CS441: Applied ML - HW 1

Parts 1-2: MNIST

Include all the code for generating MNIST results below

In [ ]:
```
# initialization code
import numpy as np
from tensorflow import keras
from keras.datasets import mnist
# from tensorflow import keras
%matplotlib inline
from matplotlib import pyplot as plt
from scipy import stats


def load_mnist():
  '''
  Loads, reshapes, and normalizes the data
  '''
  (x_train, y_train), (x_test, y_test) = mnist.load_data() # loads MNIST dat
  x_train = np.reshape(x_train, (len(x_train), 28*28))  # reformat to 768-d
  x_test = np.reshape(x_test, (len(x_test), 28*28))
  maxval = x_train.max()
  x_train = x_train/maxval  # normalize values to range from 0 to 1
  x_test = x_test/maxval
  return (x_train, y_train), (x_test, y_test)

def display_mnist(x, subplot_rows=1, subplot_cols=1):
  '''
  Displays one or more examples in a row or a grid
  '''
  if subplot_rows>1 or subplot_cols>1:
    fig, ax = plt.subplots(subplot_rows, subplot_cols, figsize=(15,15))
    for i in np.arange(len(x)):
      ax[i].imshow(np.reshape(x[i], (28,28)), cmap='gray')
      ax[i].axis('off')
  else:
      plt.imshow(np.reshape(x, (28,28)), cmap='gray')
      plt.axis('off')
  plt.show()
```

In [ ]:
```
# example of using MNIST load and display  functions
(x_train, y_train), (x_test, y_test) = load_mnist()
display_mnist(x_train[:10],1,10)
print('Total size: train={}, test ={}'.format(len(x_train), len(x_test)))
```

```
Total size: train=60000, test =10000
```

1. Retrieval, Clustering, and NN Classification

In [ ]:
```
# Retrieval
import math
def get_nearest(X_query, X):
  ''' Return the index of the sample in X that is closest to X_query accordi
      to L2 distance '''
  # TO DO
  mindis = math.inf
  n = X.shape[0]
  res = -1
  for i in range(n):
    dis = np.linalg.norm(X[i]-X_query)
    if dis<mindis:
      mindis = dis
      res = i
  if res>=0:
    return res
  else:
    print("error happens!")


# print(x_train.shape)
# print(x_test.shape)
j = get_nearest(x_test[0], x_train)
print(j)
j = get_nearest(x_test[1], x_train)
print(j)
```

```
53843
28882
```

In [ ]:
```
# K-means
def kmeans(X, K, niter=10):
  '''
  Starting with the first K samples in X as cluster centers, iteratively ass
  point to the nearest cluster and compute the mean of each cluster.
  Input: X[i] is the ith sample, K is the number of clusters, niter is the r
  Output: K cluster centers
  '''
  # TO DO -- add code to display cluster centers at each iteration also
  centers = np.copy(X[:K])
  for i in range(niter):
    choice = np.array([get_nearest(x, centers) for x in X])
    for j in range(K):
      centers[j] = np.mean(X[choice==j],axis=0)
    if i==0 or i==9:
      print(f"iter={i+1}")
      display_mnist(centers,1,30)
  return centers
K=30
centers = kmeans(x_train[:1000], K)
```

```
iter=1
```

iter=10

In [ ]:
```
# 1-NN

# TO DO
train = x_train[:10000]
wrong = 0
for i in range(100):
  if y_test[i] != y_train[get_nearest(x_test[i], train)]:
    wrong += 1
print(f"incorrect rate: {wrong}%")
```

```
incorrect rate: 8%
```

2. Make it fast

In [ ]:
```
# install libraries you need for part 2
!apt install libomp-dev
!pip install faiss-cpu
import faiss
import time
```

