hw6p2

June 2, 2022

0.1 Homework 6, Problem 2 on population vector and optimal linear estimator

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Total: 30 points. In this notebook, you will implement an optimal linear estimator decoder.

```
[2]: import numpy as np
     import matplotlib
     import matplotlib.pyplot as plt
     import scipy.special
     import scipy.io as sio
     import math
     import nsp as nsp
     import pdb

     matplotlib.style.use('dark_background')
     # Load matplotlib images inline
     %matplotlib inline
     # Reloading any code written in external .py files.
     %load_ext autoreload
     %autoreload 2
     data = sio.loadmat('JR_2015-12-04_truncated2.mat') # load the .mat file.
     R = data['R'][0,:]
```

0.1.1 (a) (4 points) Tuning curve for one neuron

Fit a cosine tuning curve for electrode 17. On the same plot, plot the average firing rate for electrode 17 to each of the 8 directions and the fitted tuning curve. The average firing rate should be computed in a window from [250, 500] ms after trial onset. Reach angle should be on the x-axis and firing rate on the y-axis.

Hint: You may reuse code from HW #2 about tuning curve fitting to do this question. We have provided two functions: calculateFR() and tuning() which ought simplify this question. Take a look at what they do before calling them. The function tuning returns the tuning curve of a neuron (i.e., the parameters of the tuning curve c_0, c_1, θ_0 such that $f(\theta) = c_0 + c_1 cos(\theta - \theta_0)$)

```
[3]: def calculateFR(i, neuron_idx=16, window=[250,500]):
         # Calculates the firing rate of neuron_idx on trial i in the given window␣
     ↪range.
         # Output units are spikes/s
```

```python
        return float(len(R[i]['spikeRaster'][neuron_idx,window[0]:window[1]].
 →todense().nonzero()[1])) / (window[1] - window[0]) * 1000

def tuning(thetas, meanFRs):
    # Calculates the parameters of a tuning curve.
    F = np.concatenate((np.ones((np.size(thetas), 1)),np.matrix(np.sin(thetas)).
 →T,np.matrix(np.cos(thetas)).T),axis = 1)

    ks = np.linalg.pinv(F)*np.matrix(meanFRs).T
    c0 = ks[0]
    pd = np.arctan2(ks[1],ks[2])
    c1 = ks[1]/np.sin(pd)

    c0 = np.asarray(c0)[0][0]
    c1 = np.asarray(c1)[0][0]
    pd = np.asarray(pd)[0][0]
    return [c0,c1,pd]
```

```python
[4]: plt.figure(figsize=(7,5))

#=======================================================#
# YOUR CODE HERE:
#    Fit the cosine tuning curve for electrode 17 and plot
#      1) the average firing rate for electrode 17 to each of the 8 directions␣
 →and
#      2) the fitted tuning curve.
#=======================================================#
shapes=[]
for i in range(506):
    shapes.append(R[i]['spikeRaster'].todense().shape[1])


FRs=np.empty((R.shape[0]))
targets=np.empty((R.shape[0],2))
Theta=np.empty(R.shape[0])
for i in range(R.shape[0]):
    FRs[i]=calculateFR(i)
    targets[i,:]=[R[i]["target"][0,0],R[i]["target"][1,0]]
    Theta[i]=np.arctan2(R[i]["target"][1,0],R[i]["target"][0,0])


Theta=Theta*(Theta>0)+(Theta<0)*(2*np.pi+Theta)
# plt.plot(np.degrees(Theta),FRs,"o")


means=[]
for t in np.unique(Theta):
```

```
    plt.plot(np.degrees(t),np.mean(FRs[Theta==t]),"o",color="orange")
    means.append(np.mean(FRs[Theta==t]))
from sklearn.linear_model import LinearRegression



c0,c1,theta0=tuning(np.unique(Theta), means)
print(f"c0={c0}")
print(f"c1={c1}")
print(f"theta0={theta0} degrees")

plt.plot(np.degrees(np.arange(0,2*np.pi,0.01)),c0+c1*np.cos(np.arange(0,2*np.
 ↪pi,0.01)-theta0))
#=================================================#
# END YOUR CODE
#=================================================#



plt.xlabel('Reach angle')
plt.ylabel('Firing rate')
plt.xlim([0,360])
plt.show()
```
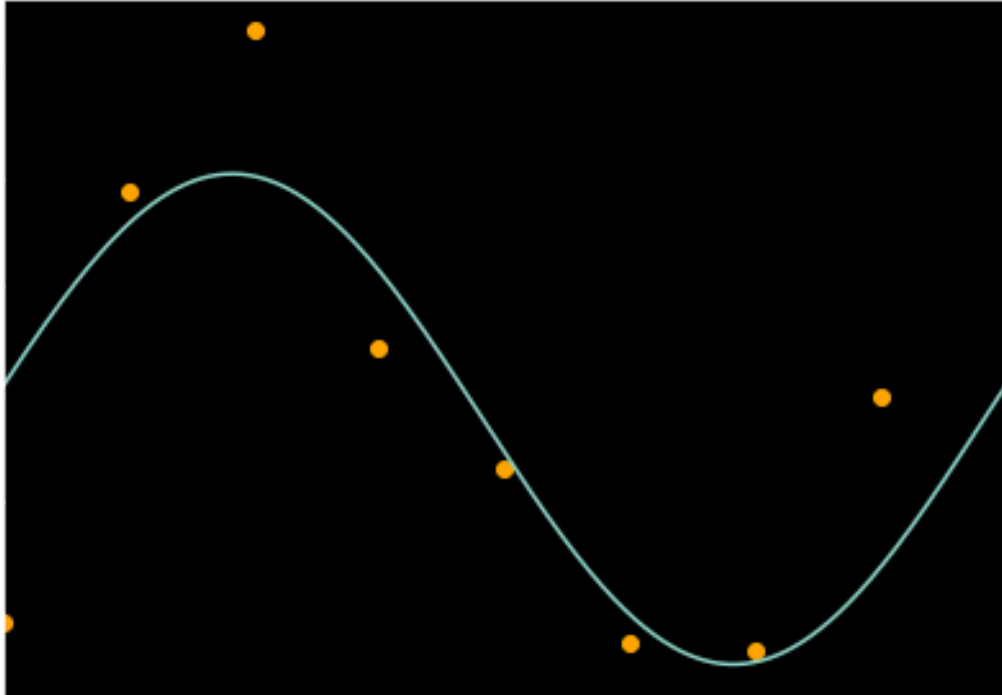
c0=57.733883626115826
c1=22.662425288615186
theta0=1.4362465767565014 degrees

```
[5]:  R[i]['spikeRaster'].todense().shape
```

```
[5]:  (96, 1033)
```

