In [ ]:

Implement model for α-synuclein aggregation by Sneppen et al. presented in the lecture.

```
a. Start with the model with 7 parameters and through parameter rescaling arrive
to 4-parameter model

b. In the presented version, protease production was assumed constant. How do th
e results change if you include the fact that protease is induced by

    i. Proto-fibrils (s)

    ii. Oligomers (ααα)

    iii. Fibrils, (F)

c. Which of i-iii have a maximal impact on model outcome?

d. How would you modify the model to include the effect of autophagy? How does t
his change the results?
```

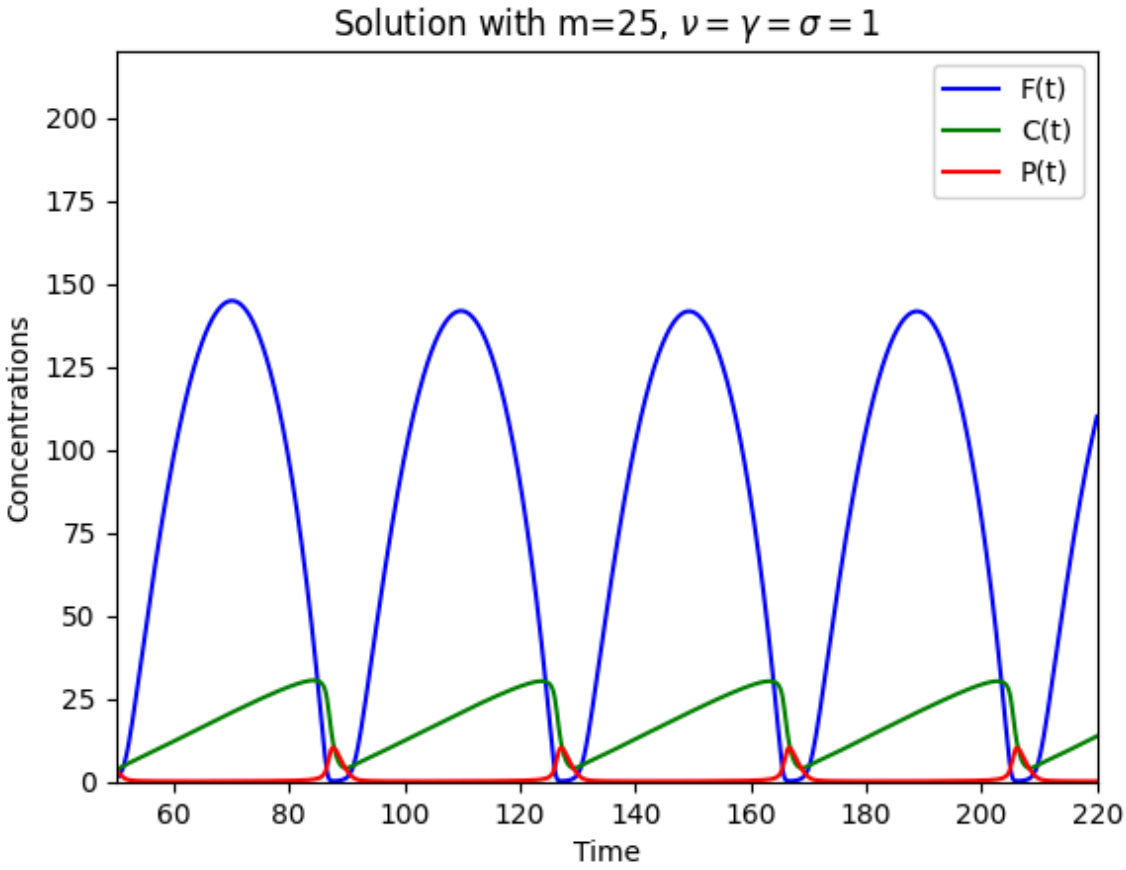
In [ ]:

```
from scipy.integrate import solve_ivp
import numpy as np
import matplotlib.pyplot as plt

def solve_original_model(gamma=1,m=25,sigma=1,nu=1,
                         ic = [0,0,0], t0 = 0, tmax=200,start_from=50):


  def derivs(t,var):
    dvar = np.zeros(3)
    F,C,P = var
    dvar[0] = m/(1+P) - gamma * F*P
    dvar[1] = gamma*F*P - nu*C
    dvar[2] = sigma - P - gamma*F*P + nu*C

    return dvar

  sol = solve_ivp(derivs,[t0,tmax],ic)

  ind = list(sol.t>start_from).index(True)


  return([sol.t[ind:], sol.y[0,:][ind:], sol.y[1,:][ind:], sol.y[2,:][in
d:]])
```

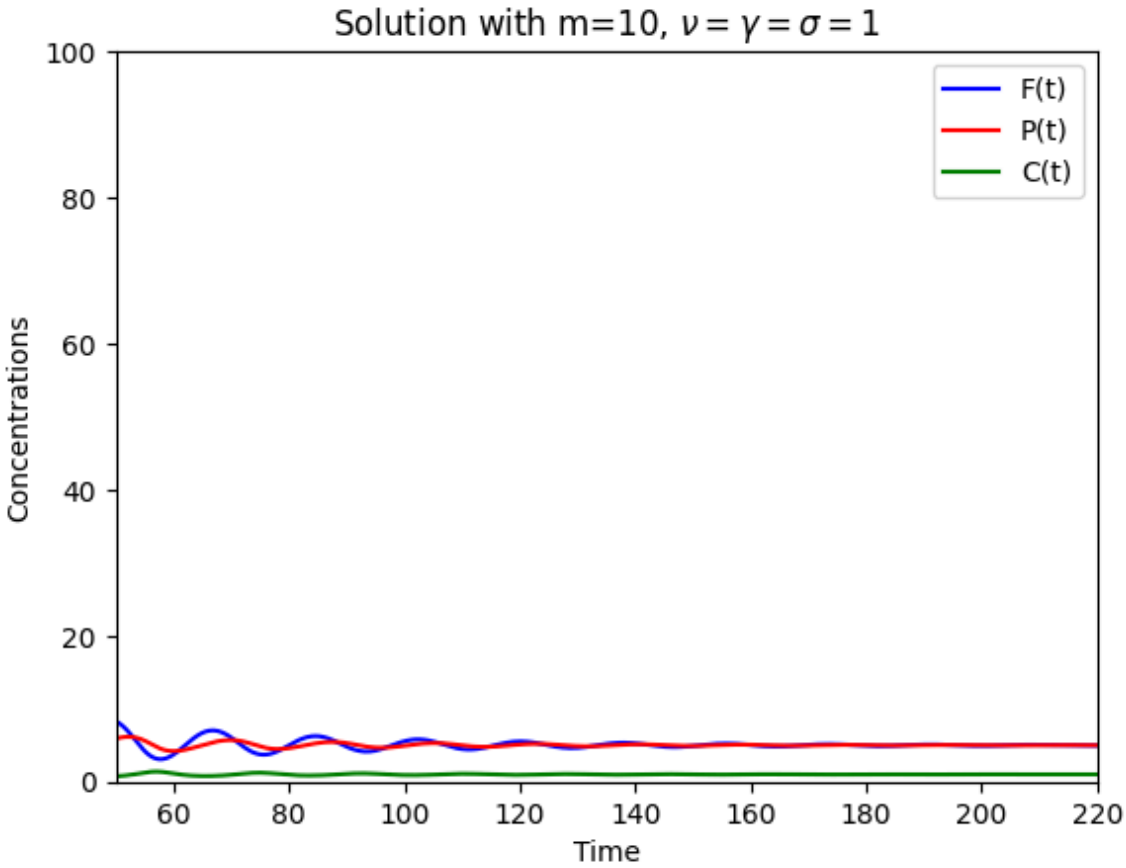
In [ ]:

```
sol_m25 = solve_original_model(m=25,tmax= 250)
sol_m10 = solve_original_model(m=10,tmax=220)
```

In [ ]:
```
plt.plot(sol_m25[0], sol_m25[1],label="F(t)",color="blue")
plt.plot(sol_m25[0],sol_m25[2],label="C(t)",color="green")
plt.plot(sol_m25[0],sol_m25[3],label="P(t)",color="red")

plt.xlim([50,220])
plt.ylim([0,220])
plt.legend()
plt.xlabel("Time")
plt.ylabel("Concentrations")
plt.title(r"Solution with m=25, $\nu = \gamma = \sigma =1$")
plt.show()
```



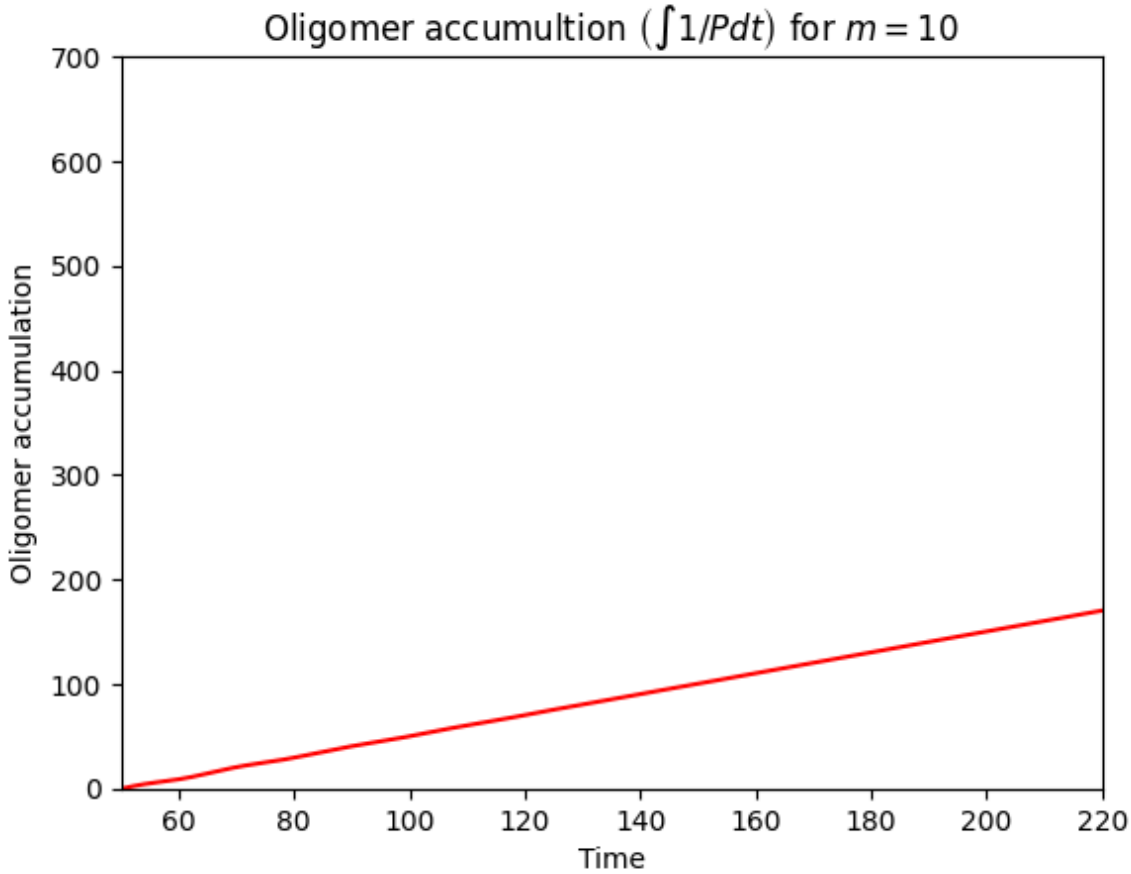
In [ ]:
```
plt.plot(sol_m10[0], sol_m10[1],label="F(t)",color="blue")
plt.plot(sol_m10[0],sol_m10[2],label="P(t)",color="red")
plt.plot(sol_m10[0],sol_m10[3],label="C(t)",color="green")
plt.xlim([50,220])
plt.ylim([0,100])
plt.legend()
plt.xlabel("Time")
plt.ylabel("Concentrations")
plt.title(r"Solution with m=10, $\nu = \gamma = \sigma =1$")
plt.show()
```



In [ ]:
```
def num_oligomers(sol):
  ts = sol[0]
  Ps = sol[3]

  cumulative_integral = [0] * len(ts)


  for i in range(2, len(ts)):
    area = 0.5 * (1/Ps[i] + 1/Ps[i-1]) * (ts[i] - ts[i-1])
    cumulative_integral[i] = cumulative_integral[i-1] + area


  return([ts,cumulative_integral])
```

In [ ]:
```
# oligomers_m25 = num_oligomers(sol_m25)
oligomers_m10 = num_oligomers(sol_m10)

plt.plot(oligomers_m10[0],oligomers_m10[1],color="red")
plt.title(r"Oligomer accumultion $\left(\int 1/P dt\right)$ for $m=10$")
plt.xlabel("Time")
plt.ylabel("Oligomer accumulation")
plt.ylim([0,700])
plt.xlim([50,220])
# plt.plot(oligomers_m10[0],oligomers_m10[1])
```

Out[ ]: (50.0, 220.0)



In [ ]:

In [ ]:
```
solve_original_model(m=1, sigma=1,tmax=2000,start_from=50)
```

Out[ ]:
```
[array([  50.49203535,   51.65935211,   52.91505153, ..., 1998.0728519 ,
        1999.24531165, 2000.        ]),
 array([0.50033912, 0.50019802, 0.50017659, ..., 0.50033534, 0.5002007 ,
        0.50003559]),
 array([0.49956204, 0.49974488, 0.49977235, ..., 0.4995669 , 0.49974139,
        0.49995525]),
 array([1.00071352, 1.00041571, 1.00037147, ..., 1.00070561, 1.00042142,
        1.00007325])]
```