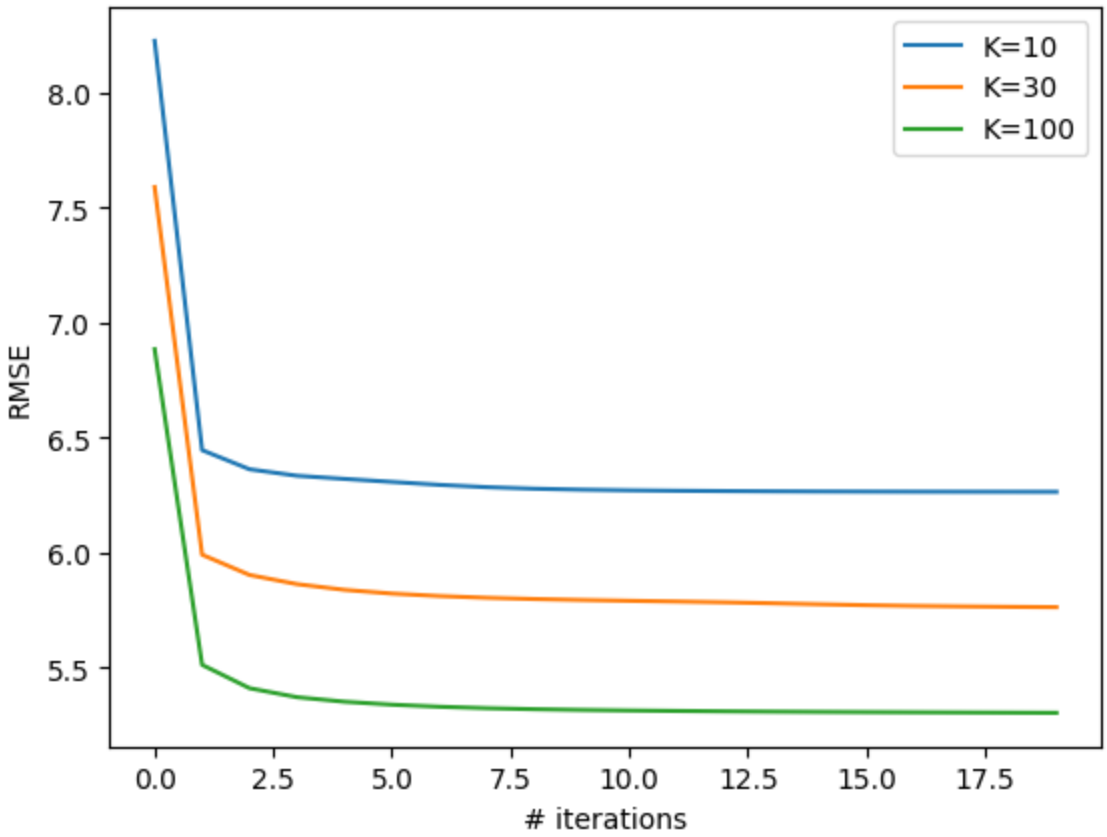
```
The operation couldn't be completed. Unable to locate a Java Runtime that su
pports apt.
Please visit http://www.java.com for information on installing Java.

Requirement already satisfied: faiss-cpu in /Users/janghl/anaconda3/envs/am
l/lib/python3.10/site-packages (1.7.4)
```

In [ ]:
```
# retrieval

# TO DO (check that you're using FAISS correctly)

def fast_nearest(X_query, X, K=1, LSH=False):
  if not LSH:
    index = faiss.IndexFlatL2(x_train.shape[1])  # set for exact search
  else:
    dim = X.shape[1]
    index = faiss.IndexLSH(dim, dim)
  index.add(X) # add the data
  dist, idx = index.search(X_query, K) # returns index and sq err for each s
  return np.array(dist), np.array(idx)

dist, idx = fast_nearest(x_test, x_train)
print(idx[0])
print(idx[1])
```

```
[53843]
[28882]
```

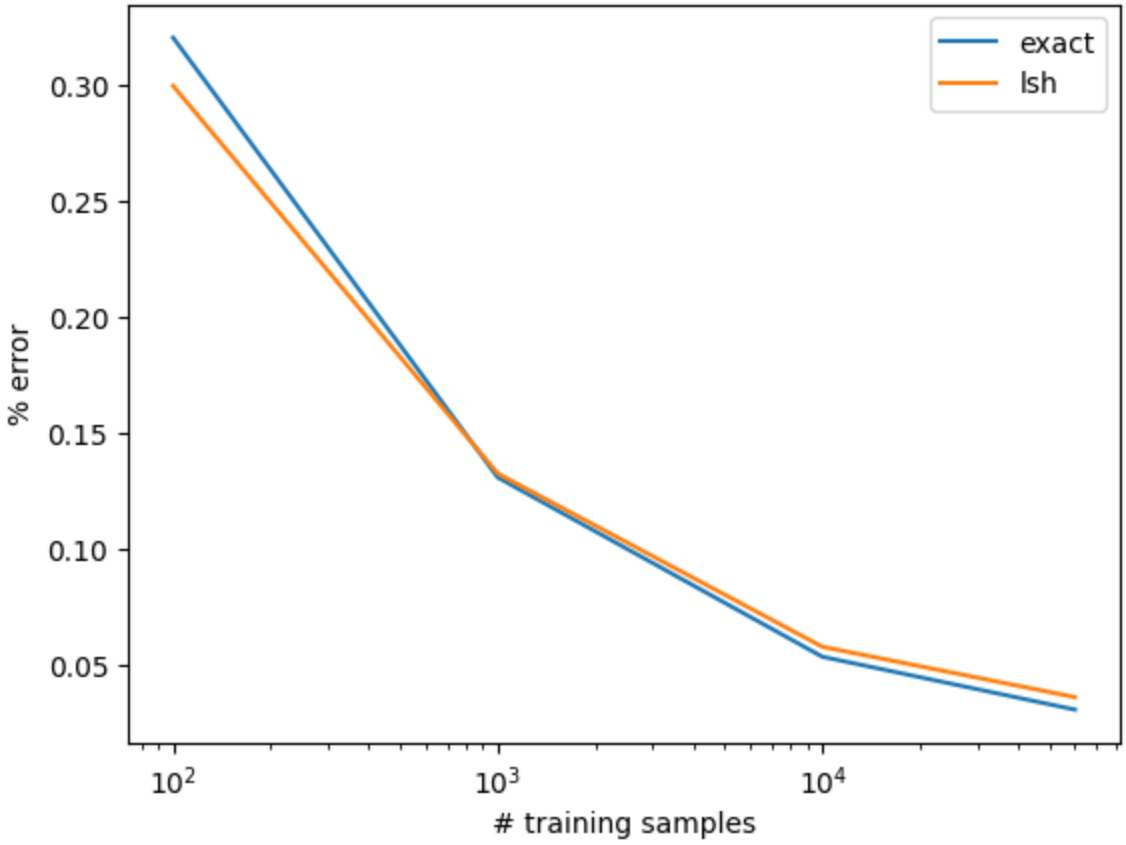
In [ ]:
```
# K-means

def kmeans_fast(X, K, niter=10):
```

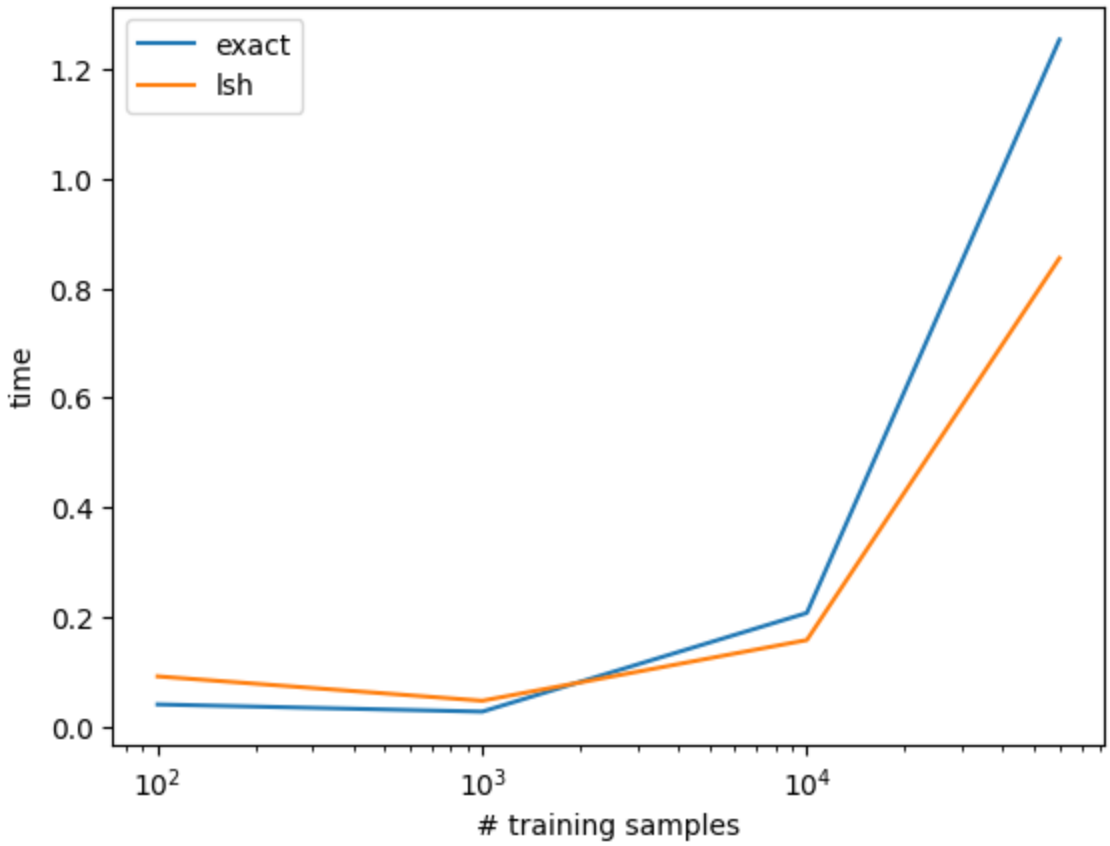
```
  '''
  Starting with the first K samples in X as cluster centers, iteratively ass
  point to the nearest cluster using faiss and compute the mean of each clus
  Input: X[i] is the ith sample, K is the number of clusters, niter is the r
  Output: K cluster centers
  '''

  # TO DO (you can base this on part 1, but use FAISS for search)
  # if you include display code, you need to re-organize the plotting code b
  rmse = []
  centers = np.copy(X[:K])
  for i in range(niter):
    dist, idx = fast_nearest(X, centers)
    choice = np.array(idx).reshape(idx.shape[0])
    rmse.append(np.sqrt(np.sum(dist)/dist.shape[0]))
    for j in range(K):
      centers[j] = np.mean(X[choice==j],axis=0)
  return centers, rmse

K=10
centers, rmse = kmeans_fast(x_train, K, niter=20)
plt.plot(np.arange(len(rmse)), rmse, label='K=10')

K=30
centers, rmse = kmeans_fast(x_train, K, niter=20)
plt.plot(np.arange(len(rmse)), rmse, label='K=30')

K=100
centers, rmse = kmeans_fast(x_train, K, niter=20)
plt.plot(np.arange(len(rmse)), rmse, label='K=100')
plt.legend(), plt.ylabel('RMSE'), plt.xlabel('# iterations')
plt.show()
```



In [ ]:
```
# 1-NN

nsample = [100, 1000, 10000, 60000]

# TO DO
def ONN(x_train, x_test, s, LSH):
  begin = time.time()
  train = x_train[:s]
  right = 0
  if LSH:
    dim = x_test.shape[1]
    index = faiss.IndexLSH(dim, dim)
  else:
    index = faiss.IndexFlatL2(x_test.shape[1])
  index.add(train)
  dist, idx = index.search(x_test,1) # returns index and sq err for each sam
  idx = np.array(idx).reshape(idx.shape[0])
  for i in range(len(x_test)):
    if y_test[i] == y_train[idx[i]]:
      right += 1
  acc = right/len(x_test)
  end = time.time()
  timing = end-begin
  return acc, timing

acc_exact = []
acc_lsh = []
timing_exact = []
timing_lsh = []
```

```
for s in nsample:
  acc_exact_elem, timing_exact_elem = ONN(x_train, x_test, s, LSH=False)
  acc_lsh_elem, timing_lsh_elem = ONN(x_train, x_test, s, LSH=True)
  acc_exact.append(1-acc_exact_elem)
  acc_lsh.append(1-acc_lsh_elem)
  timing_exact.append(timing_exact_elem)
  timing_lsh.append(timing_lsh_elem)


plt.semilogx(nsample, acc_exact, label='exact')
plt.semilogx(nsample, acc_lsh, label='lsh')
plt.legend(), plt.ylabel('% error'), plt.xlabel('# training samples')
plt.show()

plt.semilogx(nsample, timing_exact, label='exact')
plt.semilogx(nsample, timing_lsh, label='lsh')
plt.legend(), plt.ylabel('time'), plt.xlabel('# training samples')
plt.show()
```





In [ ]:
```
# Confusion matrix
from sklearn import metrics
# TO DO
index = faiss.IndexFlatL2(x_test.shape[1])
index.add(train)
dist, idx = index.search(x_test,1) # returns index and sq err for each sampl
idx = np.array(idx).reshape(idx.shape[0])
metrics.confusion_matrix(y_test, y_train[idx])
```

Out[ ]:
```
array([[ 971,    1,    1,    0,    0,    1,    4,    1,    1,    0],
       [   0, 1130,    1,    2,    0,    0,    2,    0,    0,    0],
       [  15,   14,  960,    9,    1,    1,    4,   23,    5,    0],
       [   1,    1,    4,  945,    1,   23,    3,   12,    9,   11],
       [   0,   11,    0,    0,  915,    0,    8,    6,    2,   40],
       [   8,    4,    0,   28,    3,  828,   10,    2,    2,    7],
       [   9,    3,    0,    0,    3,    4,  938,    0,    1,    0],
       [   0,   26,    8,    1,    4,    1,    0,  972,    1,   15],
       [   9,    5,    6,   32,    4,   21,    7,    8,  863,   19],
       [   6,    6,    3,    7,   20,    4,    1,   17,    4,  941]])
```

Part 3: Temperature Regression

Include all your code used for part 2 in this section.

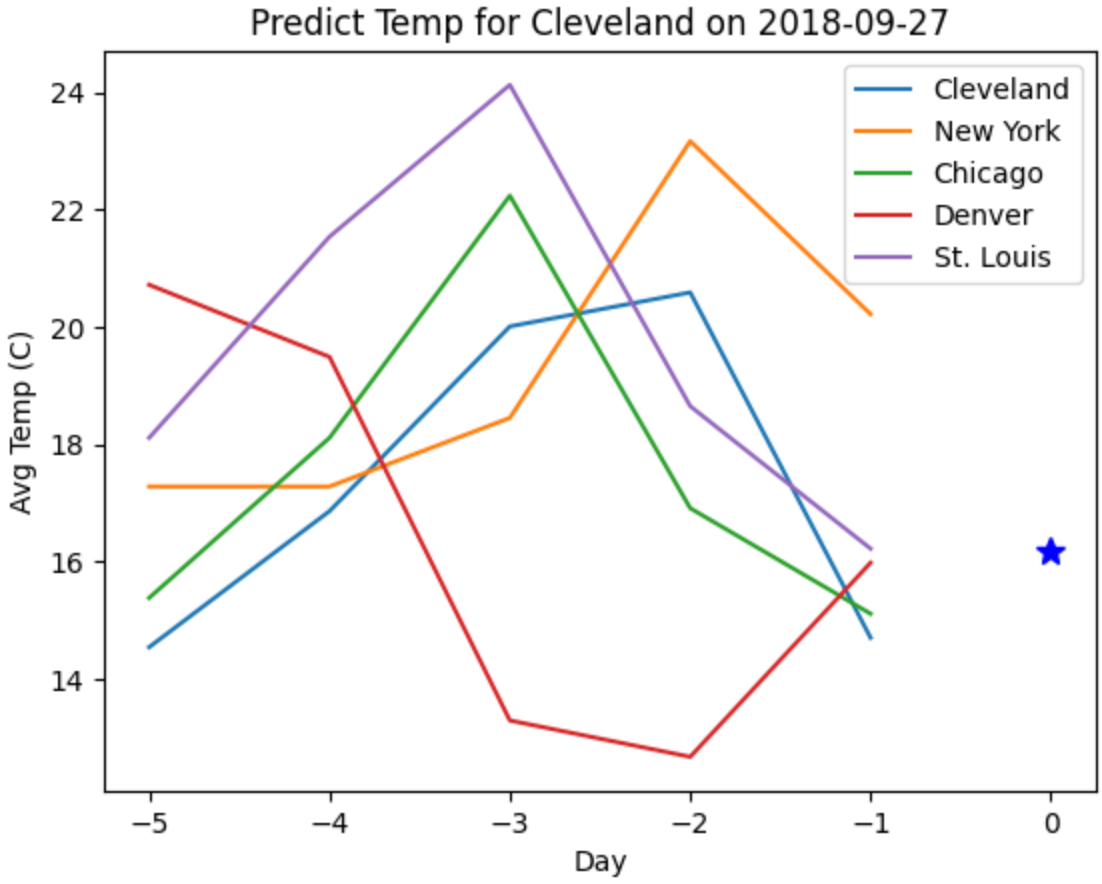
In [ ]:
```
import numpy as np
# from google.colab import drive
%matplotlib inline
```

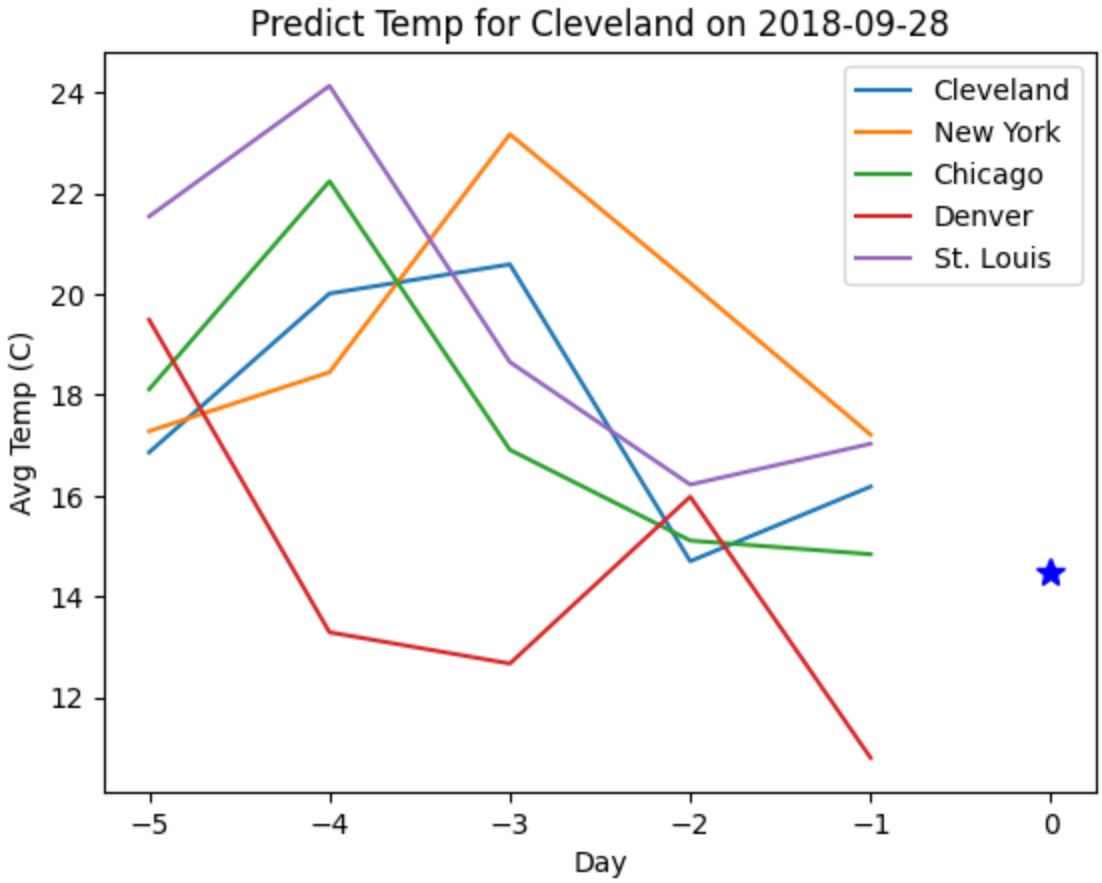
```
from matplotlib import pyplot as plt
from sklearn.linear_model import Ridge
from sklearn.linear_model import Lasso

# load data (modify to match your data directory or comment)
def load_temp_data():
  # drive.mount('/content/drive')
  # datadir = "/content/drive/My Drive/CS441/24SP/hw1/"
  datadir = "./"
  T = np.load(datadir + 'temperature_data.npz')
  x_train, y_train, x_val, y_val, x_test, y_test, dates_train, dates_val, da
  T['x_train'], T['y_train'], T['x_val'], T['y_val'], T['x_test'], T['y_test
  return (x_train, y_train, x_val, y_val, x_test, y_test, dates_train, dates

# plot one data point for listed cities and target date
def plot_temps(x, y, cities, feature_to_city, feature_to_day, target_date):
  nc = len(cities)
  ndays = 5
  xplot = np.array([-5,-4,-3,-2,-1])
  yplot = np.zeros((nc,ndays))
  for f in np.arange(len(x)):
    for c in np.arange(nc):
      if cities[c]==feature_to_city[f]:
        yplot[feature_to_day[f]+ndays,c] = x[f]
  plt.plot(xplot,yplot)
  plt.legend(cities)
  plt.plot(0, y, 'b*', markersize=10)
  plt.title('Predict Temp for Cleveland on ' + target_date)
  plt.xlabel('Day')
  plt.ylabel('Avg Temp (C)')
  plt.show()
```

In [ ]:

```
# load data
(x_train, y_train, x_val, y_val, x_test, y_test, dates_train, dates_val, dat
''' Data format:
      x_train, y_train: features and target value for each training sample (
      x_val, y_val: features and target value for each validation sample (us
      x_test, y_test: features and target value for each test sample (used t
      dates_xxx: date of the target value for the corresponding sample
      feature_to_city: maps from a feature number to the city
      feature_to_day: maps from a feature number to a day relative to the ta
      Note: 361 is the temperature of Cleveland on the previous day
'''
f = 361
print('Feature {}: city = {}, day= {}'.format(f,feature_to_city[f], feature_
baseline_rmse = np.sqrt(np.mean((y_val[1:]-y_val[:-1])**2)) # root mean squa
print('Baseline - prediction using previous day: RMSE={}'.format(baseline_rm

# plot first two x/y for val
plot_temps(x_val[0], y_val[0], ['Cleveland', 'New York', 'Chicago', 'Denver'
plot_temps(x_val[1], y_val[1], ['Cleveland', 'New York', 'Chicago', 'Denver'
```

```
Feature 361: city = Cleveland, day= -1
Baseline - prediction using previous day: RMSE=3.460601246750482
```


Predict Temp for Cleveland on 2018-09-27
Cleveland
New York
Chicago
Denver
St. Louis
Avg Temp (C)
Day
24
22
20
18
16
14
−5
−4
−3
−2
−1
0


Predict Temp for Cleveland on 2018-09-28
Cleveland
New York
Chicago
Denver
St. Louis
Avg Temp (C)
Day
24
22
20
18
16
14
12
−5
−4
−3
−2
−1
0

In [ ]:
```
# K-NN Regression
import copy

def regress_KNN(X_trn, y_trn, X_tst, K=1):
  '''
  Predict the target value for each data point in X_tst using a
  K-nearest neighbor regressor based on (X_trn, y_trn), with L2 distance.
  Input: X_trn[i] is the ith training data. y_trn[i] is the ith training lab
  Output: return y_pred, where y_pred[i] is the predicted ith test value
  '''
  # TO DO

  dist, idx = fast_nearest(x_test, x_train, K=K)
  y_pred = np.zeros(shape=X_tst.shape[0])
  for i in range(len(X_tst)):
    points = []
    for j in idx[i]:
      points.append(y_trn[j])
      y_pred[i] = np.mean(points)
  return y_pred


def normalize_features(x, y, fnum):
  ''' Normalize the features in x and y.
      For each data sample i:
        x2[i] = x[i]-x[i,fnum]
        y2[i] = y[i]-x[i,fnum]
  '''
  # TO DO
  x2 = np.zeros_like(x)
  y2 = np.zeros_like(y)
  xsub = np.array(np.copy(x[:,fnum]))
  for i in range(x.shape[1]):
    x2[:,i] = x[:,i] - xsub
  y2 = y - xsub
  return x2, y2



# KNN with original features

# TO DO
y_predict = regress_KNN(x_train, y_train, x_test, K=5)
# print(f"y_predict: {y_val.shape}\nx_test: {x_val.shape}")
print(f"rmse when K=5: {np.sqrt(np.mean((y_test-y_predict)**2))}")
# KNN with normalized features
fnum = 361 # previous day temp in Cleveland

# TO DO
x_train_new, y_train_new = normalize_features(x_train, y_train, fnum)
x_test_new, y_test_new = normalize_features(x_test, y_test, fnum)
y_predict_new = regress_KNN(x_train_new, y_train_new, x_test_new, K=5)
print(f"rmse when K=5: {np.sqrt(np.mean((y_test_new-y_predict_new)**2))}")
```

```
rmse when K=5: 3.249556245363484
rmse when K=5: 2.9770334300836487
```

Part 5: Stretch Goals

Include all your code used for part 5 in this section. You can copy-paste code from parts 1-3 if it is re-usable.

In [ ]:
```
# Stretch: KNN classification (Select K)

# find the prediction for a set
def calc_pred(valid, dist, idx, y_train, K):
  pred = np.zeros(valid.shape[0])
  for i in range(valid.shape[0]):
    count = {}
    distance = {}
    for j in range(K):            #for each of K points, p is predicted numb
      p = y_train[idx[i][j]]
      d = dist[i][j]
      if p in distance:
        distance[p] += d
      else:
        distance[p] = d
      if p in count:
        count[p] += 1
      else:
        count[p] = 1
    maxnum = -math.inf      #find all candidates with highest votes
    candidate = []
    for c in count:
      if count[c]>maxnum:
        maxnum = count[c]
        candidate = [c]
      elif count[c]==maxnum:
        candidate.append(c)
    mindist = math.inf
    result = -1
    for can in candidate:
      if distance[can]<mindist:
        result = can
    pred[i] = result
  return pred


def KNN_classification(x_train, y_train, K):
  train = x_train[:50000]
  valid = x_train[50000:]
  answer = y_train[50000:]
  dist, idx = fast_nearest(valid, train, K=K)
  correct = 0
  pred = calc_pred(valid, dist, idx, y_train, K)
  for i in range(len(valid)):
    if pred[i]==answer[i]:
      correct += 1
```

```
  print(f"incorrect rate for K={K}: {100*(1-correct/len(valid))}%")


(x_train, y_train), (x_test, y_test) = load_mnist()
hyperparameter = [1, 3, 5, 11, 25]

for K in hyperparameter:
  KNN_classification(x_train, y_train, K)

# Perform K=3 on the test set
best_K = 3
dist, idx = fast_nearest(x_test, x_train, K=best_K)
correct = 0
pred = calc_pred(x_test, dist, idx, y_train, best_K)
for i in range(len(x_test)):
  if pred[i]==y_test[i]:
    correct += 1
print(f"incorrect rate for K={best_K}: {100*(1-correct/len(x_test))}%")
```

```
incorrect rate for K=1: 2.880000000000005%
incorrect rate for K=3: 2.8200000000000003%
incorrect rate for K=5: 2.949999999999997%
incorrect rate for K=11: 3.1499999999999972%
incorrect rate for K=25: 3.8799999999999946%
incorrect rate for K=3: 2.959999999999996%
```

In [ ]:

```
# Stretch: KNN regression (Select K)
(x_train, y_train, x_val, y_val, x_test, y_test, dates_train, dates_val, dat
# K-NN Regression
hyperparameter = [1, 3, 5, 11, 25]

for K in hyperparameter:
  # KNN with original features

  y_predict = regress_KNN(x_train, y_train, x_val, K=K)
  print(f"rmse when K={K}: {np.sqrt(np.mean((y_val-y_predict)**2))}")
  # KNN with normalized features
  fnum = 361 # previous day temp in Cleveland
  x_train_new, y_train_new = normalize_features(x_train, y_train, fnum)
  x_val_new, y_val_new = normalize_features(x_val, y_val, fnum)
  y_predict_new = regress_KNN(x_train_new, y_train_new, x_val_new, K=K)
  print(f"(normalized)rmse when K={K}: {np.sqrt(np.mean((y_val_new-y_predict
```

```
rmse when K=1: 5.994830467058024
(normalized)rmse when K=1: 4.962816257477145
rmse when K=3: 5.0719820622291065
(normalized)rmse when K=3: 4.081979762608333
rmse when K=5: 4.814445285619017
(normalized)rmse when K=5: 3.7840627858326146
rmse when K=11: 4.635825782051689
(normalized)rmse when K=11: 3.6293441508410265
rmse when K=25: 4.482832870675747
(normalized)rmse when K=25: 3.544085254919383
```

In [ ]:
```
# Best on test set
y_predict = regress_KNN(x_train, y_train, x_test, K=25)
print(f"rmse when K={K}: {np.sqrt(np.mean((y_test-y_predict)**2))}")
```

```
rmse when K=25: 3.041778206247129
```

In [ ]:
```
# Stretch: K-means (more iters vs redos)
def test(niter, nredo):
  kmeans = faiss.Kmeans(x_train.shape[1], 30, niter=niter, nredo=nredo, seed
  kmeans.train(x_train)
  dist, idx = kmeans.index.search(x_train, 1)
  rmse = np.sqrt(np.sum(dist) / x_train.shape[0])
  return rmse
(x_train, y_train), (x_test, y_test) = load_mnist()
first_trail_multiple = []
first_trail_single = []
second_trail_multiple = []
second_trail_single = []
for i in range(5):
  first_trail_multiple.append(test(10,5))
  first_trail_single.append(test(50,1))
  second_trail_multiple.append(test(4,5))
  second_trail_single.append(test(20,1))
print(f"for first_trail_multiple: mean={np.mean(first_trail_multiple)}, std=
print(f"for first_trail_single: mean={np.mean(first_trail_single)}, std={np.
print(f"for second_trail_multiple: mean={np.mean(second_trail_multiple)}, st
print(f"for second_trail_single: mean={np.mean(second_trail_single)}, std={r
```

```
for first_trail_multiple: mean=5.789932893969209, std=0.0
for first_trail_single: mean=5.769123994738427, std=0.0
for second_trail_multiple: mean=5.819028949632977, std=0.0
for second_trail_single: mean=5.775398976117003, std=0.0
```

In [ ]:
```
# from https://gist.github.com/jonathanagustin/b67b97ef12c53a8dec27b343dca4a
# For use in Colab.  For local, just use jupyter nbconvert directly

import os
# @title Convert Notebook to PDF. Save Notebook to given directory
NOTEBOOKS_DIR = "/content/drive/My Drive/CS441/24SP/hw1" # @param {type:"str
NOTEBOOK_NAME = "CS441_SP24_HW1_Solution.ipynb" # @param {type:"string"}
#-------------------------------------------------------------------------
from google.colab import drive
drive.mount("/content/drive/", force_remount=True)
NOTEBOOK_PATH = f"{NOTEBOOKS_DIR}/{NOTEBOOK_NAME}"
assert os.path.exists(NOTEBOOK_PATH), f"NOTEBOOK NOT FOUND: {NOTEBOOK_PATH}"
!apt install -y texlive-xetex texlive-fonts-recommended texlive-plain-generi
!jupyter nbconvert "$NOTEBOOK_PATH" --to pdf > /dev/null 2>&1
NOTEBOOK_PDF = NOTEBOOK_PATH.rsplit('.', 1)[0] + '.pdf'
assert os.path.exists(NOTEBOOK_PDF), f"ERROR MAKING PDF: {NOTEBOOK_PDF}"
print(f"PDF CREATED: {NOTEBOOK_PDF}")
```

```
---------------------------------------------------------------------------
ModuleNotFoundError                       Traceback (most recent call last)
Cell In[30], line 9
      7 NOTEBOOK_NAME = "CS441_SP24_HW1_Solution.ipynb" # @param {type:"stri
ng"}
      8 #---------------------------------------------------------------------
----------#
----> 9 from google.colab import drive
     10 drive.mount("/content/drive/", force_remount=True)
     11 NOTEBOOK_PATH = f"{NOTEBOOKS_DIR}/{NOTEBOOK_NAME}"

ModuleNotFoundError: No module named 'google.colab'
```