0.1.2 (b) (4 points) Preferred direction and modulation depth

Calculate the tuning parameters for every electrode. Pick the top 30 electrodes having the largest values of $|c_1|$ (where c_1, from homework #2, is from the tuning curve expression θ_0 such that $f(\theta) = c_0 + c_1 cos(\theta - \theta_0)$. The larger $|c_1|$, the greater the "modulation depth" of the electrode. This modulation depth is defined as the difference in firing rate between the preferred and anti-preferred directions. For each of these top 30 electrodes, plot the preferred direction in polar coordinates. The magnitude of each vector should be $|c_1|$. Do these top 30 neurons span the reaching space well?

```
[6]:  #====================================================#
      # YOUR CODE HERE:
      #   Generate a polar plot for the top 30 electrodes where
      #   the angle is the preferred direction of a neuron and
      #   its magnitude is |c1|.
      #
      #   Hint: call plt.polar(top_30_angles, top_30_c1, '*')
      #====================================================#
```

```python
FRs=np.empty((R.shape[0],96))
Theta=np.empty(R.shape[0])
for i in range(R.shape[0]):
    for j in range(96):
        FRs[i,j]=calculateFR(i,neuron_idx=j)
    Theta[i]=np.arctan2(R[i]["target"][1,0],R[i]["target"][0,0])


C0s=np.empty(96)
C1s=np.empty(96)
Theta0s=np.empty(96)
for i in range(96):
    means=[]
    for t in np.unique(Theta):
        means.append(np.mean(FRs[Theta==t,i]))

    c0,c1,theta0=tuning(np.unique(Theta), means)

    C0s[i]=c0
    C1s[i]=c1
    Theta0s[i]=theta0

TopInds = np.argpartition(C1s, -30)[-30:]

plt.polar(Theta0s[TopInds], C1s[TopInds], '*')



#===================================================#
# END YOUR CODE
#===================================================#
```
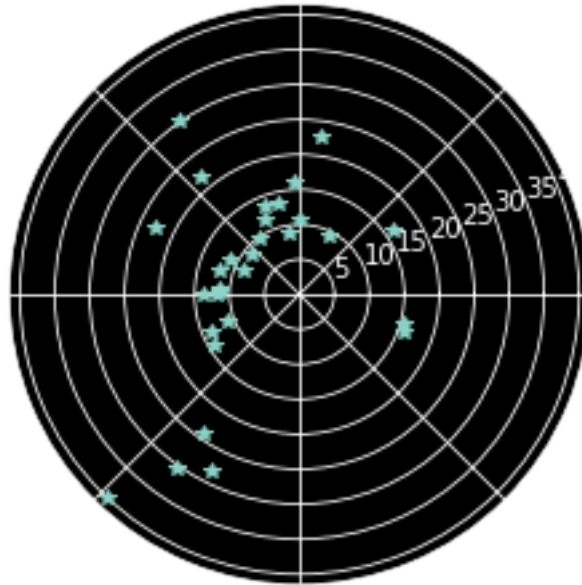
[6]: [<matplotlib.lines.Line2D at 0x7f880d58faf0>]

Question: Do these top 30 neurons span the reaching space well?

Answer: No, for instance there are no neurons at around the 270 degree location

0.1.3 (c) (4 points) Preparing kinematics for optimal linear estimator. [Code solution provided; please understand it and answer the question.]

Fit the preferred directions by building an optimal linear estimator. We'll use the first 400 trials in the R-struct for training and reserve the last 106 trials for testing our decoder in part (g). Concatenate all the neural data, at 1 ms resolution (hint: use the command `Y = scipy.sparse.hstack(R[0:400]['spikeRaster'])`).

Next, bin the millisecond resolution neural data, Y (representing the concatenated millisecond activity across the 400 trials), by counting the spikes in non-overlapping 25 ms bins. (Hint: use the `nsp.bin` function we provided.)

To be clear, each row, corresponding to one electrode of neural data, should be binned in non-overlapping 25 ms bins. Name this variable `Y_bin`. Append a row of 1's at the bottom of `Y_bin` via: `Y_bin= np.vstack((Y_bin,np.ones(np.size(Y_bin,1))))` to allow a bias term to be fit.

Similarly, calculate the corresponding hand velocities in 25 ms intervals by using a first order Euler approximation, i.e.,

$$v(t) = \frac{cursorPos[t + 25] - cursorPos[t]}{0.025}$$

(Hint: Like the neural data, concatenate all the cursor positions, at 1 ms resolution, by using the command `X =scipy.sparse.hstack(R[0:train_num]['cursorPos'])`, then sample these veloci-

ties every 25 ms, and call the resultant matrix of velocities `X_bin`. Discard the last bin that does not have 25 ms worth of data.).

Note that if you have done everything correctly, then `np.size(Y_bin, 1)` should equal `np.size(X_bin, 1)`. What are the dimensions of `Y_bin` and `X_bin`?

(Aside: If you observe the velocities, you'll notice that they are not as smooth as they could be; this could be improved by using higher-order approximations to compute velocity – however, we wanted to keep the velocity calculation simple in this homework.)

```
[7]: #=====================================================#
     # YOUR CODE HERE:
     #   Bin the data.
     #=====================================================#
     dt = 25
     binnedR = np.empty((0,0),dtype = list)
     train_num = 400
     Y = scipy.sparse.hstack(R[0:train_num]['spikeRaster'])
     print(Y.shape)
     X = scipy.sparse.hstack(R[0:train_num]['cursorPos'])
     X = scipy.sparse.csc_matrix(X)
     Y_bin = nsp.bin(Y, dt,'sum')
     Y_bin = np.vstack((Y_bin, np.ones(np.size(Y_bin,1))))

     X_bin = nsp.bin(X, dt,'first')
     X_bin = np.diff(X_bin[0:2,:])/dt*1000
     #=====================================================#
     # END YOUR CODE
     #=====================================================#
```

(96, 411626)

```
[8]: X_bin
```

```
[8]: array([[-18.000000000000114, -54.39999999999998, -39.19999999999959, …,
              -0.399999999999915, 0.399999999999915, 0.0],
             [-8.799999999999955, -31.200000000000045, -24.800000000000182,
              …, -17.200000000000273, -9.19999999999959, -17.600000000000477]],
           dtype=object)
```

```
[9]: print("size of Y_bin:", Y_bin.shape)
     print("size of X_bin:", X_bin.shape)
```

size of Y_bin: (97, 16465)
size of X_bin: (2, 16465)

Question: What are the dimensions of `Y_bin` and `X_bin`?

Answer:

size of Y_bin: (97, 16465)

```
size of X_bin: (2, 16465)
```

0.1.4 (d) (6 points) Fitting the parameters in an OLE

Fit the optimal linear estimator that takes your spike counts binned at 25 ms resolution, `Y_bin`, and your sampled velocities every 25 ms, `X_bin`, and calculates the optimal linear decoder via:

$$L = X_{bin} * Y_{bin}^{\dagger}$$

where $Y_{bin}^{\dagger}$ is the pseudo inverse of Y_{bin}, you can use `scipy.linalg.pinv` in python to calculate the pseudo inverse. Consider the top 30 electrodes in part (b). For each of these 30 electrodes, we want to visualize their preferred direction and modulation depth (like we did for the cosine fits of preferred direction). If electrode i is one of these 30 electrodes, plot `L[:, i]` in polar coordinates. (Think about why we can think of `L[:,i]` as a preferred direction and magnitude.) Does this plot look similar to the plot you derived in part (b)?

```
[15]:  #=====================================================#
       # YOUR CODE HERE:
       #    Fit the OLE matrix L via least squares, and visualize
       #    L[:,i] for the top 30 electrodes found in part (b) in
       #    an analogous polar plot.
       #=====================================================#
       Y_bin=Y_bin.astype(float)
       L=np.matmul(X_bin,scipy.linalg.pinv(Y_bin))
       r=[]
       theta=[]
       for i in TopInds:

           theta.append( np.arctan2(L[0,i],L[1,i]))
           r.append(np.sqrt(L[0,i]**2+L[1,i]**2))
       plt.polar(theta,r, '*')


       #=====================================================#
       # END YOUR CODE
       #=====================================================#
```

```
[15]:  [<matplotlib.lines.Line2D at 0x7f8804b617f0>]
```

Question: Does this plot have better coverage of the entire workspace than the plot you derived in part (b)?

Abswer: yes

0.1.5 (e) (6 points)

Using the matrix L you derived in part (d), we will now decode new neural data. Using the last 106 trials, we'll evaluate how good our optimal linear estimator is. We are going to operate trial by trial. For each trial in the R-struct, bin the neural data at 25 ms resolution. Remember to append a row of 1's at the bottom of the neural data. Use the matrix L to decode the neural activity and get decoded velocities for each trial. On the same plot, show the decoded trajectory for each trial. Use `R[i]['cursorPos'][0:2,0]` as the starting cursor position on trial i, and find position by integrating the decoded velocity. Do the trajectories appear normal, or are there idiosyncracies in the decoder?

```
[18]: plt.figure(figsize=(7,7))
      #=====================================================#
      # YOUR CODE HERE:
      #    Decode data for the last 106 trials, and plot the
      #    decoded positions.   If pos is a 2 x T array holding
      #    all the decoded positions, you may plot them via:
      #
      #      plt.plot(pos[0,:], pos[1,:], '.')
      #
```