In [ ]:
```
mnum = 35
sigmanum = 35
mat_oligomers = np.zeros((mnum,sigmanum))

for i,m in enumerate(np.logspace(0,2,mnum)):
  print(i)
  for j,sigma in enumerate(np.logspace(-1,1.5,sigmanum)):
    sol = solve_original_model(m=m, sigma=sigma,tmax=1000,start_from=50)
    oligomers = num_oligomers(sol)

    final_oligomer_number = oligomers[-1][-1]

    mat_oligomers[i,j] = final_oligomer_number

    print(m,sigma,final_oligomer_number)
```

```
0
1.0 0.1 9497.23837149094
1.0 0.11844845812380056 8021.484175784347
1.0 0.14030037231905737 6772.82796507447
1.0 0.16618362775387496 5719.918675913305
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1.0 0.27616998133438475 3440.050476115269
1.0 0.32711908469136664 2904.3435956801495
1.0 0.38746751204561314 2450.472386433967
1.0 0.45894929374867993 2069.556378595097
1.0 0.5436183620153837 1745.6864258858702
1.0 0.6439075678850823 1474.1702801649012
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1.0 0.9034047151333576 1048.9131739112513
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1.0 1.2674801788800205 747.7423336190142
1.0 1.5013107289081735 631.5121204366185
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1.0 2.955209235202888 320.8941670323715
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1.0 5.817091329374358 163.17146862474078
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1.0 9.66705340091042 98.20727783562079
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1.0 13.562911913759416 70.02227422561164
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1.0 22.539339047347912 42.13679158144729
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1.1450475699382818 4.911073914777701 193.28319151314247
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100.0 0.16618362775387496 325728.42626543297
100.0 0.19684194472866123 236157.8072892566
100.0 0.23315624847200295 188323.00931877817
100.0 0.27616998133438475 160274.23495368764
```
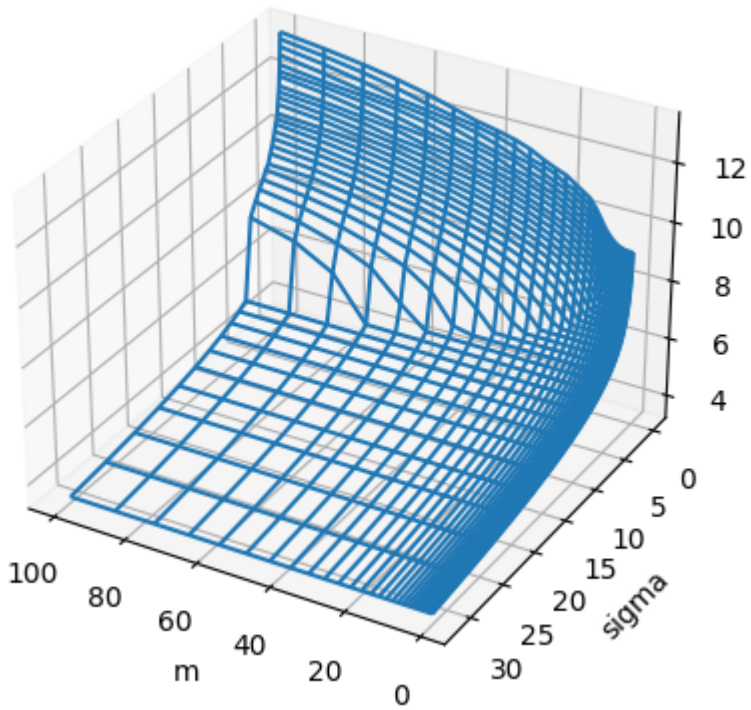

In [ ]:

```
from mpl_toolkits.mplot3d import Axes3D

fig = plt.figure()
ax = plt.axes(111, projection='3d')

ax.set_yscale("log")
ax.set_xscale("log")
# ax.set_zscale("log")

x = np.logspace(0,2,mnum)
y = np.logspace(-1,1.5,sigmanum)

ax.plot_wireframe(x,y, np.log(mat_oligomers.T))


ax.set_xlabel('m')
ax.set_ylabel('sigma')
ax.set_zlabel('ln(oligomers)')
ax.view_init(elev=30, azim=120)

plt.show()
```



In [ ]:

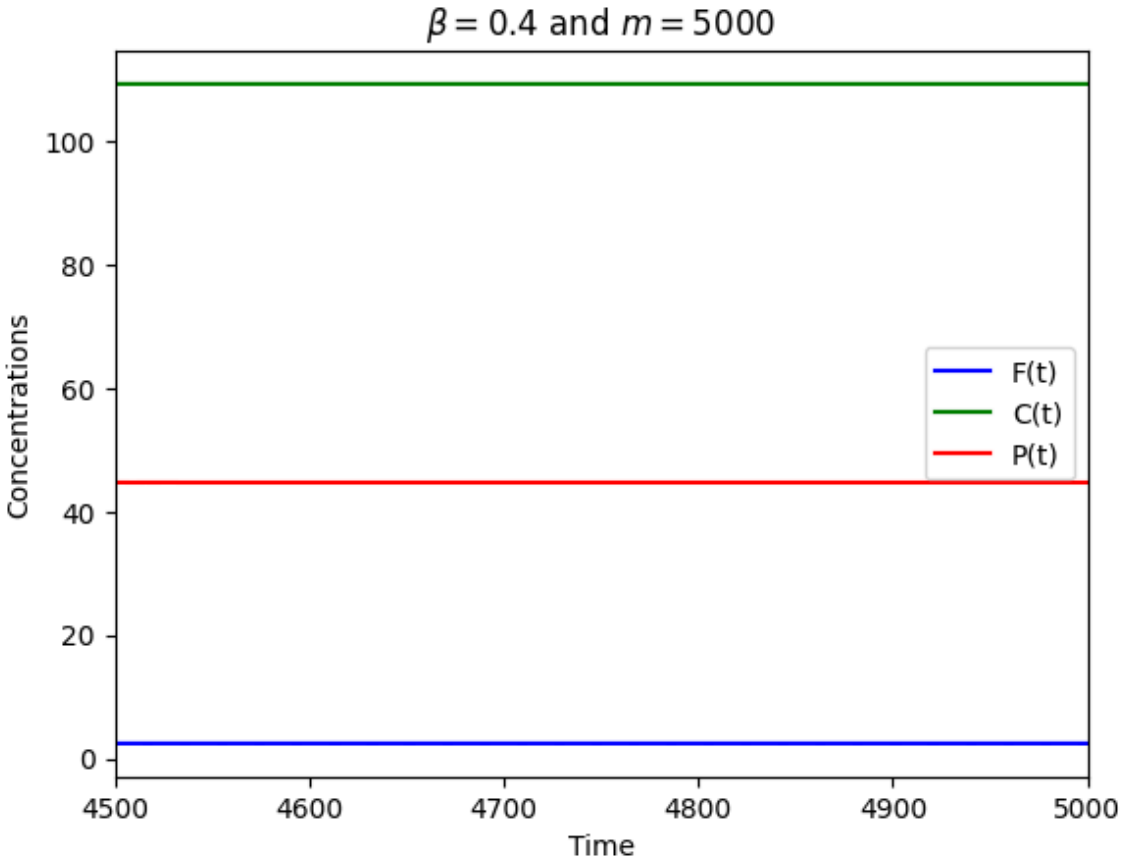
In [ ]:

Protease can be induced by proto fibrils

In [ ]:
```
from scipy.integrate import solve_ivp
import numpy as np
import matplotlib.pyplot as plt

def solve(gamma=1,m=25,sigma=1,nu=1, beta = 1,
                        ic = [0,0,0], t0 = 0, tmax=200,start_from=50):


  def derivs(t,var):
    dvar = np.zeros(3)
    F,C,P = var
    dvar[0] = m/(1+P) - gamma * F*P
    dvar[1] = gamma*F*P - nu*C
    dvar[2] = sigma - P - gamma*F*P + nu*C + beta*m/(1+P)

    return dvar

  sol = solve_ivp(derivs,[t0,tmax],ic)

  ind = list(sol.t>start_from).index(True)


  return([sol.t[ind:], sol.y[0,:][ind:], sol.y[1,:][ind:], sol.y[2,:][in
d:]])


def num_oligomers(sol):
  ts = sol[0]
  Ps = sol[3]

  cumulative_integral = [0] * len(ts)


  for i in range(2, len(ts)):
    area = 0.5 * (1/Ps[i] + 1/Ps[i-1]) * (ts[i] - ts[i-1])
    cumulative_integral[i] = cumulative_integral[i-1] + area


  return([ts,cumulative_integral])
```

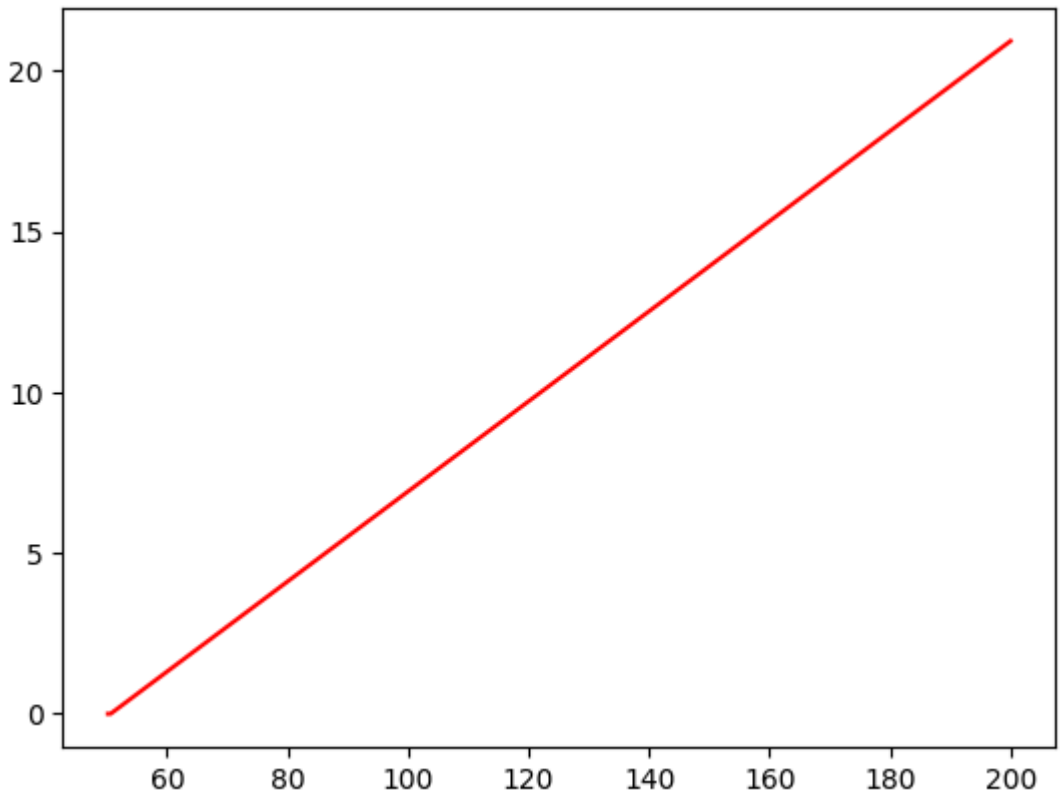
In [ ]:
```
sol = solve(m=5000,beta=0.4,tmax=5000)
```

In [ ]:
```
plt.plot(sol[0], sol[1],label="F(t)",color="blue")
plt.plot(sol[0],sol[2],label="C(t)",color="green")
plt.plot(sol[0],sol[3],label="P(t)",color="red")

plt.xlim([4500,5000])
# plt.ylim([0,220])
plt.legend()
plt.xlabel("Time")
plt.ylabel("Concentrations")
plt.title(r"$\beta = 0.4$ and $m = 5000$")
plt.show()
```



In [ ]:
```
oligomers = num_oligomers(sol)

plt.plot(oligomers[0],oligomers[1],color="red")
```

Out[ ]:
```
[<matplotlib.lines.Line2D at 0x7fe1d5a638e0>]
```



In [ ]:
```
beta = 5
mnum = 35
sigmanum = 35
mat_oligomers = np.zeros((mnum,sigmanum))

for i,m in enumerate(np.logspace(0,2,mnum)):
  print(i)
  for j,sigma in enumerate(np.logspace(-1,1.5,sigmanum)):
    sol = solve(m=m,beta=beta, sigma=sigma,tmax=1000,start_from=50)
    oligomers = num_oligomers(sol)

    final_oligomer_number = oligomers[-1][-1]

    mat_oligomers[i,j] = final_oligomer_number

    print(m,sigma,final_oligomer_number)
```

```
0
1.0 0.1 511.41766281010337
1.0 0.11844845812380056 508.282307598556
1.0 0.14030037231905737 504.6094489466907
1.0 0.16618362775387496 500.3149069386491
1.0 0.19684194472866123 495.30446272587585
1.0 0.23315624847200295 489.47253410520057
1.0 0.27616998133438475 482.7046971936214
1.0 0.32711908469136664 474.82948603786764
1.0 0.38746751204561314 465.9060063600262
1.0 0.45894929374867993 455.5689395363075
1.0 0.5436183620153837 443.7709516259087
1.0 0.6439075678850823 429.95827983023764
1.0 0.7626985859023444 415.05735626377776
1.0 0.9034047151333576 397.93644606713445
1.0 1.070068955693175 379.3205528228079
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1.0 1.5013107289081735 337.05017398350293
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1.1450475699382818 0.32711908469136664 441.58914820654854
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1.1450475699382818 0.45894929374867993 425.1155464603425
1.1450475699382818 0.5436183620153837 414.5316522492409
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1.1450475699382818 1.5013107289081735 321.4351051912131
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1.1450475699382818 2.106344542324121 278.4995537248994
1.1450475699382818 2.4949326331577466 255.60337938750845
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1.1450475699382818 4.911073914777701 164.84861738610914
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```
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66.60846290809158 0.9034047151333576 52.11266785526541
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66.60846290809158 1.7782794100389228 50.809936433397695
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66.60846290809158 2.955209235202888 49.12364596281132
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66.60846290809158 4.146169559796819 47.47864778201853
66.60846290809158 4.911073914777701 46.459041700256286
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66.60846290809158 19.028815912310247 31.8411646617076
66.60846290809158 22.539339047347912 29.240129054076306
66.60846290809158 26.697499572879334 26.562506126292426
66.60846290809158 31.622776601683793 23.873276554596085
32
76.26985859023443 0.1 49.75818012910519
76.26985859023443 0.11844845812380056 49.7346668223998
76.26985859023443 0.14030037231905737 49.70683054073009
76.26985859023443 0.16618362775387496 49.67388010686295
76.26985859023443 0.19684194472866123 49.63488019156462
76.26985859023443 0.23315624847200295 49.58050603038659
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76.26985859023443 0.27616998133438475 49.525900234866086
76.26985859023443 0.32711908469136664 49.46131776550998
76.26985859023443 0.38746751204561314 49.375880897654135
76.26985859023443 0.45894929374867993 49.28556469419561
76.26985859023443 0.5436183620153837 49.169171047402564
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33
87.33261623828433 0.1 46.43649451457636
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87.33261623828433 0.16618362775387496 46.355225439287736
87.33261623828433 0.19684194472866123 46.32133536653159
87.33261623828433 0.23315624847200295 46.28120058842418
87.33261623828433 0.27616998133438475 46.22525245153999
87.33261623828433 0.32711908469136664 46.16912172603966
87.33261623828433 0.38746751204561314 46.10271752186752
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87.33261623828433 0.6439075678850823 45.80754072645235
87.33261623828433 0.7626985859023444 45.67031240778621
87.33261623828433 0.9034047151333576 45.509302998894185
87.33261623828433 1.070068955693175 45.321309911961684
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87.33261623828433 1.7782794100389228 44.52121132793289
87.33261623828433 2.106344542324121 44.162540679427536
87.33261623828433 2.4949326331577466 43.735948233764894
87.33261623828433 2.955209235202888 43.23437595431577
87.33261623828433 3.5003997734299794 42.654706279516596
87.33261623828433 4.146169559796819 41.977274414576165
87.33261623828433 4.911073914777701 41.185266230249866
87.33261623828433 5.817091329374358 40.2785264177356
87.33261623828433 6.890254987297223 39.23126535134751
87.33261623828433 8.16140079325183 38.03379164588084
87.33261623828433 9.66705340091042 36.67075170804738
87.33261623828433 11.450475699382825 35.14109228773759
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87.33261623828433 16.065060038537286 31.552977886951673
```

```
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87.33261623828433 22.539339047347912 27.330708531835093
87.33261623828433 26.697499572879334 25.051600948797024
87.33261623828433 31.622776601683793 22.713341670022366
34
100.0 0.1 43.335390087438796
100.0 0.11844845812380056 43.31761501643087
100.0 0.14030037231905737 43.29658364429708
100.0 0.16618362775387496 43.265373545534274
100.0 0.19684194472866123 43.23585652230511
100.0 0.23315624847200295 43.2009670535969
100.0 0.27616998133438475 43.15280492053543
100.0 0.32711908469136664 43.103982735327094
100.0 0.38746751204561314 43.04635911656055
100.0 0.45894929374867993 42.97154701458065
100.0 0.5436183620153837 42.88362423240803
100.0 0.6439075678850823 42.788229914034176
100.0 0.7626985859023444 42.668395086396714
100.0 0.9034047151333576 42.528939362792734
100.0 1.070068955693175 42.36605781206383
100.0 1.2674801788800205 42.168408397883574
100.0 1.5013107289081735 41.93740929051012
100.0 1.7782794100389228 41.668507898570965
100.0 2.106344542324121 41.3544078787129
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100.0 2.955209235202888 40.54387163643198
100.0 3.5003997734299794 40.03602421182966
100.0 4.146169559796819 39.44242886238599
100.0 4.911073914777701 38.752987685604786
100.0 5.817091329374358 37.94960941566005
100.0 6.890254987297223 37.028083292868246
100.0 8.16140079325183 35.97004586321035
100.0 9.66705340091042 34.76592498607281
100.0 11.450475699382825 33.400570637752075
100.0 13.562911913759416 31.873827681830967
100.0 16.065060038537286 30.18646749851656
100.0 19.028815912310247 28.340994999233388
100.0 22.539339047347912 26.35725125785444
100.0 26.697499572879334 24.262362817911903
100.0 31.622776601683793 22.09530063870254
```

