = 0
# with torch.no_grad():
#     for data in test_loader:
#         images, labels = data
#         outputs = net_in(images)
#         _, predicted = torch.max(outputs.data, 1)
#         total += labels.size(0)
#         correct += (predicted == labels).sum().item()

# print('\n Accuracy of the network on the 10000 test images: %d %%' % (
#     100 * correct / total))

# # What are the classes that performed well, and the classes that did not perfo
# print('')
# class_correct = list(0. for i in range(10))
# class_total = list(0. for i in range(10))
# with torch.no_grad():
#     for data in test_loader:
#         images, labels = data
#         outputs = net_in(images)
#         _, predicted = torch.max(outputs, 1)
#         c = (predicted == labels).squeeze()
#         for i in range(4):
#             label = labels[i]
#             class_correct[label] += c[i].item()
#             class_total[label] += 1

# for i in range(10):
#     print('Accuracy of %5s : %2d %%' % (
#         classes[i], 100 * class_correct[i] / class_total[i]))
```


```
GroundTruth:    cat  ship  ship plane  frog  frog   car  frog   cat   car plane
truck
Predicted:    cat truck plane  bird  deer  frog   cat  frog   dog   car plane tr
uck

 Accuracy of the network on the 10000 test images: 53 %

Accuracy of plane : 61 %
Accuracy of   car : 61 %
Accuracy of  bird : 31 %
Accuracy of   cat : 36 %
Accuracy of  deer : 44 %
Accuracy of   dog : 41 %
Accuracy of  frog : 59 %
Accuracy of horse : 66 %
Accuracy of  ship : 69 %
Accuracy of truck : 61 %
```