9

```python
#=========================================================#

for i in range(106):
    Y_test = R[train_num+i]['spikeRaster']
    Y_bin_test=nsp.bin(Y_test, dt,'sum').astype('float64')
    Y_bin_test=np.vstack((Y_bin_test, np.ones(np.size(Y_bin_test,1))))

    predV=np.matmul(L,Y_bin_test)
    #print(predV)
    #print(R[train_num+i]['cursorPos'][0:2,0])
    predLoc=(np.cumsum(predV,axis=1).T*25/1000+R[train_num+i]['cursorPos'][0:
 →2,0]).T
    plt.plot(predLoc[0,:],predLoc[1,:])
    # plt.plot(R[train_num+i]['cursorPos'][0,:],R[train_num+i]['cursorPos'][1,:
 →],'--')
    # plt.
 →plot(R[train_num+i]['cursorPos'][0,0],R[train_num+i]['cursorPos'][1,0],'o',color="red")

#=========================================================#
# END YOUR CODE
#=========================================================#
```

```
[  12.08 -124.38]
[[13.668423783758136 14.514977393827875 16.038225753313956
  14.475724001017944 12.290161906598595 12.043176411046167
  10.422689538031303 9.000545569604862 11.244097248061625
  10.386851384284512 11.361099413276992 11.272413193738377
  9.56463689286901 10.729347273396526 11.906738449464287
  13.535846110907404 13.136430709027666 12.927879737559694
  12.623452648100049 13.78561441268197 13.5283095469888 13.25077371425269
  12.864609347497325 12.55259095044122 13.295367478456155
  11.484993888339007 11.740256749488383 11.320454911859045
  11.90717569731249 12.378159480639567 12.779692095374688
  13.414898892655046 12.951060792247475 12.902942971839051
  14.437315111231172 15.144685578642044 15.556467874250663
  16.216961394755174]
 [-123.31063028941435 -124.96812033644277 -124.77095113845567
  -124.27944870428541 -127.89226569849518 -129.7601034831108
  -131.59059275076078 -131.82704007854764 -133.80764424689454
  -135.4849797858174 -133.9887293944403 -133.30257599562185
  -132.0972922194066 -129.23043768418896 -127.45313650202839
  -127.22766783246897 -126.95492006634638 -126.46215090098693
  -128.4944875365655 -127.40754721812291 -130.6101364801732
  -127.36874728157738 -126.65833124387107 -125.42380752033286
  -126.47572138287462 -126.53887058212412 -126.49206560640674
  -128.39997321681136 -127.86756227690681 -127.51930438570731
  -129.06233091559983 -128.6033367091295 -129.07823017715967
```

```
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    -132.3140833819292 -132.02236674319204]]
[-0.55  3.46]
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  -2.3568357406617593 -5.930519518026869 -8.168565730969453
  -9.707377142337979 -11.394267939297041 -14.040948066229948
  -15.369851357879886 -16.910013983680408 -20.46559541065166
  -22.23529783903097 -25.625704671482364 -28.147662777031655
  -30.225676292123826 -32.47642171506439 -31.719454443881116
  -32.61104124305058 -31.50957618627574 -33.344269375462844
  -34.08862476340776 -34.92606268134655 -34.02407003510464
  -34.176515888430096 -34.355943810123655 -35.187627958339505
  -35.02047493517137 -36.282972269114246 -38.08521481441831
  -38.28765869861337 -39.934762393743114 -40.898759189555165
  -41.13849850328836 -41.792013062030136 -41.768861592331845
  -42.15368116649123 -43.42969060199842 -45.80763925413156
  -46.8145644393368 -47.61089791937836 -45.730665504485934
  -47.78967943768653 -46.30025363085898 -47.16245151086902]
 [0.6710925308201379 0.6581059827482205 0.6651452081820324
  -1.5703625361170799 -1.2041760224834546 -0.9746111894953966
  -0.9357270919934111 0.013492008075989048 1.1044253050112944
   2.459445656253779 -1.4721509141600189 -0.803418827047226
  -0.6759289068707712 -6.168563130858634 -13.633038428607222
  -18.4999181430062 -23.0832109373673 -25.168339953333934
  -27.56032681057372 -31.485531388576348 -35.5082153473007
  -37.752588523812165 -38.64590347730142 -40.606363558361416
  -43.135389240379354 -44.29278110079444 -46.14592504415644
  -45.37448690873283 -46.43388825848655 -48.58715416935824
  -49.94099262690035 -53.05672134218618 -54.02691138065411
  -57.09942664458732 -58.61537926443421 -57.042427143919475
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  -56.60730525558054 -56.539668772447406 -56.155790722718635
  -55.46074627693617 -54.52605398730128 -52.81102455170954
  -51.67576763634228 -48.46743563185105 -49.75703667058096]]
[-87.74 -95.52]
[[-87.11187401835318 -89.43720795865143 -90.36605707367903
  -92.71937388379216 -92.62434063836639 -92.14623909294602
  -91.96403010572581 -91.17385431634418 -89.30508882442976
  -88.06863440669628 -90.64474691442214 -91.28186842032903
  -91.58474409056012 -91.35492536648655 -92.17138492467096
  -91.4721603061684 -93.57455315010432 -94.92318382683614
  -94.9175196274035 -95.70925505902441 -94.74008363068475
  -94.16745276492043 -93.83538449696717 -92.47805119558171
  -92.78359395739135 -93.34157755707461 -93.24962897721151
  -91.78640509166371 -91.32260289019868 -89.65722418245264
  -90.05367333179379 -91.06734601838895 -90.40994929700331
  -89.96541405783111 -89.93091832726851 -88.53999696940603]
```

```
[-95.59880279562637 -97.99907176990946 -98.88884109245944
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 -102.18156934695448 -102.35307569483015 -101.12015120634048
 -98.79863524708405 -96.59636437838981 -92.35842194873123
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 -85.70199702988029 -85.91110867716945 -86.18608016958235
 -86.3293329370809 -86.43864555747192 -86.13165505846953
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 -88.20835552866441 -86.2723113975266 -86.7963153933946
 -86.34422725863496 -86.97310248172744 -87.03287706522805]]
[2.41 3.63]
[[1.8796466148788986 1.7310147734501184 2.1984991557004867
  2.5292226428317113 0.8062584729552438 2.6945875763457394
  2.539913194047517 3.720623519854785 4.644377866720021 3.346015795084449
  -0.18334592844180397 -1.7583260350545942 -2.661669958577895
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  -28.828005151314127 -28.180342907750145 -30.094614844289655
  -30.640907801846392 -31.819069465676055 -32.38362424972148
  -32.81442100238965 -34.64960029110513 -35.56692380771885
  -36.264930685815514 -37.41170970573222 -36.909399843453016
  -36.779782001210265 -36.5455903422763 -36.334520624124806]
 [4.618068233921428 4.278374047127354 3.840350209323763 4.197243638954653
  4.982575652001126 4.49808917027209 0.7430831186210693
  3.1752433182553355 5.881936372599512 4.3094482081873835
  2.782073143809182 5.445862489894496 8.9151438589679 7.561385753736342
  8.936704735459895 10.525087467653488 9.610565100718112
  11.246080490559262 9.020751103104306 8.851706455394911
  9.831656807939316 10.611365480311408 10.56662155404036
  10.323427529005762 11.056999551761546 8.122690037547677
  6.3960786776055105 5.954780721198425 6.2619363812344595
  5.943412142793512 6.542827193605498 6.5769957014393405 5.60236784813773
  7.592426601959495 6.562586524426125 7.571584172450127 8.651432966140584
  8.862424402327951 8.995108333935189 11.43808420185437]]
[-122.16   -2.55]
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  -118.91362195940894 -119.04817212264426 -117.77341136325158
  -119.5799099617191 -117.41433867538251 -114.91719244600007
  -114.33543508964209 -113.63961662581356 -113.51643341024194
  -113.26557296420488 -109.9504386079877 -109.48511298464766
  -106.6492592776048 -106.75800286653207 -104.37618590226191
  -103.87176755498949 -101.579260906238 -100.33548765679943
  -99.22205877193271 -98.06687443728717 -96.77927993546083
  -94.51010460712796 -94.15337219451514 -91.76798222761042
```

```
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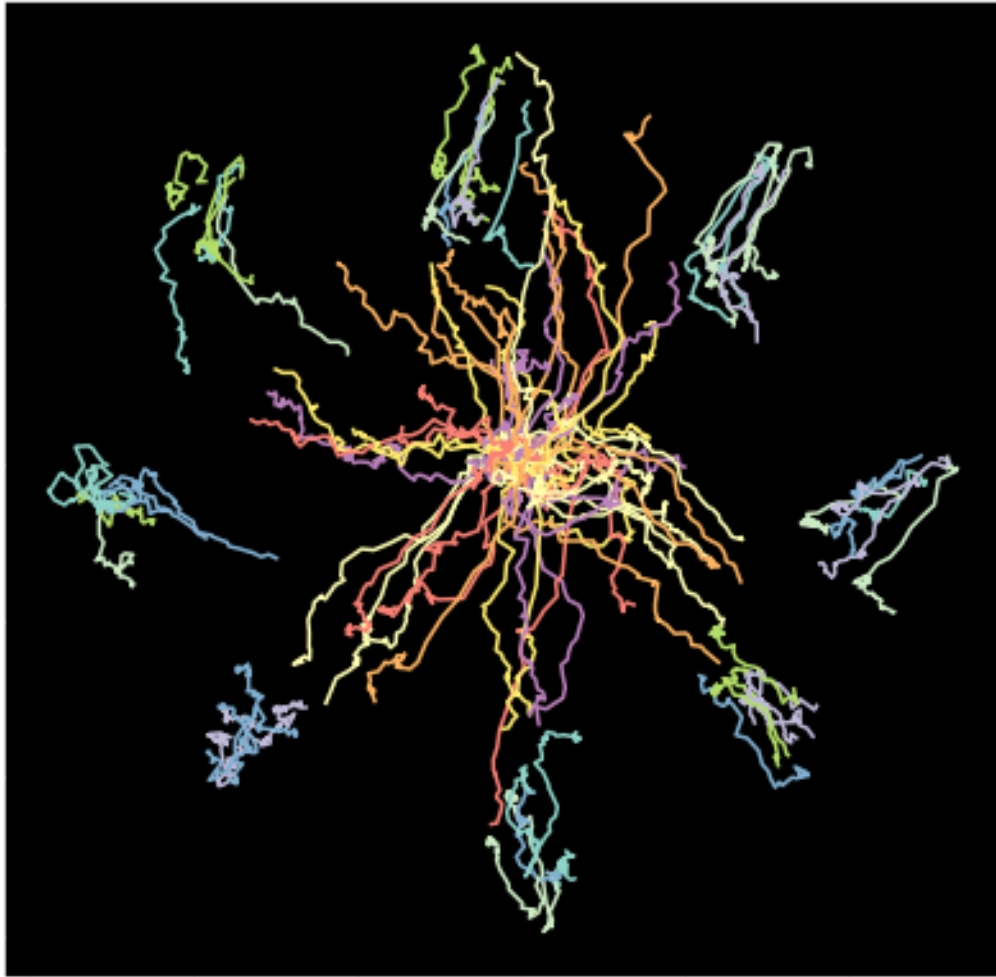
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  -71.46010648696637 -72.88406864824665 -72.12309280093118
  -71.04265694296372 -75.60674703031195]]
```

Question: Do the trajectories appear normal, or are there idiosyncracies in the decoder?

Answer: There seems to be idiosyncracies in the decoder, the lines seem to be squilely and are note able to fully connect the two nodes

0.1.6 (f) (3 points)

For the decoder in part (e), what is the average mean-square error in position per trial? (For each time bin in a trial, calculate the squared Euclidean distance between the decoded position and the true hand position. Average all these squared Euclidean distance differences across all time in the trial. Finally, average across all trials.)

```
[12]:  #==================================================#
       # YOUR CODE HERE:
       #   Calculate the mean-squared error between the decoded
       #   hand position and the true hand position.  Average
```

```python
    #    the squared errors across time; then average the squared
    #    errors across trials.
    #=================================================#
    sum_distance=0
    for i in range(106):
        Y_test = R[train_num+i]['spikeRaster']
        Y_bin_test=nsp.bin(Y_test, dt,'sum').astype('float64')
        Y_bin_test=np.vstack((Y_bin_test, np.ones(np.size(Y_bin_test,1))))

        predV=np.matmul(L,Y_bin_test)
        #print(R[train_num+i]['cursorPos'][0:2,0])
        predLoc=(np.cumsum(predV,axis=1).T*dt/1000+R[train_num+i]['cursorPos'][0:
    ↪2,0]).T
        t=np.arange(0,predLoc.shape[1]*dt,dt)+dt-1

        distance=(R[train_num+i]['cursorPos'][:2,t]-predLoc).astype(float)
        distance=np.sum(distance**2,axis=0)
        sum_distance+=np.mean(distance)

    print(sum_distance/106)
    #=================================================#
    # END YOUR CODE
    #=================================================#
```

5471.086443792241

Answer: 5471.086443792241

[ ]: