In [ ]:
```
import numpy as np
import matplotlib.pyplot as plt
import pandas as pd

%matplotlib inline
```

In [ ]:
```
from google.colab import files
uploaded=files.upload()
```

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```
Saving 3mv.csv to 3mv (2).csv
```

In [ ]:
```
# csv 파일을 읽어서 DataFrame 객체로 만듦, 인덱스 컬럼은 point로 설정
dg = pd.read_csv('3mv.csv')
dg=dg[:495]
v=np.array(dg['v'], dtype='object')
t=np.array(dg['t'])
#v
```

In [ ]:
```
uploaded=files.upload()
```

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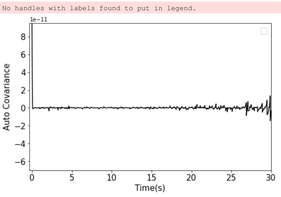
```
Saving v.csv to v (1).csv
```

In [ ]:
```
dg = pd.read_csv('v.csv')
dg=dg[:495]
v=np.array(dg['v1'])
v=np.vstack((v,np.array(dg['v2'])))
v=np.vstack((v,np.array(dg['v3'])))
v=np.vstack((v,np.array(dg['v4'])))
v=np.vstack((v,np.array(dg['v5'])))
v=np.vstack((v,np.array(dg['v6'])))
v=np.vstack((v,np.array(dg['v7'])))
v=np.vstack((v,np.array(dg['v8'])))
v=np.vstack((v,np.array(dg['v9'])))
v=np.vstack((v,np.array(dg['v10'])))
t=np.array(dg['t'])
#v
```

In [ ]:
```
# autocorrelation, (averaged over all trajectory)
autocorr = np.zeros(495)

autocorr[0] = np.average(v*v)

for i in range (494):
    autocorr[i+1] = np.average(v[:,i+1:]*v[:,:-i-1])



fig = plt.figure(1,figsize=(8,5))
plt.plot(t, autocorr,color='black')
plt.ylim((-1e-10, 2e-10))     # y축의 범위: [ymin, ymax]
# plt.axis((0, 5, 0, 20))  # x, y축의 범위: [xmin, xmax, ymin, ymax]
plt.xlim(-0.3, 30)
plt.ylim(-0.7e-10,0.95e-10)
plt.legend(fontsize=15)
plt.xticks(fontsize=15)
plt.yticks(fontsize=15)
plt.xlabel('Time(s)',fontsize=15)
plt.ylabel('Auto Covariance',fontsize=15)
plt.savefig('auto_covar_3.png')
plt.show()
# this shows delta_correlation
```

```
No handles with labels found to put in legend.
```



In [ ]:
```
uploaded=files.upload()
```

Choose Files | No file chosen — Upload widget is only available when the cell has been executed in the current browser session. Please rerun this cell to enable.

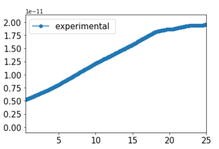
```
Saving 3m.csv to 3m (1).csv
```

In [ ]:
```
# csv 파일을 읽어서 DataFrame 객체로 만듦, 인덱스 컬럼은 point로 설정
df = pd.read_csv('3m.csv')
df=df[:495]
df
x=np.array(df['x1'])
x=np.vstack((x,np.array(df['x2'])))
x=np.vstack((x,np.array(df['x3'])))
x=np.vstack((x,np.array(df['x4'])))
x=np.vstack((x,np.array(df['x5'])))
y=np.array(df['y1'])
y=np.vstack((y,np.array(df['y2'])))
y=np.vstack((y,np.array(df['y3'])))
y=np.vstack((y,np.array(df['y4'])))
y=np.vstack((y,np.array(df['y5'])))
# x
# y
```

In [ ]:
```
for i,arr in enumerate(x) :

  if i == 0 :
    arr = arr[10:300]
    xt = np.array(arr)
  else :
    arr = arr[10:300]
    xt = np.vstack((xt,arr))

for i,arr in enumerate(y) :

  if i == 0 :
    arr = arr[10:300]
    yt = np.array(arr)
  else :
    arr = arr[10:300]
    yt = np.vstack((yt,arr))


xt = np.array(xt)
yt = np.array(yt)
```

In [ ]:
```
# Mean Square Displacement
MSD = np.zeros(495)
# # MSD[0]=0
# t=t[1:]
for tau in range (494):
    MSD[tau+1] = np.average((x[:,tau+1:]-x[:,:-tau-1])**2+(y[:,tau+1:]-x[:,:-tau-1])**2)
plt.plot(t,MSD,'o-',label='experimental ')
plt.xlim(0.5, 25)
plt.legend(fontsize=15)
plt.xticks(fontsize=15)
plt.yticks(fontsize=15)
plt.show
```

Out[ ]:
```
<function matplotlib.pyplot.show>
```



In [ ]:
```
from scipy.optimize import curve_fit

yy = np.zeros(290)
for tau in range (289):
    yy[tau+1] = np.average((xt[:,tau+1:]-xt[:,:-tau-1])**2+(yt[:,tau+1:]-yt[:,:-tau-1])**2)

def func(x,a,b) :
  return a*x+b

tt = t[10:300]
MSDt = MSD[10:300]
popt,pcov = curve_fit(func,tt,MSDt)


popt
```

Out[ ]:
```
array([7.39926169e-13, 4.56254096e-12])
```

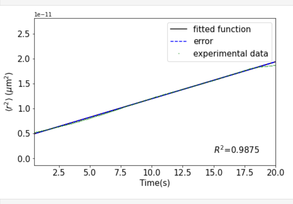
In [ ]:
```
from sklearn.metrics import r2_score
MSDt = MSD[10:300]
r2 = r2_score(MSDt,popt[0]*tt+0.5e-11)
r2
```

Out[ ]:
```
0.9874829648199883
```

In [ ]:
```
perr = np.sqrt(np.diag(pcov))
perr
```

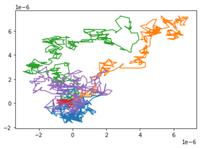
Out[ ]:
```
array([1.57883954e-15, 1.84958427e-14])
```

In [ ]:
```
xxx = np.linspace(0,30,31)
xxxx = np.linspace(0,20,21)


fig = plt.figure(1,figsize=(8,5))
plt.plot(xxx,func(xxx,popt[0],popt[1]),color='red',ms=1)
plt.plot(xxxx,func(xxxx,popt[0],popt[1]),color='black',ms=1,label='fitted function')
plt.plot(xxxx,func(xxxx,popt[0]+perr[0],popt[1]),'--',ms=1,color='blue',label='error')
plt.plot(xxxx,func(xxxx,popt[0]-perr[0],popt[1]),'--',ms=1,color='blue')
plt.plot(t,MSD,'o',color='green',ms=0.5,label='experimental data')
plt.xlim(0.5, 20)
plt.text(15,0.1e-11,f'$R^2$={r2:.4f}',fontsize=15)
plt.legend(fontsize=15)
plt.xticks(fontsize=15)
plt.yticks(fontsize=15)
plt.xlabel('Time(s)',fontsize=15)
plt.ylabel('$  \langle  r^2  \\rangle $ ($\mu$m$^2$)',fontsize=15)
plt.savefig('MSDfitted_3.png')
plt.show()
```



In [ ]:
```
plt.plot(df['x1'],df['y1'],df['x2'],df['y2'],df['x3'],df['y3'], df['x4'],df['y4'], df['x5'],df['y5'])
```

Out[ ]:
```
[<matplotlib.lines.Line2D at 0x7f40fa274d90>,
 <matplotlib.lines.Line2D at 0x7f40fa2283d0>,
 <matplotlib.lines.Line2D at 0x7f40fa228590>,
 <matplotlib.lines.Line2D at 0x7f40fa228750>,
 <matplotlib.lines.Line2D at 0x7f40fa228910>]
```



In [ ]:
```
m = popt[0]
m
```

Out[ ]:
```
7.399261694829944e-13
```

In [ ]:
```
err = perr[0]
err
```

Out[ ]:
```
1.5788395405908946e-15
```