In [ ]:

```
np.savetxt('oligomers_a_beta-5.txt', mat_oligomers, fmt='%d')
import time
time.sleep(100)
```

In [ ]:

```
from google.colab import files

# Download the file
files.download('oligomers_a_beta-5.txt')
```

In [ ]:
```
from mpl_toolkits.mplot3d import Axes3D

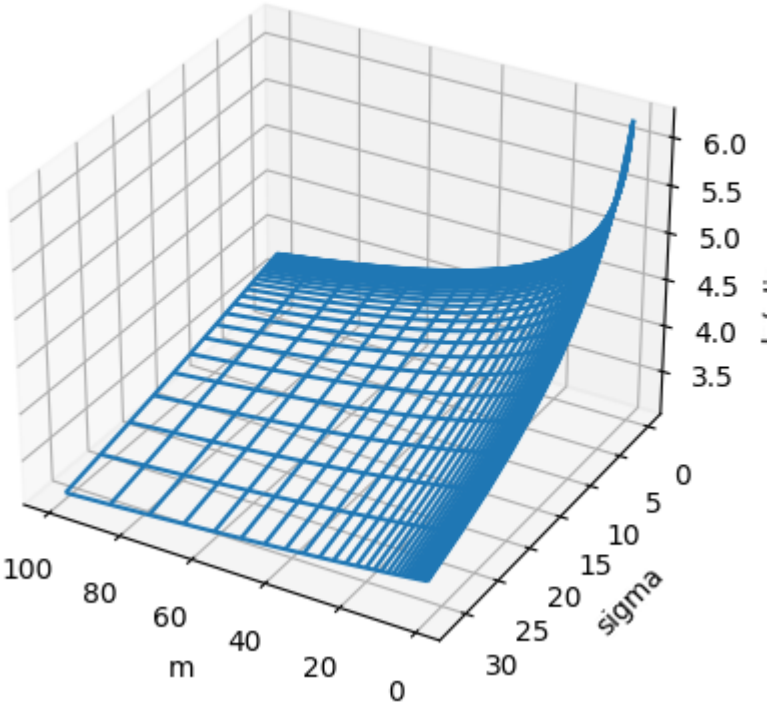
fig = plt.figure()
ax = fig.add_subplot(projection='3d')


x = np.logspace(0,2,mnum)
y = np.logspace(-1,1.5,sigmanum)
X, Y = np.meshgrid(x, y)  # Create a meshgrid for X and Y


ax.plot_wireframe(X,Y , np.log(mat_oligomers.T))


ax.set_xlabel('m')
ax.set_ylabel('sigma')
ax.set_zlabel('ln(oligomers)')
ax.view_init(elev=30, azim=120)

plt.show()
```



In [ ]:

In [ ]:

Protease induced by oligomers (1/P)

In [ ]:
```
from scipy.integrate import solve_ivp
import numpy as np
import matplotlib.pyplot as plt

def solve(gamma=1,m=25,sigma=1,nu=1, beta = 1,
                        ic = [0,0,0.1], t0 = 0, tmax=200,start_from=50):


  def derivs(t,var):
    dvar = np.zeros(3)
    F,C,P = var
    dvar[0] = m/(1+P) - gamma * F*P
    dvar[1] = gamma*F*P - nu*C
    dvar[2] = sigma - P - gamma*F*P + nu*C + beta/P

    return dvar

  sol = solve_ivp(derivs,[t0,tmax],ic)

  ind = list(sol.t>start_from).index(True)


  return([sol.t[ind:], sol.y[0,:][ind:], sol.y[1,:][ind:], sol.y[2,:][in
d:]])


def num_oligomers(sol):
  ts = sol[0]
  Ps = sol[3]

  cumulative_integral = [0] * len(ts)

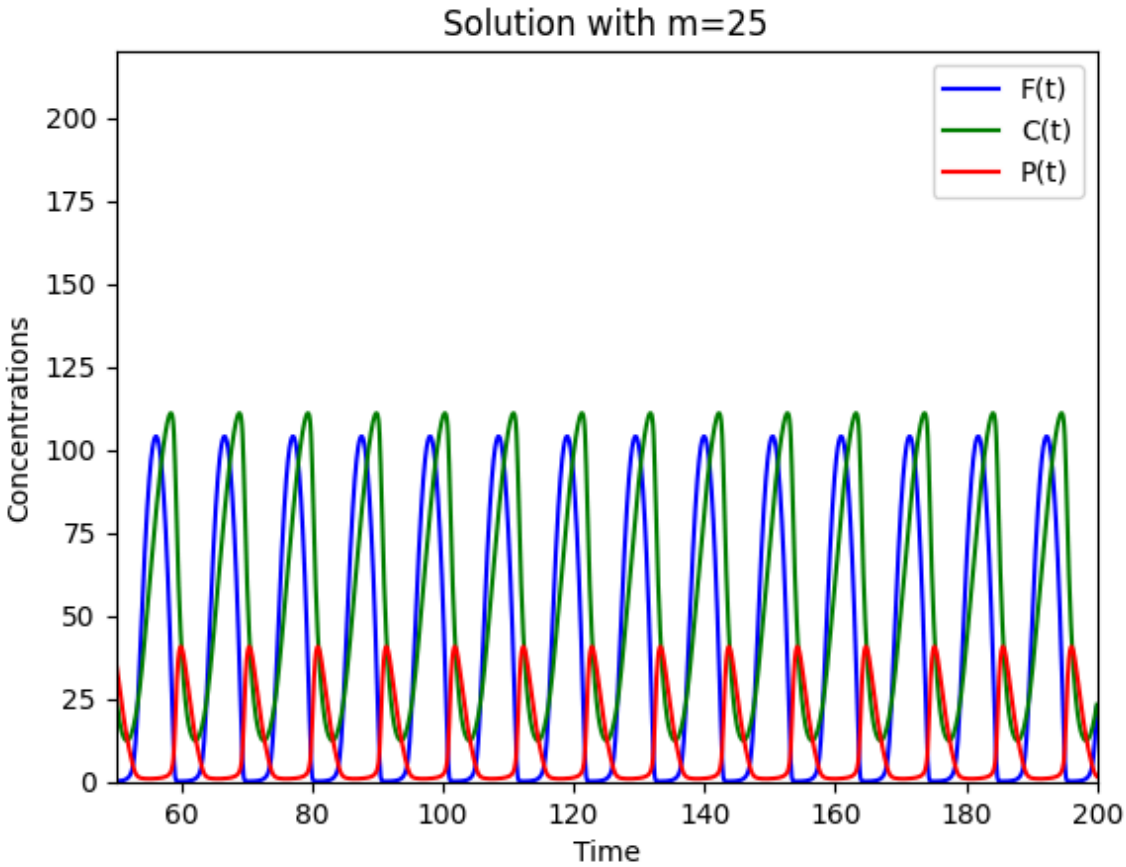

  for i in range(2, len(ts)):
    area = 0.5 * (1/Ps[i] + 1/Ps[i-1]) * (ts[i] - ts[i-1])
    cumulative_integral[i] = cumulative_integral[i-1] + area


  return([ts,cumulative_integral])
```

In [ ]:
```
sol = solve(m=200,beta=20)
```

In [ ]:
```
plt.plot(sol[0], sol[1],label="F(t)",color="blue")
plt.plot(sol[0],sol[2],label="C(t)",color="green")
plt.plot(sol[0],sol[3],label="P(t)",color="red")

plt.xlim([50,200])
plt.ylim([0,220])
plt.legend()
plt.xlabel("Time")
plt.ylabel("Concentrations")
plt.title("Solution with m=25")
plt.show()
```



In [ ]:
```
import time
from google.colab import files
from mpl_toolkits.mplot3d import Axes3D



for beta in [20,10,5,1,0.5,0.1,0.05,0.01]:
  mnum = 35
  sigmanum = 35
  mat_oligomers = np.zeros((mnum,sigmanum))
  print(beta)
  for i,m in enumerate(np.logspace(0,2,mnum)):
    print(i)
    for j,sigma in enumerate(np.logspace(-1,1.5,sigmanum)):
      sol = solve(m=m,beta=beta, sigma=sigma,tmax=1000,start_from=50)
      oligomers = num_oligomers(sol)

      final_oligomer_number = oligomers[-1][-1]

      mat_oligomers[i,j] = final_oligomer_number

  np.savetxt('oligomers_b_beta-' + str(beta) + '.txt', mat_oligomers, fmt
='%d')
  time.sleep(20)
  files.download('oligomers_b_beta-' + str(beta) + '.txt')



  fig = plt.figure()
  ax = fig.add_subplot(projection='3d')


  x = np.logspace(0,2,mnum)
  y = np.logspace(-1,1.5,sigmanum)
  X, Y = np.meshgrid(x, y)  # Create a meshgrid for X and Y


  ax.plot_wireframe(X,Y , np.log(mat_oligomers.T))


  ax.set_xlabel('m')
  ax.set_ylabel('sigma')
  ax.set_zlabel('oligomers')
  ax.view_init(elev=30, azim=120)

  plt.show()
```

```
20
0
1
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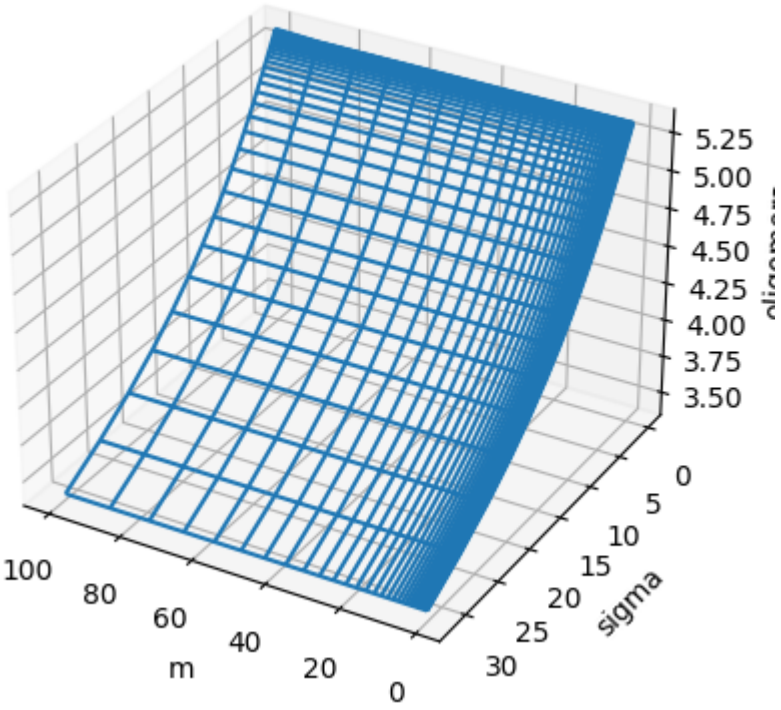
32
33
34
```




```
10
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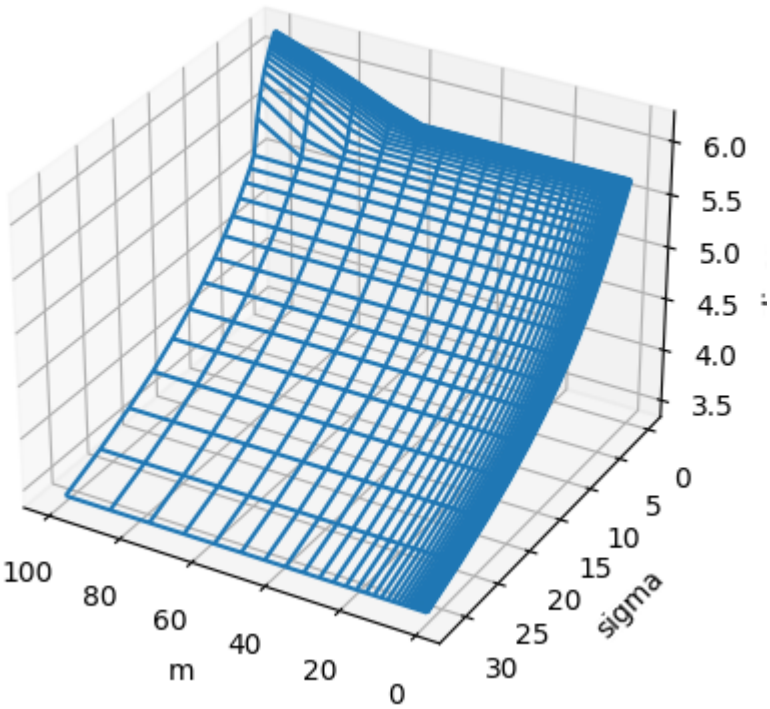
```

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```

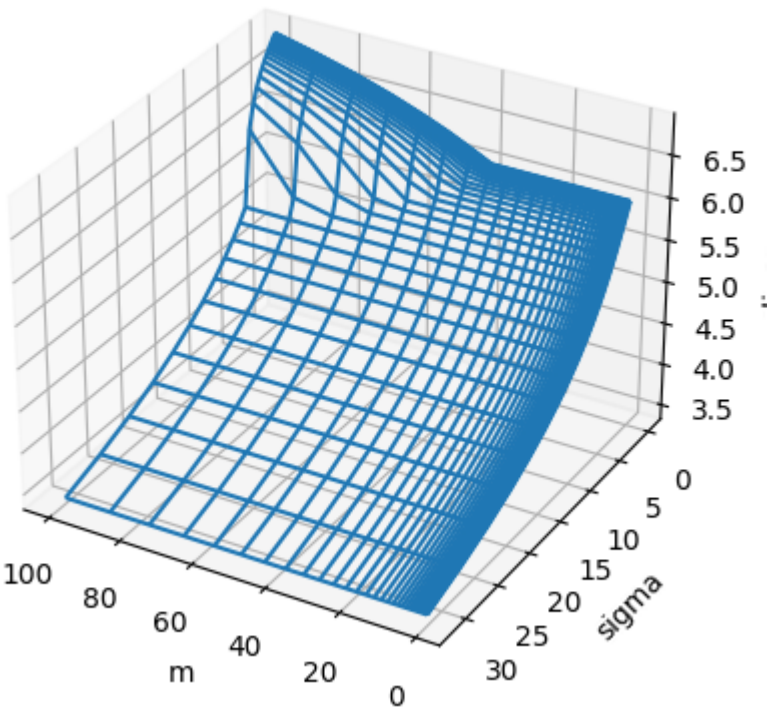
6.5
6.0
5.5
5.0
4.5
4.0
3.5
0
5
10
15
20
25
30
sigma
100
80
60
40
20
0
m

```
1
0
1
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3
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5
6
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8
9
10
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12
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14
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16
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21
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31
32
33
34
```

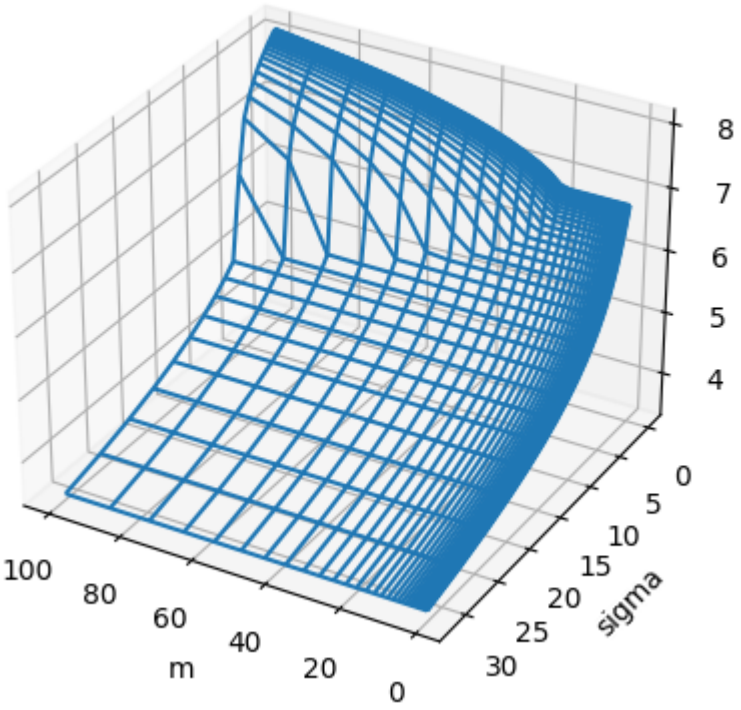


```
0.5
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```

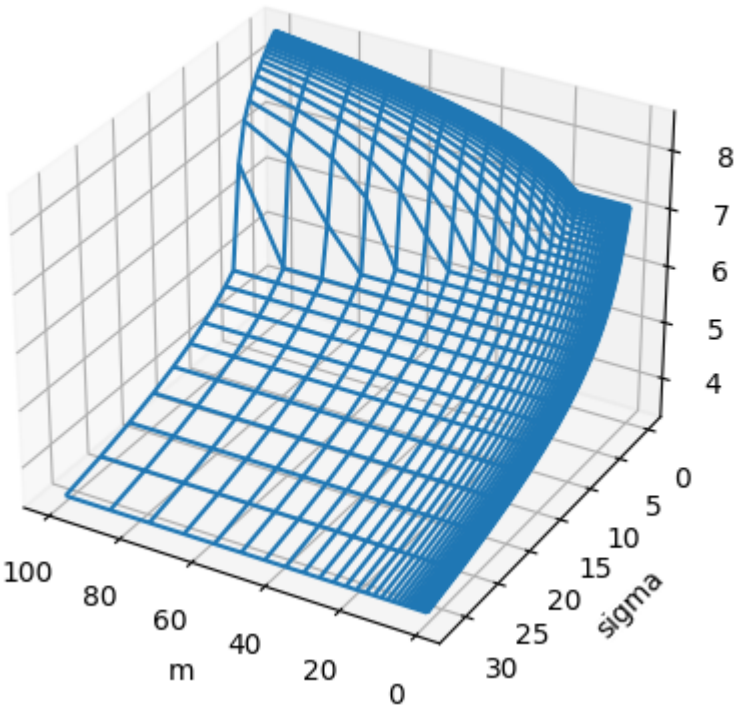


```
0.1
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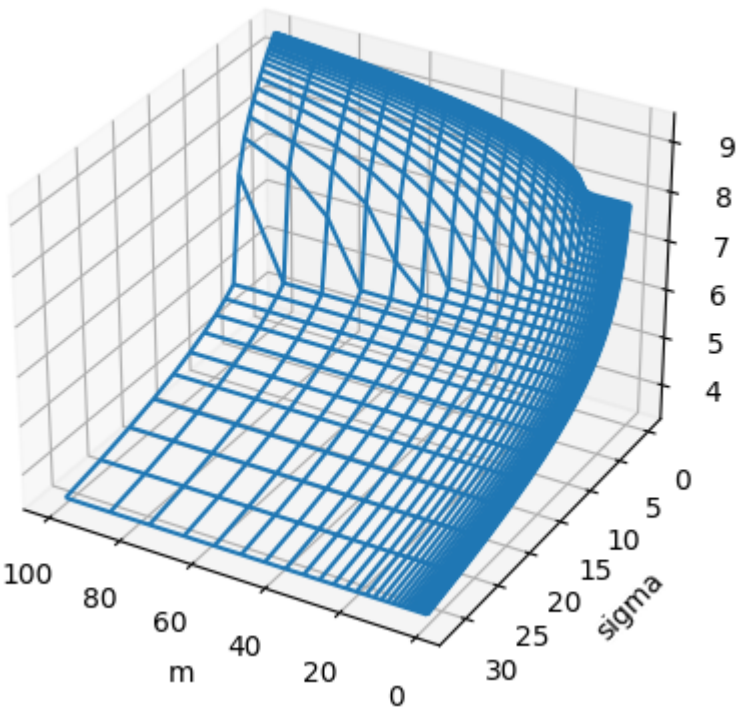
9
8
7
6
5
4
0
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10
15
20
25
30
sigma
100
80
60
40
20
0
m

```
0.05
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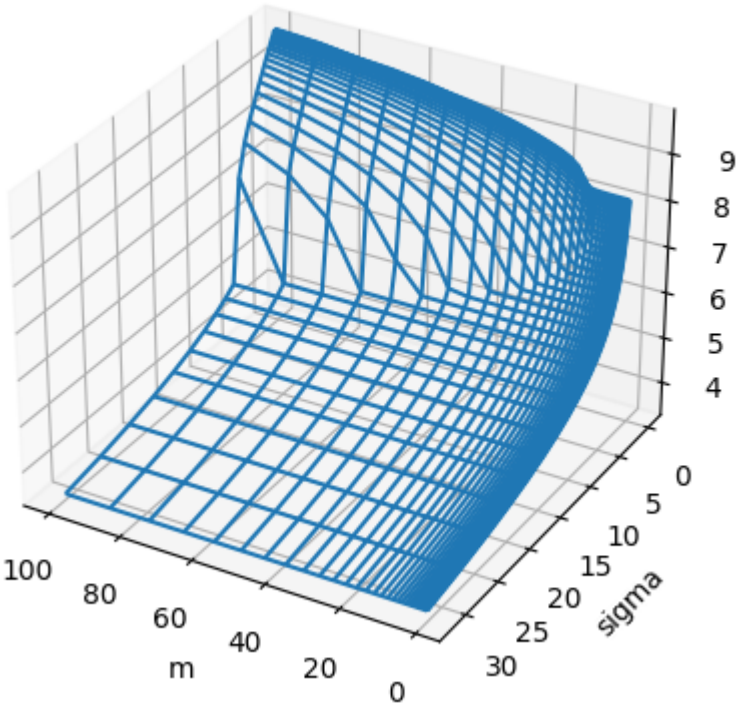
32
33
34
```

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0.01
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32
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34
```
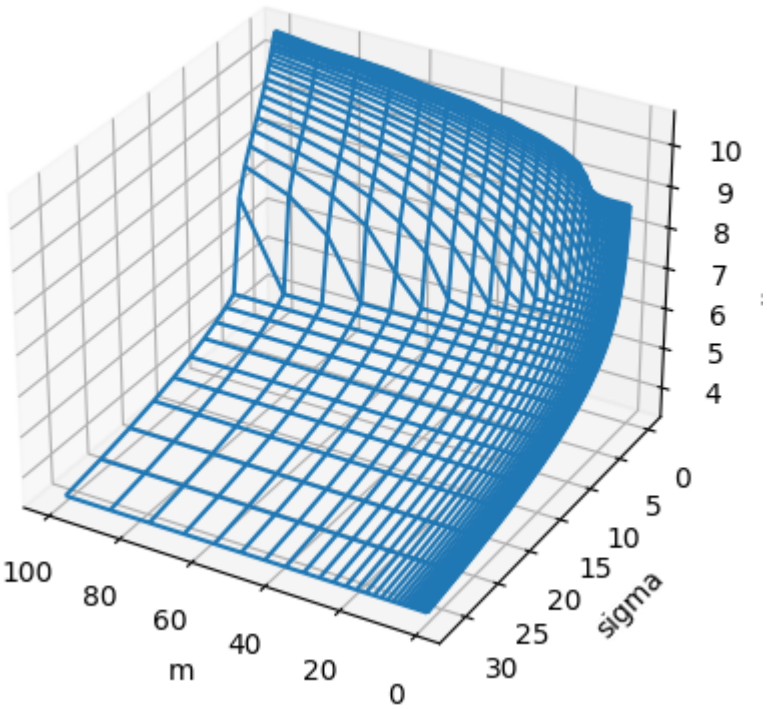
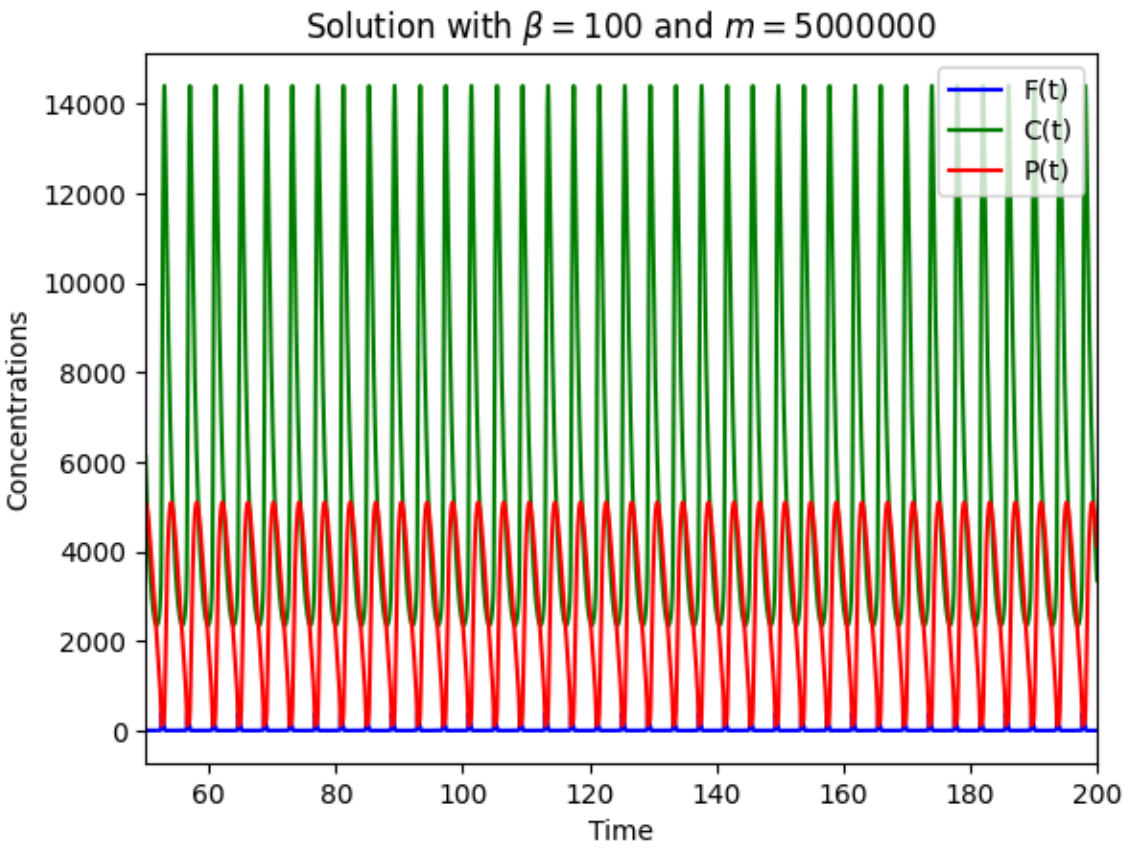



Protease induced by Fibrils F

In [ ]:
```
from scipy.integrate import solve_ivp
import numpy as np
import matplotlib.pyplot as plt

def solve(gamma=1,m=25,sigma=1,nu=1, beta = 1,
                        ic = [0,0,0.1], t0 = 0, tmax=200,start_from=50):


  def derivs(t,var):
    dvar = np.zeros(3)
    F,C,P = var
    dvar[0] = m/(1+P) - gamma * F*P
    dvar[1] = gamma*F*P - nu*C
    dvar[2] = sigma - P - gamma*F*P + nu*C + beta*F

    return dvar

  sol = solve_ivp(derivs,[t0,tmax],ic)

  ind = list(sol.t>start_from).index(True)


  return([sol.t[ind:], sol.y[0,:][ind:], sol.y[1,:][ind:], sol.y[2,:][in
d:]])


def num_oligomers(sol):
  ts = sol[0]
  Ps = sol[3]

  cumulative_integral = [0] * len(ts)


  for i in range(2, len(ts)):
    area = 0.5 * (1/Ps[i] + 1/Ps[i-1]) * (ts[i] - ts[i-1])
    cumulative_integral[i] = cumulative_integral[i-1] + area


  return([ts,cumulative_integral])
```

In [ ]:
```
sol = solve(m=5000000,beta=100)
```

In [ ]:
```
plt.plot(sol[0], sol[1],label="F(t)",color="blue")
plt.plot(sol[0],sol[2],label="C(t)",color="green")
plt.plot(sol[0],sol[3],label="P(t)",color="red")

plt.xlim([50,200])
# plt.ylim([0,220])
plt.legend()
plt.xlabel("Time")
plt.ylabel("Concentrations")
plt.title(r"Solution with $\beta = 100$ and $m=5000000$")
plt.show()
```



In [ ]:
```
import time
from google.colab import files
from mpl_toolkits.mplot3d import Axes3D



for beta in [0.005]:
  mnum = 35
  sigmanum = 35
  mat_oligomers = np.zeros((mnum,sigmanum))
  print(beta)
  for i,m in enumerate(np.logspace(0,2,mnum)):
    print(i)
    for j,sigma in enumerate(np.logspace(-1,1.5,sigmanum)):
      sol = solve(m=m,beta=beta, sigma=sigma,tmax=1000,start_from=50)
      oligomers = num_oligomers(sol)

      final_oligomer_number = oligomers[-1][-1]

      mat_oligomers[i,j] = final_oligomer_number

  np.savetxt('oligomers_c_beta-' + str(beta) + '.txt', mat_oligomers, fmt
='%d')
  time.sleep(20)
  files.download('oligomers_c_beta-' + str(beta) + '.txt')



  fig = plt.figure()
  ax = fig.add_subplot(projection='3d')


  x = np.logspace(0,2,mnum)
  y = np.logspace(-1,1.5,sigmanum)
  X, Y = np.meshgrid(x, y)  # Create a meshgrid for X and Y


  ax.plot_wireframe(X,Y , np.log(mat_oligomers.T))


  ax.set_xlabel('m')
  ax.set_ylabel('sigma')
  ax.set_zlabel('oligomers')
  ax.view_init(elev=30, azim=120)

  plt.show()
```

```
0.005
0
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
17
18
19
20
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32
33
34
```
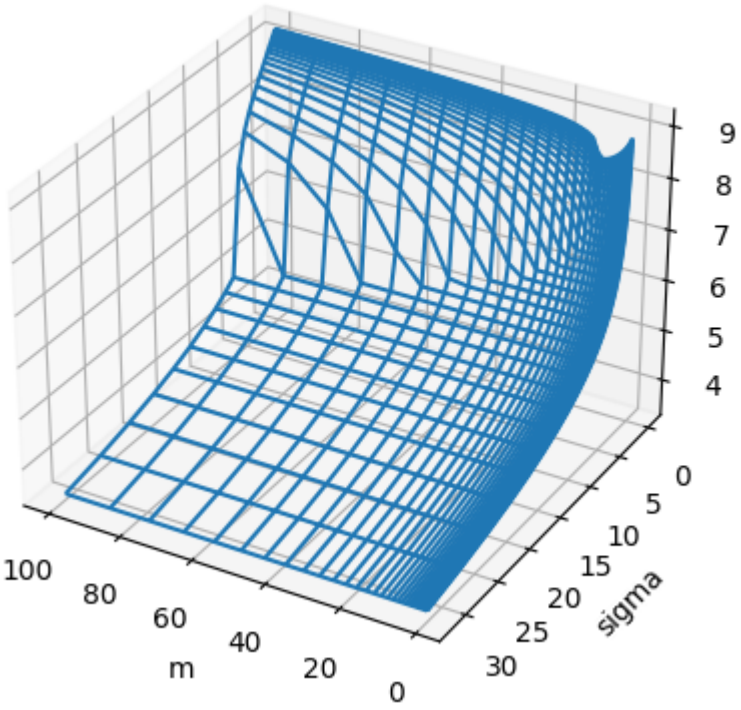



In [ ]:

Read data and make graphs

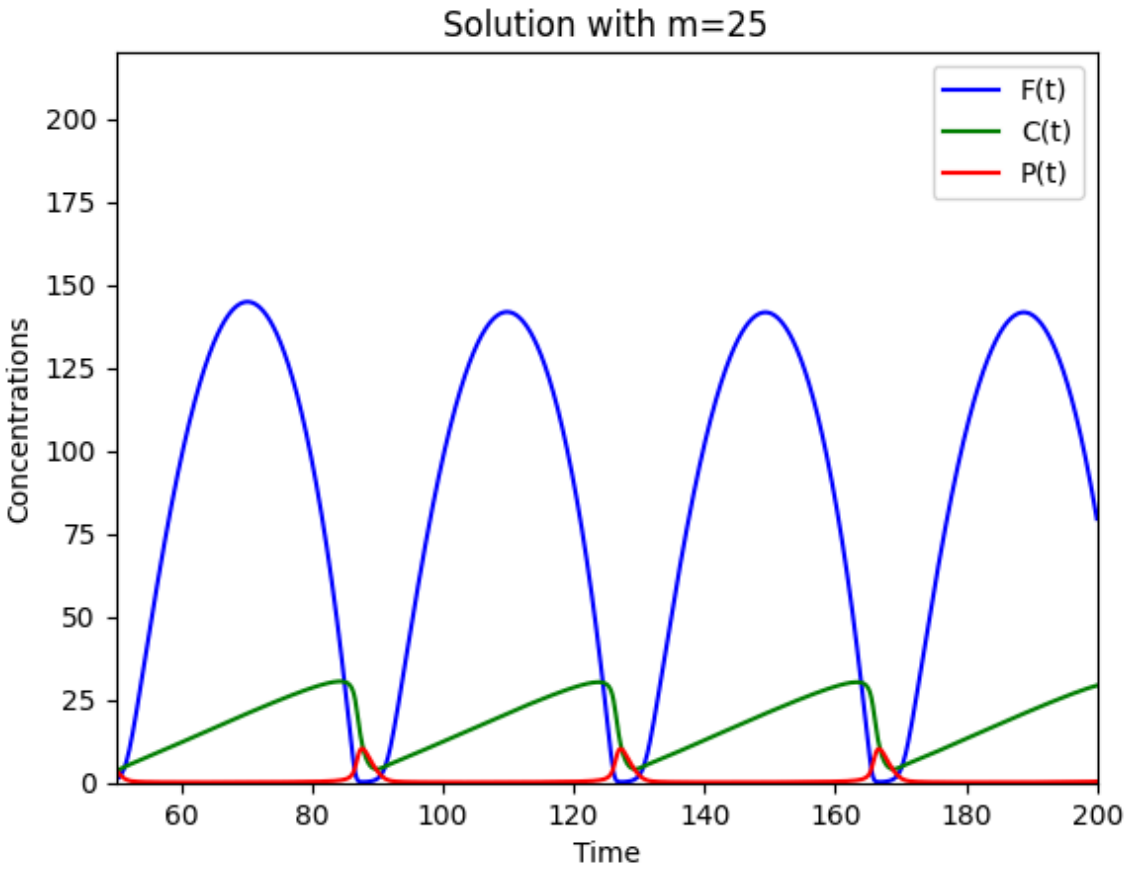
In [ ]:
```
import numpy as np
import matplotlib.pyplot as plt

import numpy as np

# Mount Google Drive
from google.colab import drive
drive.mount('/content/drive')
```

```
Mounted at /content/drive
```

Normal model

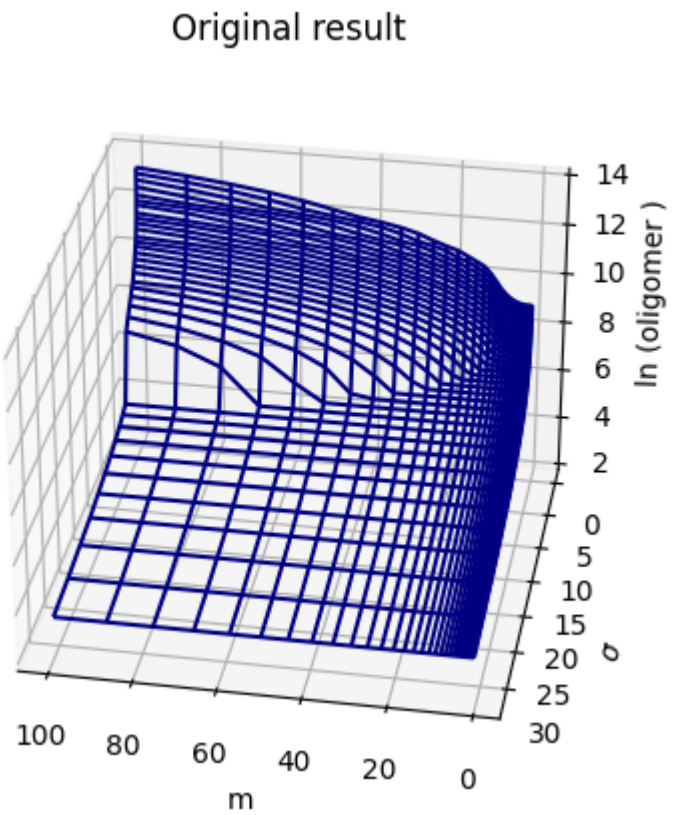
In [ ]:
```
from scipy.integrate import solve_ivp
import numpy as np
import matplotlib.pyplot as plt

def solve_original_model(gamma=1,m=25,sigma=1,nu=1,
                         ic = [0,0,0], t0 = 0, tmax=200,start_from=50):


  def derivs(t,var):
    dvar = np.zeros(3)
    F,C,P = var
    dvar[0] = m/(1+P) - gamma * F*P
    dvar[1] = gamma*F*P - nu*C
    dvar[2] = sigma - P - gamma*F*P + nu*C

    return dvar

  sol = solve_ivp(derivs,[t0,tmax],ic)

  ind = list(sol.t>start_from).index(True)


  return([sol.t[ind:], sol.y[0,:][ind:], sol.y[1,:][ind:], sol.y[2,:][in
d:]])
```

In [ ]:
```
sol_m25 = solve_original_model(m=25)


plt.plot(sol_m25[0], sol_m25[1],label="F(t)",color="blue")
plt.plot(sol_m25[0],sol_m25[2],label="C(t)",color="green")
plt.plot(sol_m25[0],sol_m25[3],label="P(t)",color="red")

plt.xlim([50,200])
plt.ylim([0,220])
plt.legend()
plt.xlabel("Time")
plt.ylabel("Concentrations")
plt.title("Solution with m=25")
plt.show()
```



In [ ]:
```
from mpl_toolkits.mplot3d import Axes3D
mnum = 35
sigmanum = 35

def plot_matrix(file_path,title="",limi=14):
  mat_oligomers = np.loadtxt(file_path, delimiter=' ')
  fig = plt.figure()
  ax = plt.axes(111, projection='3d')

  x = np.logspace(0,2,mnum)
  y = np.logspace(-1,1.5,sigmanum)

  X, Y = np.meshgrid(x, y)  # Create a meshgrid for X and Y

  ax.plot_wireframe(X,Y,np.log(mat_oligomers.T),color="navy")


  ax.set_xlabel('m')
  ax.set_ylabel(r'$\sigma$')
  ax.set_zlabel('ln (oligomer )')

  ax.view_init(elev=30, azim=100)

  plt.title(title)
  ax.set_zlim([2,limi])

  plt.show()
```

In [ ]:
```
plot_matrix("/content/drive/MyDrive/Project/oligomers_normal.txt", "Origina
l result")
```

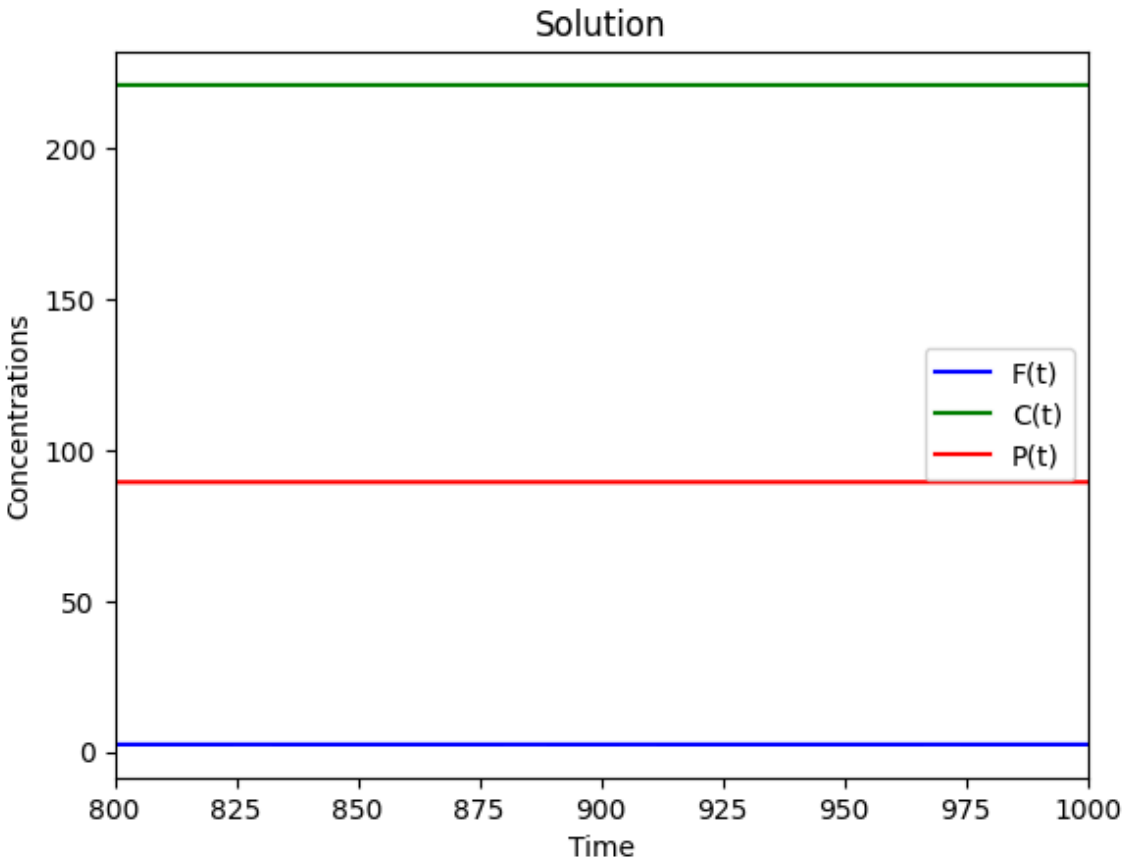


Induced by protofibrils

$$\frac{dP}{dt} = \sigma - P - \gamma F \cdot P + \nu C + \beta \frac{m}{1+P}$$

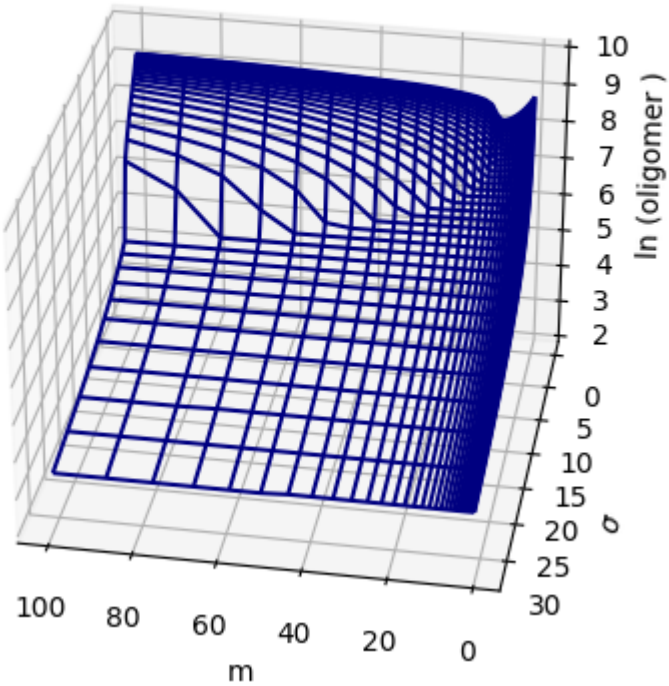
In [ ]:
```
from scipy.integrate import solve_ivp
import numpy as np
import matplotlib.pyplot as plt

def solve(gamma=1,m=25,sigma=1,nu=1, beta = 1,
                        ic = [0,0,0], t0 = 0, tmax=200,start_from=50):


  def derivs(t,var):
    dvar = np.zeros(3)
    F,C,P = var
    dvar[0] = m/(1+P) - gamma * F*P
    dvar[1] = gamma*F*P - nu*C
    dvar[2] = sigma - P - gamma*F*P + nu*C + beta*m/(1+P)

    return dvar

  sol = solve_ivp(derivs,[t0,tmax],ic)

  ind = list(sol.t>start_from).index(True)


  return([sol.t[ind:], sol.y[0,:][ind:], sol.y[1,:][ind:], sol.y[2,:][in
d:]])
```

In [ ]:
```
sol = solve(m=20000,beta=0.4,sigma=1,tmax=1000,ic=[2.5,250,90])

plt.plot(sol[0], sol[1],label="F(t)",color="blue")
plt.plot(sol[0],sol[2],label="C(t)",color="green")
plt.plot(sol[0],sol[3],label="P(t)",color="red")

plt.xlim([800,1000])
# plt.ylim([0,220])
plt.legend()
plt.xlabel("Time")
plt.ylabel("Concentrations")
plt.title("Solution")
plt.show()
```

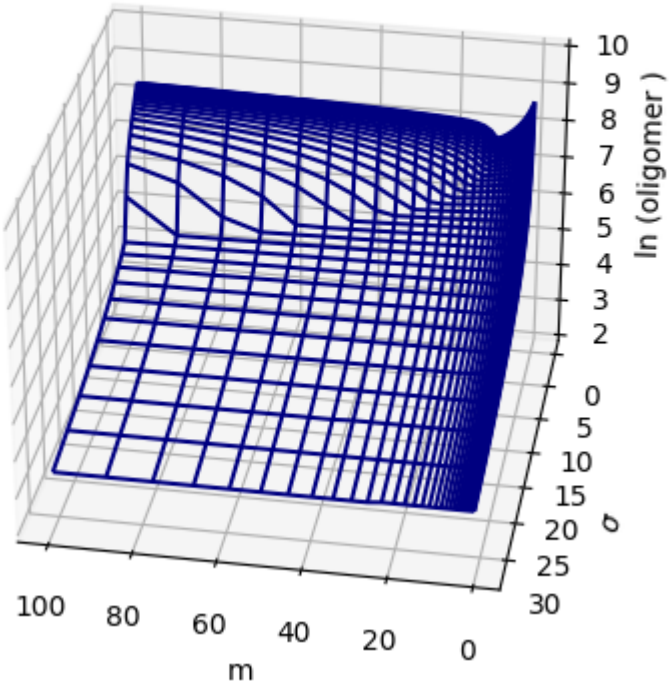


In [ ]:
```
for beta in ["0.025","0.05","0.1","0.2","0.5","1","5"]:
  plot_matrix("/content/drive/MyDrive/Project/oligomers"+"_a_beta-"+beta+".
txt", "Protofibrils, beta = " + beta,limi=10)
```

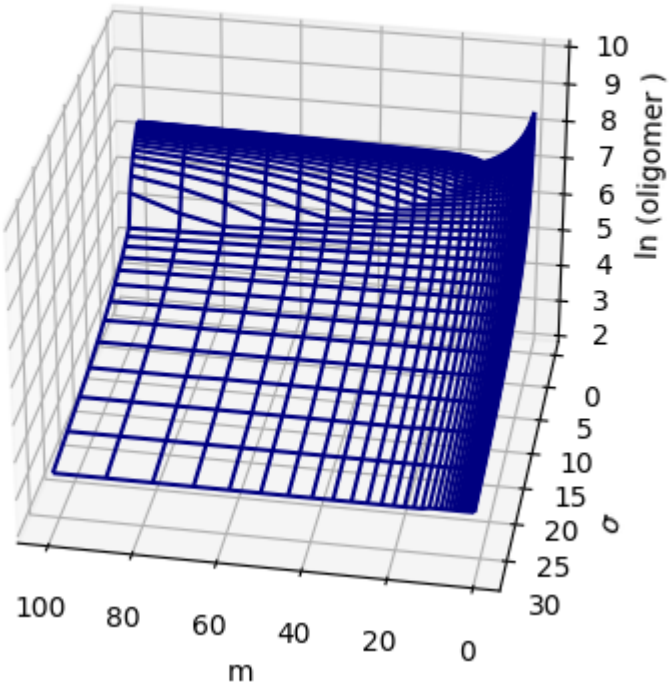
Protofibrils, beta = 0.025



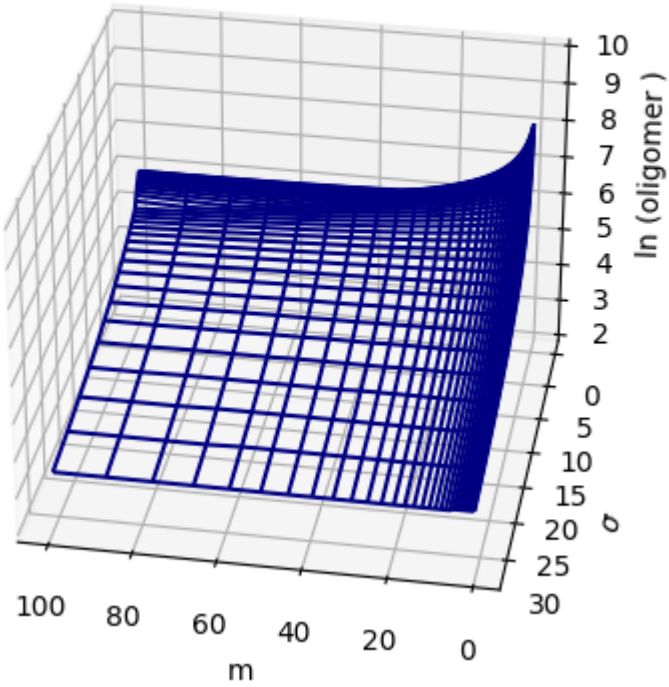
Protofibrils, beta = 0.05



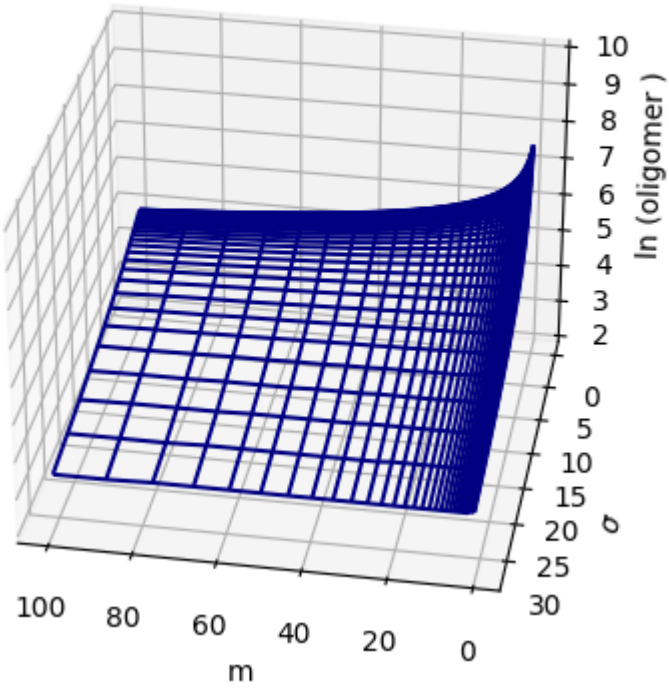
Protofibrils, beta = 0.1



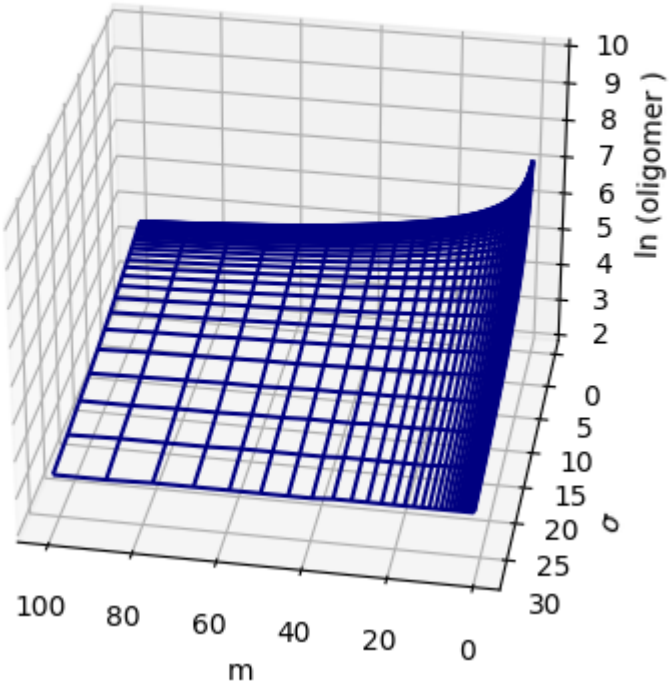
Protofibrils, beta = 0.2

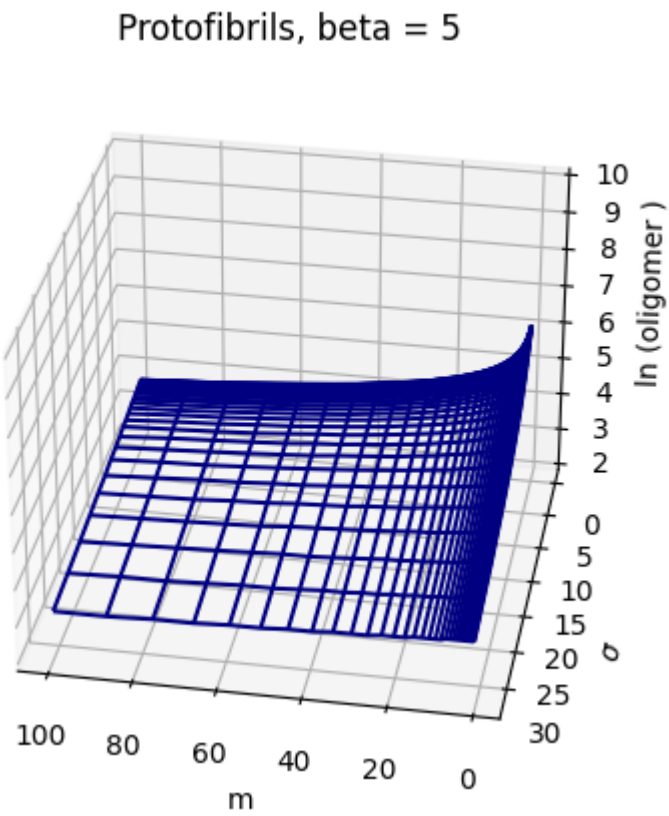


Protofibrils, beta = 0.5



Protofibrils, beta = 1





In [ ]:

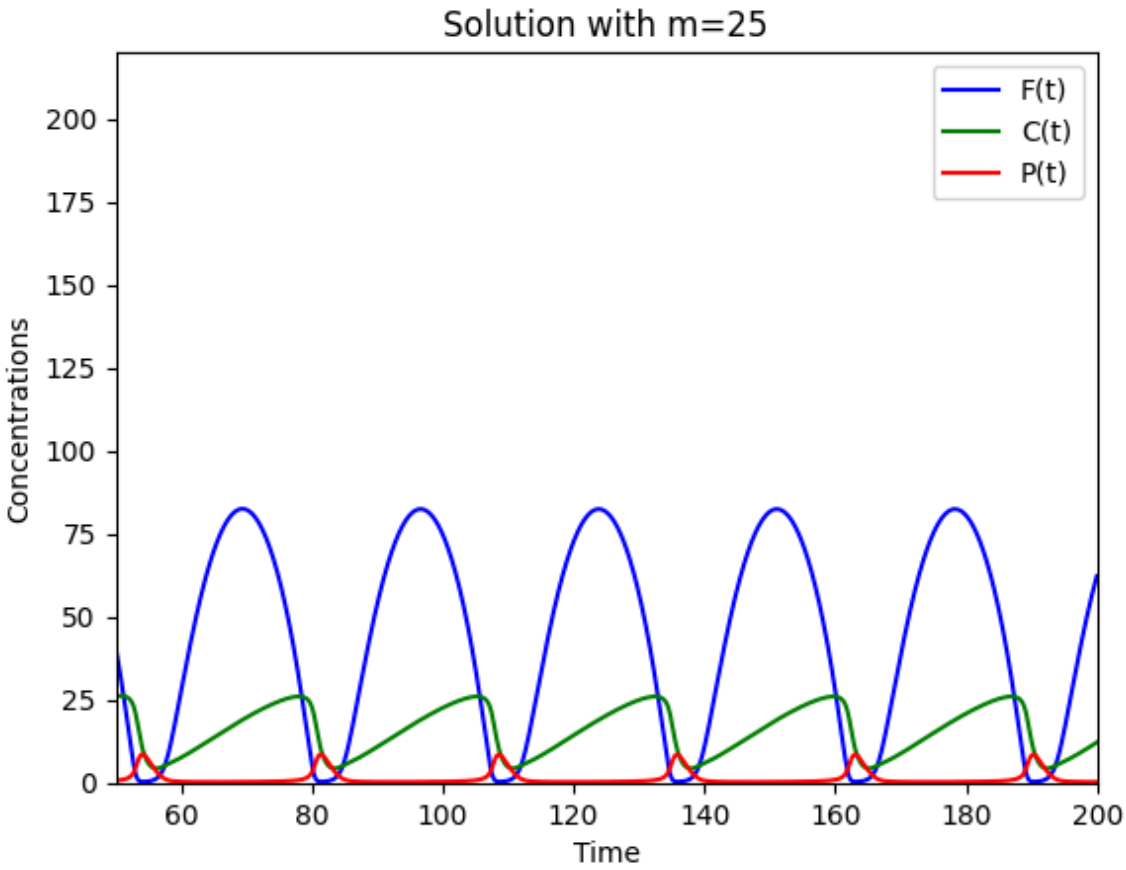
Induced by oligomers

$$\frac{dP}{dt} = \sigma - P - \gamma F \cdot P + \nu C + \beta \frac{1}{P}$$

In [ ]:

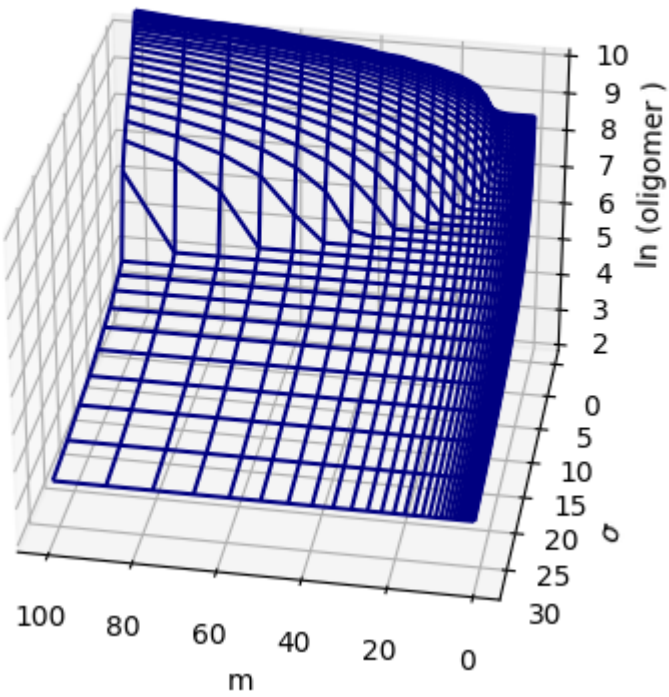
```
from scipy.integrate import solve_ivp
import numpy as np
import matplotlib.pyplot as plt

def solve(gamma=1,m=25,sigma=1,nu=1, beta = 1,
                         ic = [0,0,0.1], t0 = 0, tmax=200,start_from=50):


  def derivs(t,var):
    dvar = np.zeros(3)
    F,C,P = var
    dvar[0] = m/(1+P) - gamma * F*P
    dvar[1] = gamma*F*P - nu*C
    dvar[2] = sigma - P - gamma*F*P + nu*C + beta/P

    return dvar

  sol = solve_ivp(derivs,[t0,tmax],ic)

  ind = list(sol.t>start_from).index(True)


  return([sol.t[ind:], sol.y[0,:][ind:], sol.y[1,:][ind:], sol.y[2,:][in
d:]])
```

In [ ]:
```
sol = solve(m=25,beta=0.1)

plt.plot(sol[0], sol[1],label="F(t)",color="blue")
plt.plot(sol[0],sol[2],label="C(t)",color="green")
plt.plot(sol[0],sol[3],label="P(t)",color="red")

plt.xlim([50,200])
plt.ylim([0,220])
plt.legend()
plt.xlabel("Time")
plt.ylabel("Concentrations")
plt.title("Solution with m=25")
plt.show()
```

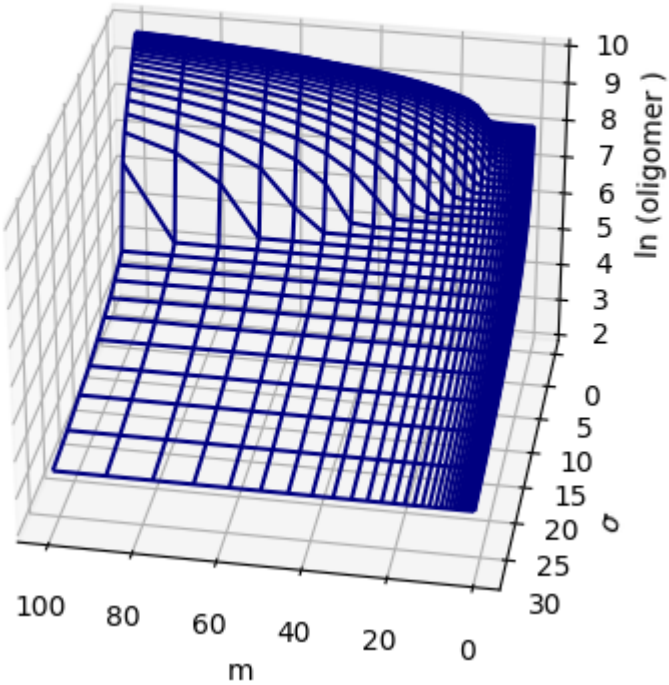


In [ ]:
```
for beta in ["0.01","0.05","0.1","0.5","1","10","20"]:
  plot_matrix("/content/drive/MyDrive/Project/oligomers"+"_b_beta-"+beta+".
txt", "Protofibrils, beta = " + beta,limi=10)
```

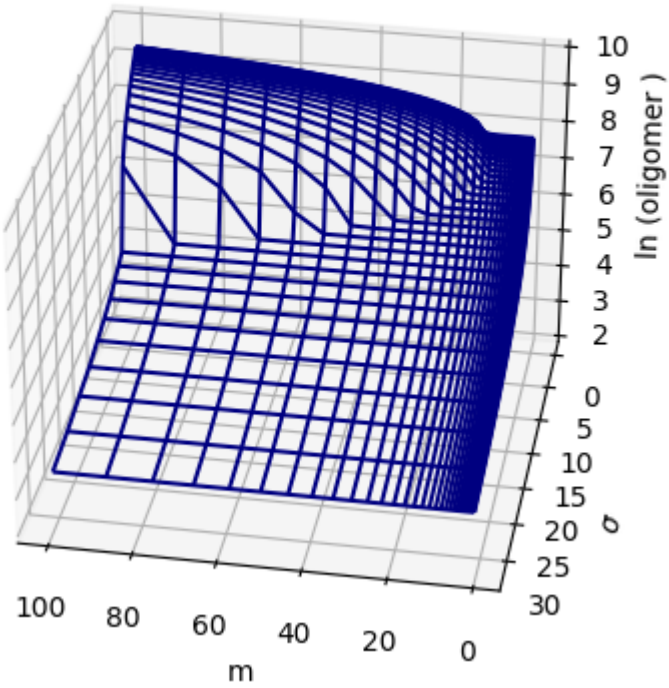
Protofibrils, beta = 0.01



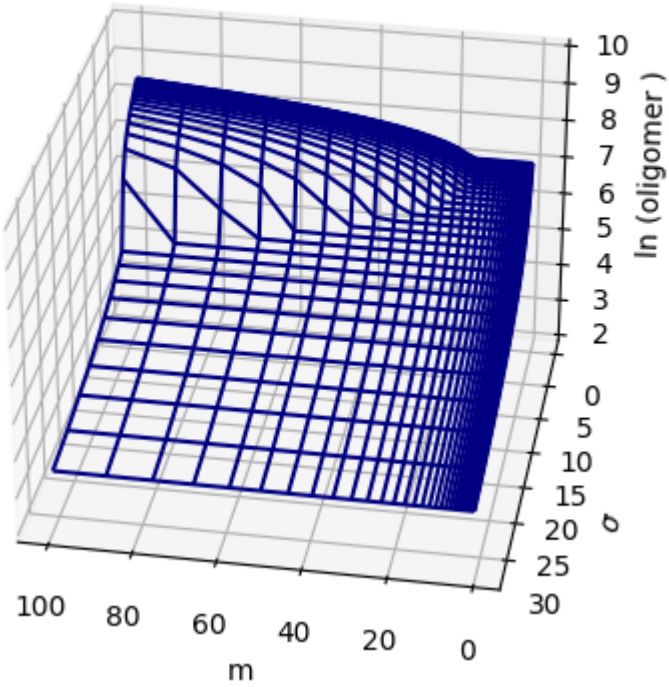
Protofibrils, beta = 0.05



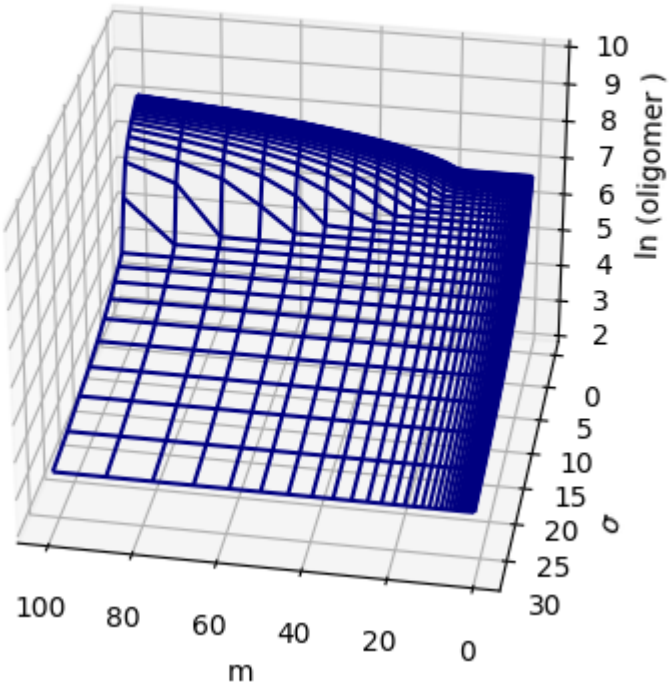
Protofibrils, beta = 0.1



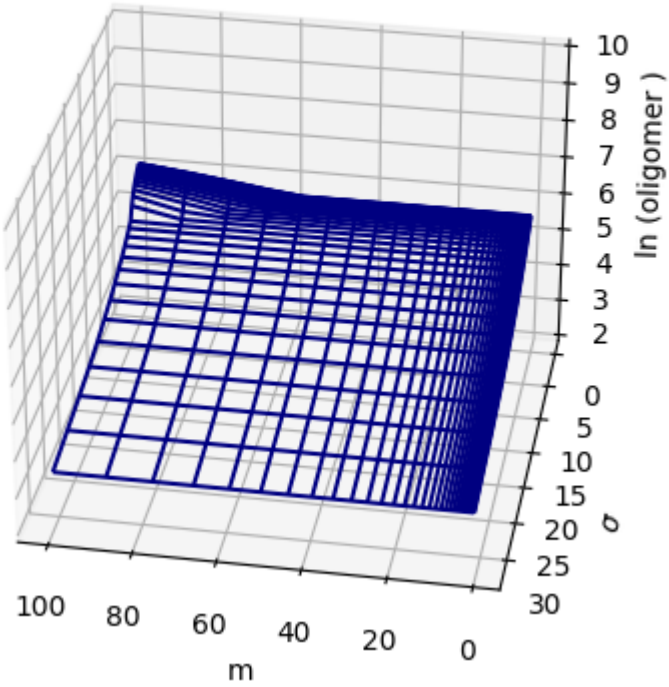
Protofibrils, beta = 0.5

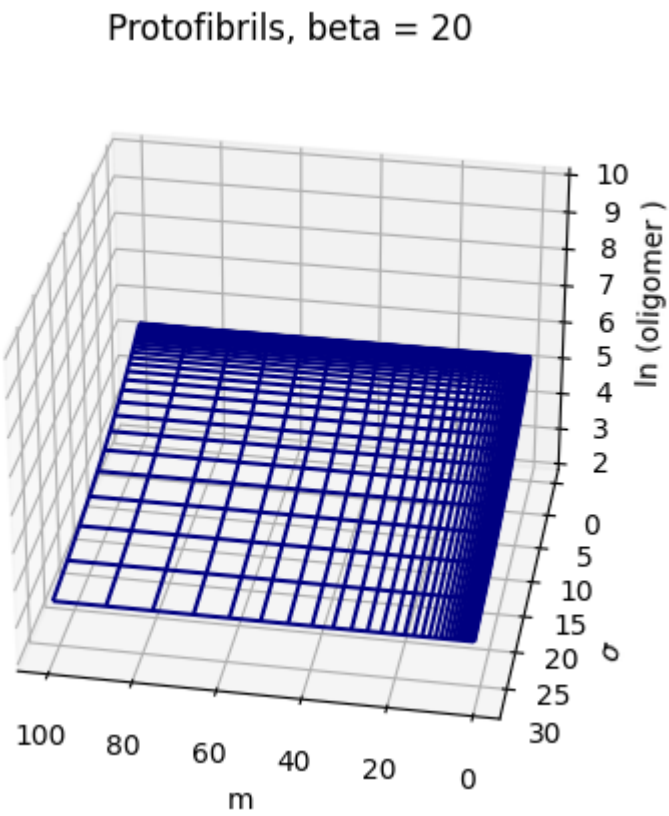


Protofibrils, beta = 1



Protofibrils, beta = 10



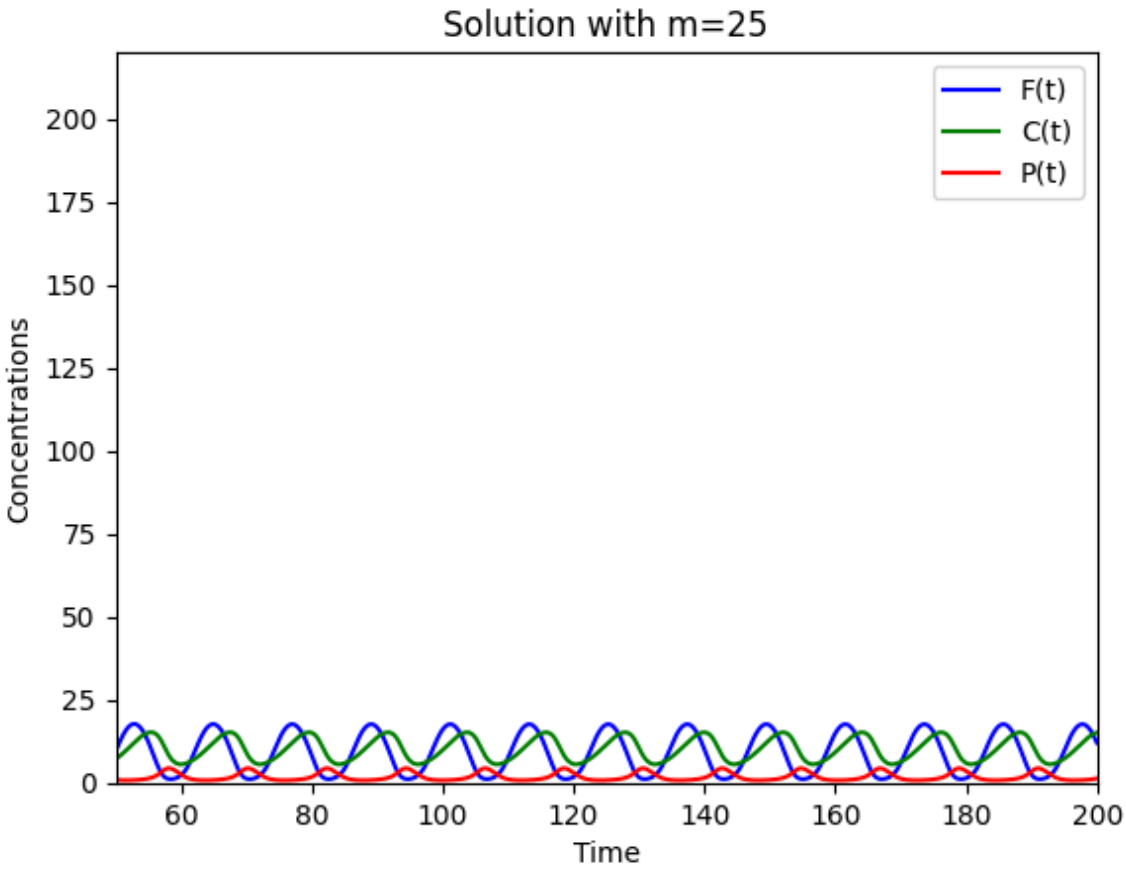


Induced by Fibrils

$$\frac{dP}{dt} = \sigma - P - \gamma F \cdot P + \nu C + \beta F$$

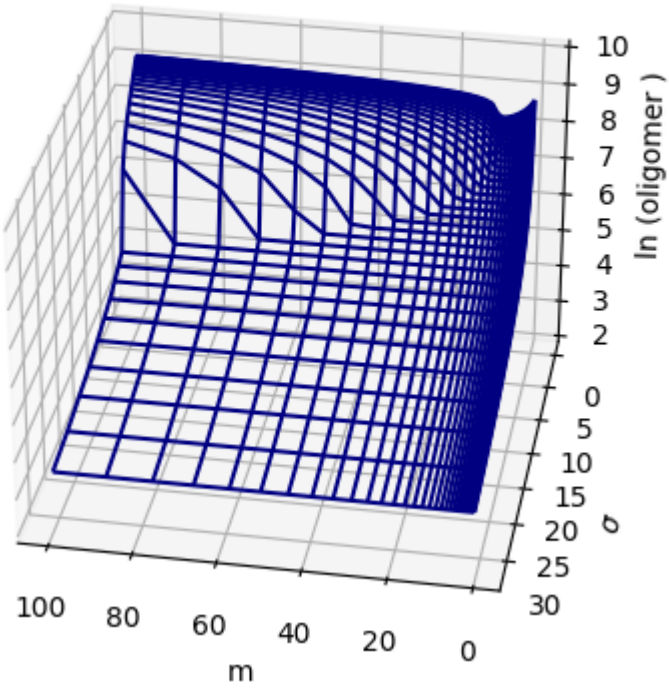
In [ ]:
```
from scipy.integrate import solve_ivp
import numpy as np
import matplotlib.pyplot as plt

def solve(gamma=1,m=25,sigma=1,nu=1, beta = 1,
                          ic = [0,0,0], t0 = 0, tmax=200,start_from=50):


  def derivs(t,var):
    dvar = np.zeros(3)
    F,C,P = var
    dvar[0] = m/(1+P) - gamma * F*P
    dvar[1] = gamma*F*P - nu*C
    dvar[2] = sigma - P - gamma*F*P + nu*C + beta*F

    return dvar

  sol = solve_ivp(derivs,[t0,tmax],ic)

  ind = list(sol.t>start_from).index(True)


  return([sol.t[ind:], sol.y[0,:][ind:], sol.y[1,:][ind:], sol.y[2,:][in
d:]])
```

In [ ]:
```
sol = solve(m=25,beta=0.1)

plt.plot(sol[0], sol[1],label="F(t)",color="blue")
plt.plot(sol[0],sol[2],label="C(t)",color="green")
plt.plot(sol[0],sol[3],label="P(t)",color="red")

plt.xlim([50,200])
plt.ylim([0,220])
plt.legend()
plt.xlabel("Time")
plt.ylabel("Concentrations")
plt.title("Solution with m=25")
plt.show()
```

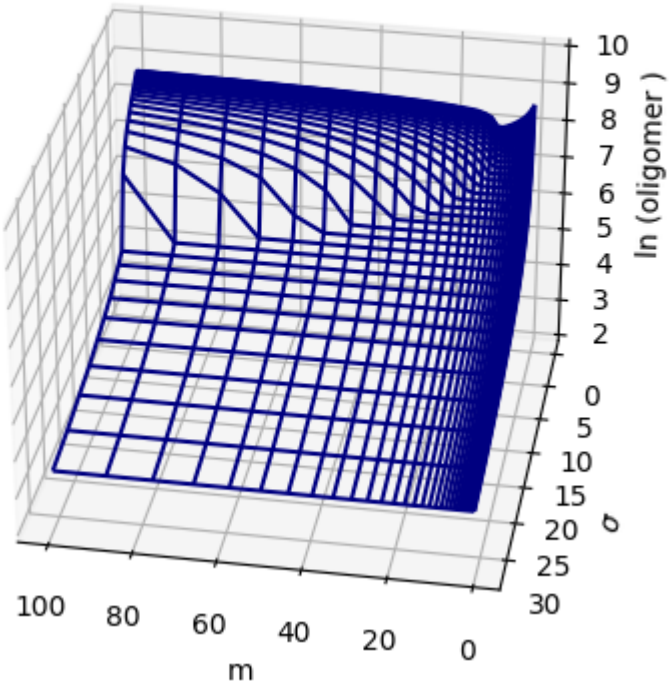


In [ ]:
```
for beta in ["0.005","0.01","0.02","0.05 (1)","0.1","0.5","1","5","10"]:
  plot_matrix("/content/drive/MyDrive/Project/oligomers"+"_c_beta-"+beta+".
txt", "Protofibrils, beta = " + beta,limi=10)
```

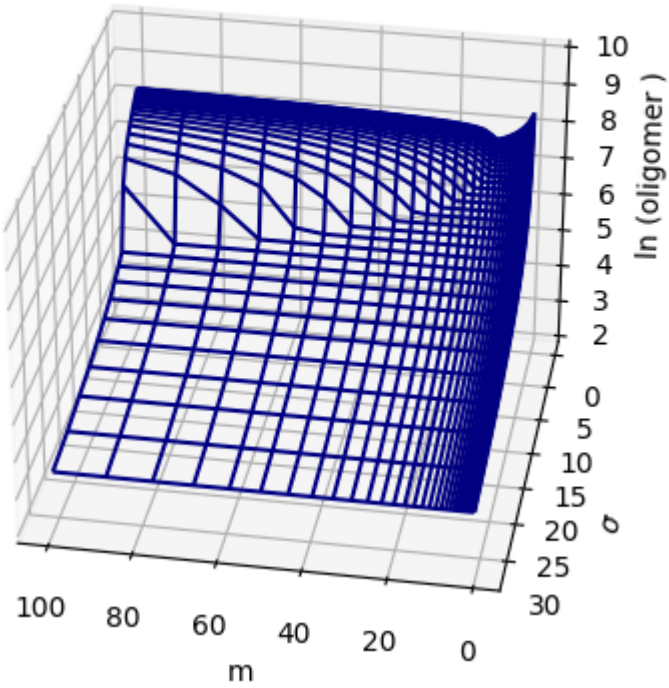
Protofibrils, beta = 0.005



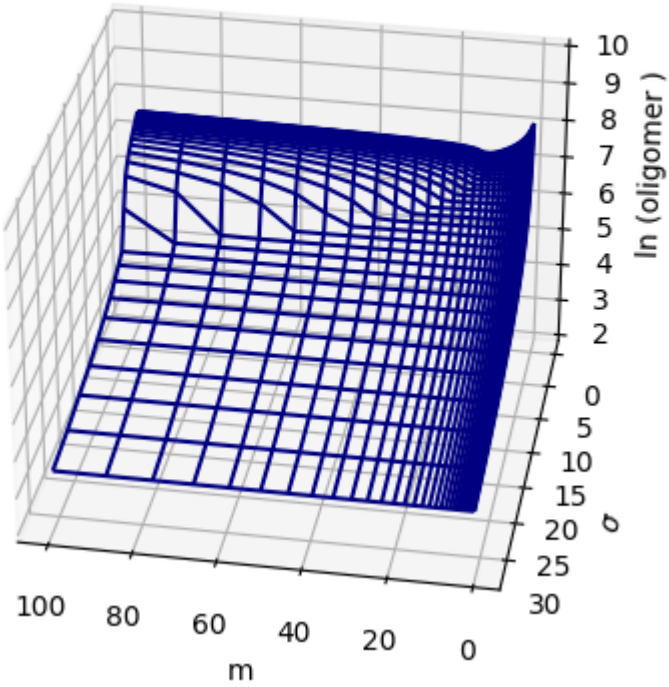
Protofibrils, beta = 0.01



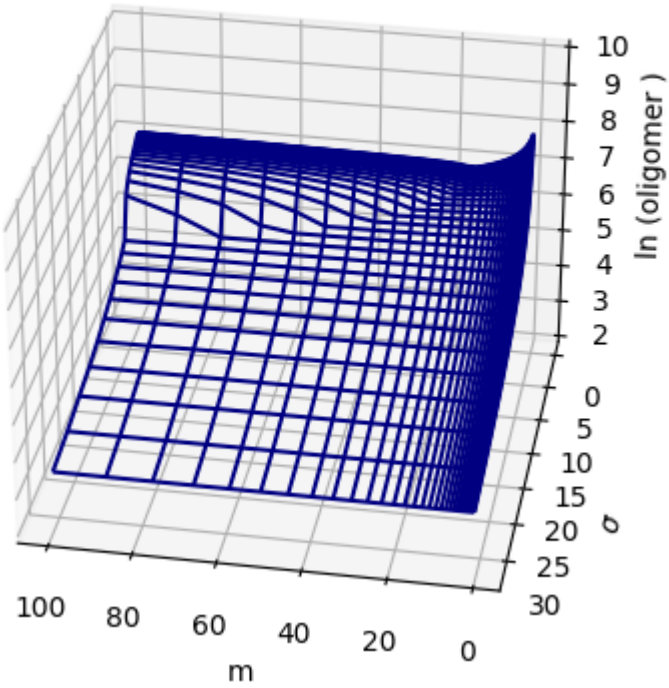
Protofibrils, beta = 0.02



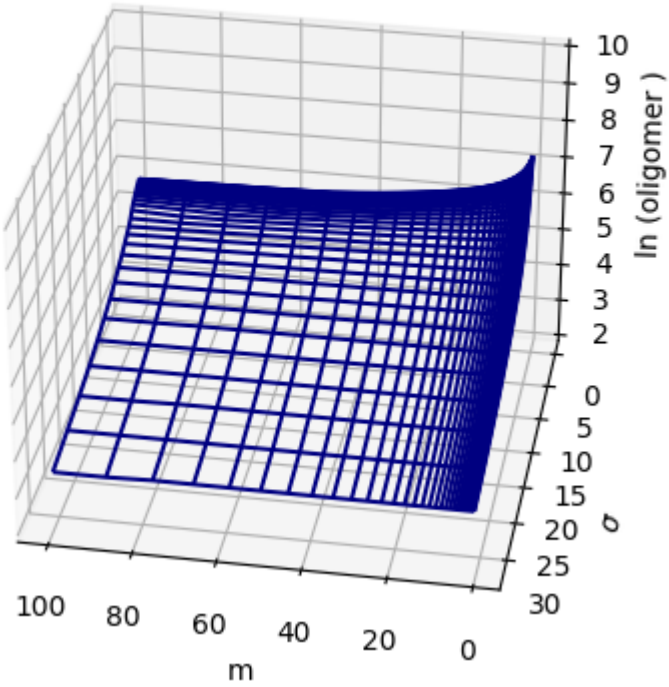
Protofibrils, beta = 0.05 (1)



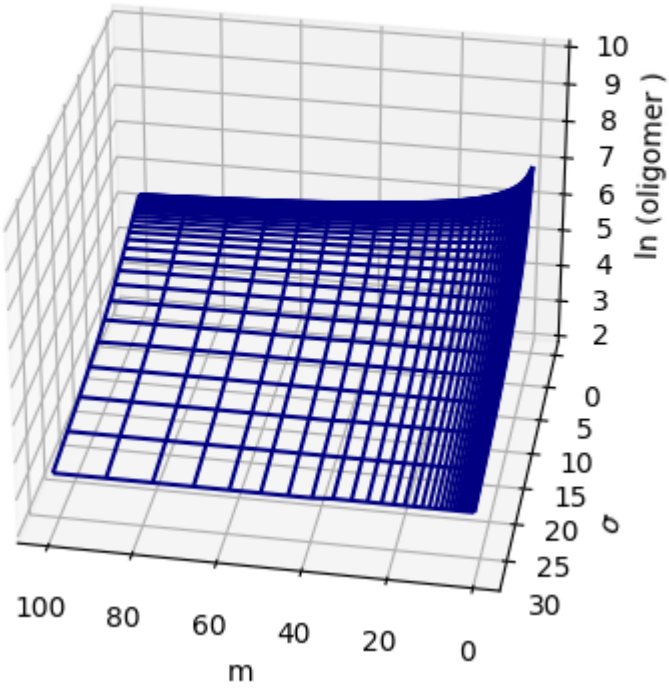
Protofibrils, beta = 0.1



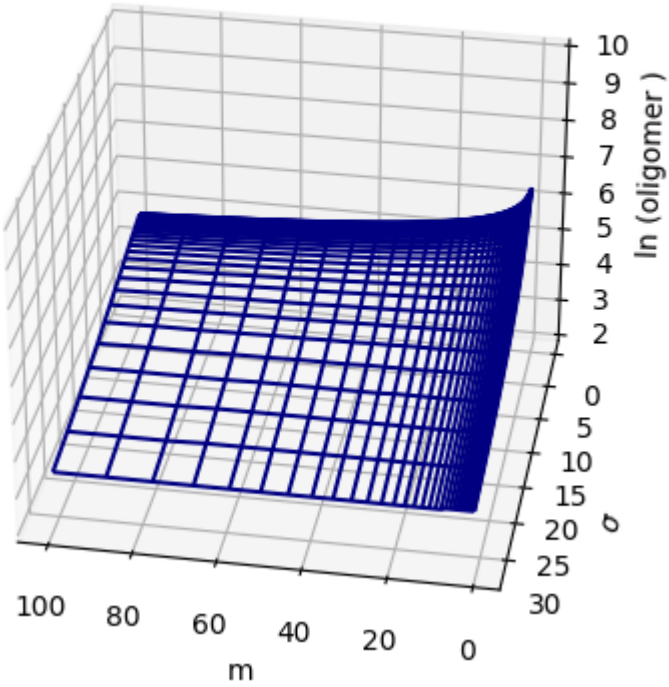
Protofibrils, beta = 0.5

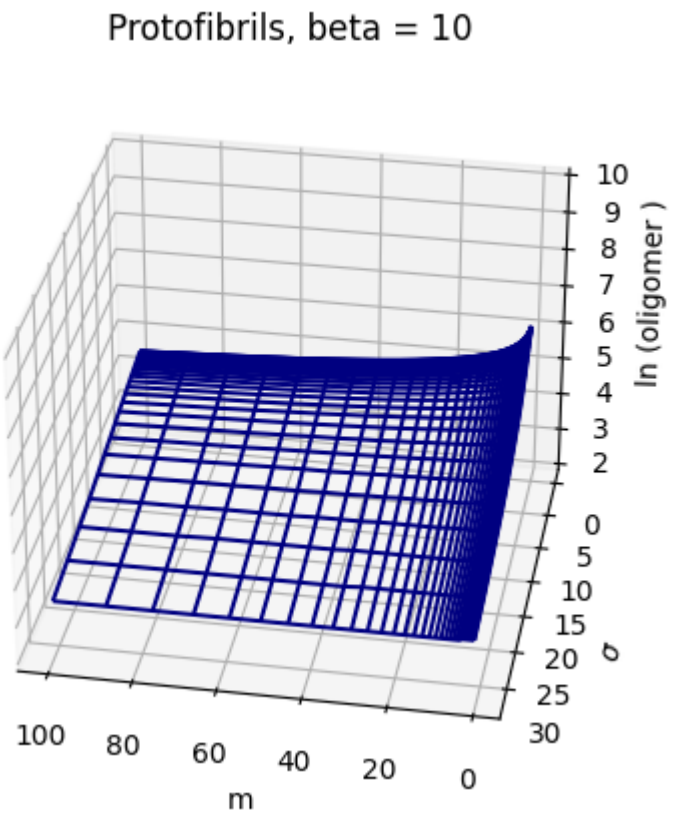


Protofibrils, beta = 1



Protofibrils, beta = 5




Protofibrils, beta = 10
ln (oligomer)
10
9
8
7
6
5
4
3
2
0
5
10
15
20
25
30
q
100
80
60
40
20
0
m

In [ ]: