Problem 1: Support Vector Machines

Instructions:

1. Please use this q1.ipynb file to complete SVM using cvxopt
2. You may create new cells for discussions or visualizations

In [3]:
```
# Import modules
import numpy as np
import matplotlib.pyplot as plt
from cvxopt import matrix, solvers
```

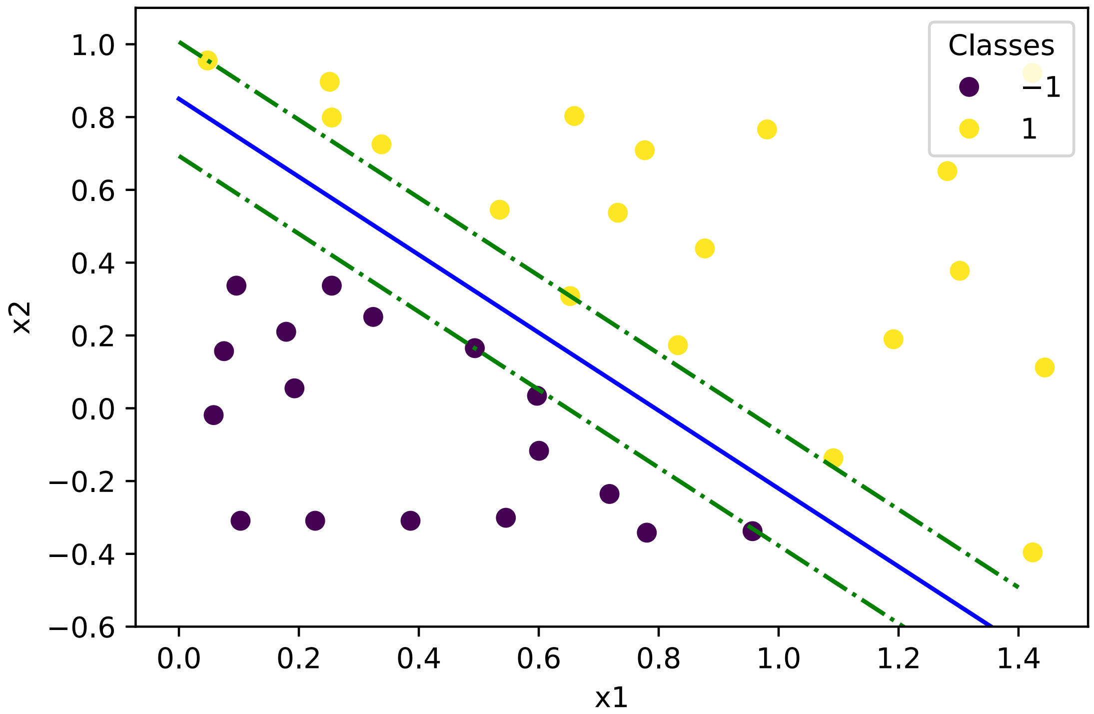
a): Linearly Separable Dataset

In [11]:
```
data = np.loadtxt('clean_lin.txt', delimiter='\t')
x = data[:, 0:2]
y = data[:, 2].reshape(-1,1)
n = x.shape[0]
Q = matrix(np.eye((3)),tc = "d")
Q[2,2] = 0
p = matrix(np.zeros((3,1)),tc = "d")
h = matrix(-np.ones((n,1)),tc = "d")
ones = np.ones((n)).reshape(-1,1)
G1 = (-y) * np.hstack((x,ones))
G = matrix(G1,tc = "d")
solvers.options['show_progress'] = False
sol = solvers.qp(Q, p, G, h)
print(sol['x'])
z = sol['x']

# Plot points
x_point = np.linspace(0,1.4,100)
y_point = (-z[2]-z[0]* x_point) / z[1]
y_point1 = (1-z[2]-z[0]* x_point) / z[1]
y_point2 = (-1-z[2]-z[0]* x_point) / z[1]
plt.figure(1)
scatter = plt.scatter(x[:,0],x[:,1],c = y)
plt.xlabel("x1")
plt.ylabel("x2")
legend1 = plt.legend(*scatter.legend_elements(),loc="upper right", title="Classes")
plt.plot(x_point,y_point,c = "b")
plt.plot(x_point,y_point1,c = "green",linestyle="-.")
plt.plot(x_point,y_point2,c = "green",linestyle="-.")
plt.ylim(-0.6,1.1)
```

```
[ 6.83e+00]
[ 6.38e+00]
[-5.43e+00]
```

Out[11]: (-0.6, 1.1)



In [14]:
```
print("Q matrix:",Q)
print("p matrix:",p)
print("G matrix:",G)
print("h matrix:",h)
```

```
Q matrix: [ 1.00e+00  0.00e+00  0.00e+00]
[ 0.00e+00  1.00e+00  0.00e+00]
[ 0.00e+00  0.00e+00  0.00e+00]

p matrix: [ 0.00e+00]
[ 0.00e+00]
[ 0.00e+00]

G matrix: [-4.78e-02 -9.56e-01 -1.00e+00]
[-1.42e+00  3.96e-01 -1.00e+00]
[-2.51e-01 -8.97e-01 -1.00e+00]
[-2.55e-01 -7.99e-01 -1.00e+00]
[-3.38e-01 -7.25e-01 -1.00e+00]
[-5.35e-01 -5.45e-01 -1.00e+00]
[-7.32e-01 -5.37e-01 -1.00e+00]
[-7.77e-01 -7.09e-01 -1.00e+00]
[-6.59e-01 -8.03e-01 -1.00e+00]
[-9.81e-01 -7.66e-01 -1.00e+00]
[-8.77e-01 -4.39e-01 -1.00e+00]
[-8.32e-01 -1.73e-01 -1.00e+00]
[-6.52e-01 -3.08e-01 -1.00e+00]
[-1.42e+00 -9.21e-01 -1.00e+00]
[-1.28e+00 -6.51e-01 -1.00e+00]
[-1.30e+00 -3.78e-01 -1.00e+00]
[-1.19e+00 -1.90e-01 -1.00e+00]
[-1.09e+00  1.37e-01 -1.00e+00]
[-1.44e+00 -1.12e-01 -1.00e+00]
[ 9.59e-02  3.37e-01  1.00e+00]
[ 7.52e-02  1.57e-01  1.00e+00]
[ 1.79e-01  2.10e-01  1.00e+00]
[ 2.55e-01  3.37e-01  1.00e+00]
[ 3.24e-01  2.51e-01  1.00e+00]
[ 4.93e-01  1.65e-01  1.00e+00]
[ 5.97e-01  3.43e-02  1.00e+00]
[ 6.01e-01 -1.17e-01  1.00e+00]
[ 7.18e-01 -2.35e-01  1.00e+00]
[ 5.45e-01 -3.01e-01  1.00e+00]
[ 2.27e-01 -3.09e-01  1.00e+00]
[ 7.80e-01 -3.42e-01  1.00e+00]
[ 9.57e-01 -3.38e-01  1.00e+00]
[ 1.03e-01 -3.09e-01  1.00e+00]
[ 5.79e-02 -1.88e-02  1.00e+00]
[ 1.93e-01  5.47e-02  1.00e+00]
[ 3.86e-01 -3.09e-01  1.00e+00]

h matrix: [-1.00e+00]
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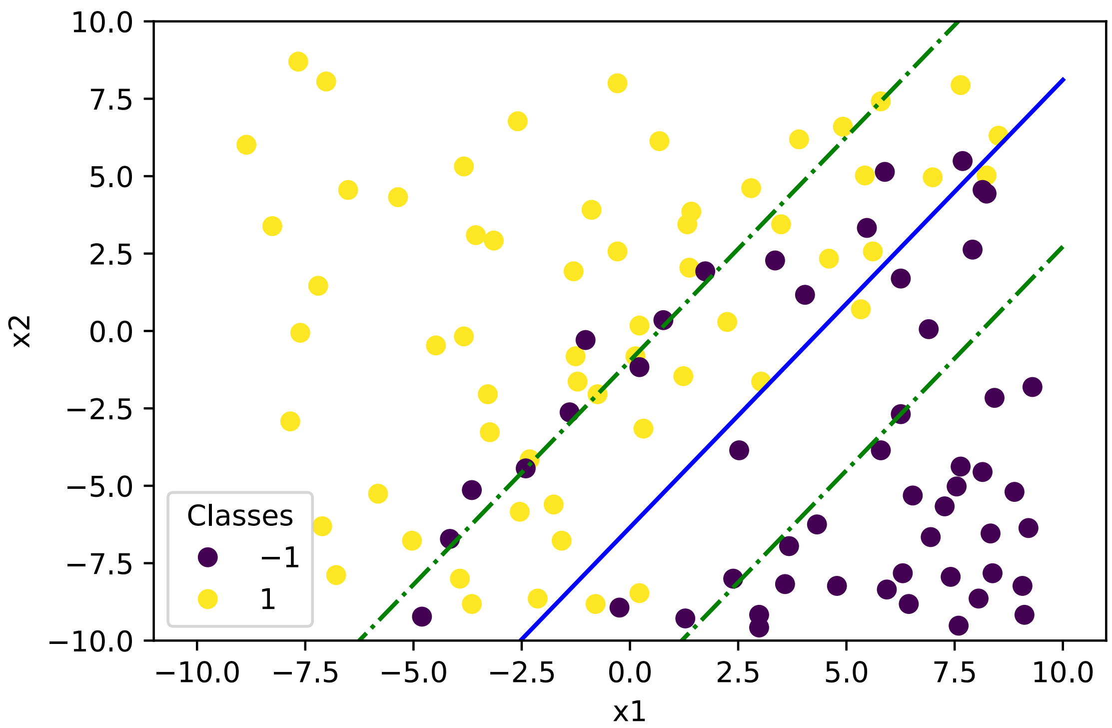
```

b): Linearly Non-separable Dataset

In [15]:
```
# Load the data set that is not linearly separable
data = np.loadtxt('dirty_nonlin.txt', delimiter='\t')
x = data[:, 0:2]
y = data[:, 2].reshape(-1,1)
n = x.shape[0]
Q = np.zeros((n+3,n+3))
Q[0,0] = 1
Q[1,1] = 1
Q = matrix(Q,tc = "d")
p = np.ones((n+3,1))
p[0:3,:] = 0
p = matrix(0.05*p,tc = "d")
h = -np.ones((2*n,1))
h[n:2*n,:] = 0
h = matrix(h,tc = "d")
ones = np.ones((n)).reshape(-1,1)
G1 = (-y) * (np.hstack((x,ones)))
G2 = -np.eye((n))
G3 = np.zeros((n,3))
Ga = np.hstack((G1,G2))
Gb = np.hstack((G3,G2))
G = np.vstack((Ga,Gb))
G = matrix(G,tc = "d")
sol = solvers.qp(Q, p, G, h)
#print(sol['x'])
z = sol['x']

# Plot points
x_point = np.linspace(-10,10,200)
y_point = (-z[2]-z[0]* x_point) / z[1]
y_point1 = (1-z[2]-z[0]* x_point) / z[1]
y_point2 = (-1-z[2]-z[0]* x_point) / z[1]
plt.figure(1)
scatter = plt.scatter(x[:,0],x[:,1],c = y)
plt.xlabel("x1")
plt.ylabel("x2")
legend1 = plt.legend(*scatter.legend_elements(),loc="lower left", title="Classes")
plt.plot(x_point,y_point,c = "b")
plt.plot(x_point,y_point1,c = "green",linestyle="-.")
plt.plot(x_point,y_point2,c = "green",linestyle="-.")
plt.ylim(-10,10)
```

Out[15]: (-10.0, 10.0)



In [16]:
```
print("Q matrix:",Q)
print("p matrix:",p)
print("G matrix:",G)
print("h matrix:",h)
```

```
Q matrix: [ 1.00e+00  0.00e+00  0.00e+00  0.00e+00  0.00e+00  0.00e+00  0.00e+00 ... ]
[ 0.00e+00  1.00e+00  0.00e+00  0.00e+00  0.00e+00  0.00e+00  0.00e+00 ... ]
[ 0.00e+00  0.00e+00  0.00e+00  0.00e+00  0.00e+00  0.00e+00  0.00e+00 ... ]
[ 0.00e+00  0.00e+00  0.00e+00  0.00e+00  0.00e+00  0.00e+00  0.00e+00 ... ]
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[ 0.00e+00  0.00e+00  0.00e+00  0.00e+00  0.00e+00  0.00e+00  0.00e+00 ... ]
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[ 0.00e+00  0.00e+00  0.00e+00  0.00e+00  0.00e+00  0.00e+00  0.00e+00 ... ]
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[ 0.00e+00  0.00e+00  0.00e+00  0.00e+00  0.00e+00  0.00e+00  0.00e+00 ... ]
[ 0.00e+00  0.00e+00  0.00e+00  0.00e+00  0.00e+00  0.00e+00  0.00e+00 ... ]
[ 0.00e+00  0.00e+00  0.00e+00  0.00e+00  0.00e+00  0.00e+00  0.00e+00 ... ]
[ 0.00e+00  0.00e+00  0.00e+00  0.00e+00  0.00e+00  0.00e+00  0.00e+00 ... ]
[ 0.00e+00  0.00e+00  0.00e+00  0.00e+00  0.00e+00  0.00e+00  0.00e+00 ... ]
[ 0.00e+00  0.00e+00  0.00e+00  0.00e+00  0.00e+00  0.00e+00  0.00e+00 ... ]
[ 0.00e+00  0.00e+00  0.00e+00  0.00e+00  0.00e+00  0.00e+00  0.00e+00 ... ]
[ 0.00e+00  0.00e+00  0.00e+00  0.00e+00  0.00e+00  0.00e+00  0.00e+00 ... ]
[ 0.00e+00  0.00e+00  0.00e+00  0.00e+00  0.00e+00  0.00e+00  0.00e+00 ... ]
[ 0.00e+00  0.00e+00  0.00e+00  0.00e+00  0.00e+00  0.00e+00  0.00e+00 ... ]
[ 0.00e+00  0.00e+00  0.00e+00  0.00e+00  0.00e+00  0.00e+00  0.00e+00 ... ]
[ 0.00e+00  0.00e+00  0.00e+00  0.00e+00  0.00e+00  0.00e+00  0.00e+00 ... ]
[ 0.00e+00  0.00e+00  0.00e+00  0.00e+00  0.00e+00  0.00e+00  0.00e+00 ... ]
[ 0.00e+00  0.00e+00  0.00e+00  0.00e+00  0.00e+00  0.00e+00  0.00e+00 ... ]
[ 0.00e+00  0.00e+00  0.00e+00  0.00e+00  0.00e+00  0.00e+00  0.00e+00 ... ]
[ 0.00e+00  0.00e+00  0.00e+00  0.00e+00  0.00e+00  0.00e+00  0.00e+00 ... ]
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[ 0.00e+00  0.00e+00  0.00e+00  0.00e+00  0.00e+00  0.00e+00  0.00e+00 ... ]
[ 0.00e+00  0.00e+00  0.00e+00  0.00e+00  0.00e+00  0.00e+00  0.00e+00 ... ]
[ 0.00e+00  0.00e+00  0.00e+00  0.00e+00  0.00e+00  0.00e+00  0.00e+00 ... ]
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[ 0.00e+00  0.00e+00  0.00e+00  0.00e+00  0.00e+00  0.00e+00  0.00e+00 ... ]
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[ 0.00e+00  0.00e+00  0.00e+00  0.00e+00  0.00e+00  0.00e+00  0.00e+00 ... ]
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[ 0.00e+00  0.00e+00  0.00e+00  0.00e+00  0.00e+00  0.00e+00  0.00e+00 ... ]
[ 0.00e+00  0.00e+00  0.00e+00  0.00e+00  0.00e+00  0.00e+00  0.00e+00 ... ]
[ 0.00e+00  0.00e+00  0.00e+00  0.00e+00  0.00e+00  0.00e+00  0.00e+00 ... ]
[ 0.00e+00  0.00e+00  0.00e+00  0.00e+00  0.00e+00  0.00e+00  0.00e+00 ... ]
[ 0.00e+00  0.00e+00  0.00e+00  0.00e+00  0.00e+00  0.00e+00  0.00e+00 ... ]
[ 0.00e+00  0.00e+00  0.00e+00  0.00e+00  0.00e+00  0.00e+00  0.00e+00 ... ]

p matrix: [ 0.00e+00]
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G matrix: [-8.51e+00 -6.31e+00 -1.00e+00 -1.00e+00 -0.00e+00 -0.00e+00 -0.00e+00 ... ]
 [-8.24e+00 -5.02e+00 -1.00e+00 -0.00e+00 -1.00e+00 -0.00e+00 -0.00e+00 ... ]
 [-6.99e+00 -4.96e+00 -1.00e+00 -0.00e+00 -0.00e+00 -1.00e+00 -0.00e+00 ... ]
 [-5.61e+00 -2.57e+00 -1.00e+00 -0.00e+00 -0.00e+00 -0.00e+00 -1.00e+00 ... ]
 [-4.60e+00 -2.34e+00 -1.00e+00 -0.00e+00 -0.00e+00 -0.00e+00 -0.00e+00 ... ]
 [-3.49e+00 -3.45e+00 -1.00e+00 -0.00e+00 -0.00e+00 -0.00e+00 -0.00e+00 ... ]
 [-1.32e+00 -3.45e+00 -1.00e+00 -0.00e+00 -0.00e+00 -0.00e+00 -0.00e+00 ... ]
 [ 1.30e+00 -1.93e+00 -1.00e+00 -0.00e+00 -0.00e+00 -0.00e+00 -0.00e+00 ... ]
 [ 3.15e+00 -2.92e+00 -1.00e+00 -0.00e+00 -0.00e+00 -0.00e+00 -0.00e+00 ... ]
 [ 3.84e+00  1.75e-01 -1.00e+00 -0.00e+00 -0.00e+00 -0.00e+00 -0.00e+00 ... ]
 [ 3.28e+00  2.04e+00 -1.00e+00 -0.00e+00 -0.00e+00 -0.00e+00 -0.00e+00 ... ]
 [ 1.26e+00  8.18e-01 -1.00e+00 -0.00e+00 -0.00e+00 -0.00e+00 -0.00e+00 ... ]
 [-2.19e-01 -1.75e-01 -1.00e+00 -0.00e+00 -0.00e+00 -0.00e+00 -0.00e+00 ... ]
 [-1.37e+00 -2.04e+00 -1.00e+00 -0.00e+00 -0.00e+00 -0.00e+00 -0.00e+00 ... ]
 [ 4.48e+00  4.67e-01 -1.00e+00 -0.00e+00 -0.00e+00 -0.00e+00 -0.00e+00 ... ]
 [ 7.62e+00  5.84e-02 -1.00e+00 -0.00e+00 -0.00e+00 -0.00e+00 -0.00e+00 ... ]
 [ 7.85e+00  2.92e+00 -1.00e+00 -0.00e+00 -0.00e+00 -0.00e+00 -0.00e+00 ... ]
 [ 7.11e+00  6.31e+00 -1.00e+00 -0.00e+00 -0.00e+00 -0.00e+00 -0.00e+00 ... ]
 [ 6.79e+00  7.88e+00 -1.00e+00 -0.00e+00 -0.00e+00 -0.00e+00 -0.00e+00 ... ]
 [ 5.03e+00  6.77e+00 -1.00e+00 -0.00e+00 -0.00e+00 -0.00e+00 -0.00e+00 ... ]
 [ 2.55e+00  5.84e+00 -1.00e+00 -0.00e+00 -0.00e+00 -0.00e+00 -0.00e+00 ... ]
 [ 3.24e+00  3.27e+00 -1.00e+00 -0.00e+00 -0.00e+00 -0.00e+00 -0.00e+00 ... ]
 [ 1.21e+00  1.64e+00 -1.00e+00 -0.00e+00 -0.00e+00 -0.00e+00 -0.00e+00 ... ]
 [-3.11e-01  3.15e+00 -1.00e+00 -0.00e+00 -0.00e+00 -0.00e+00 -0.00e+00 ... ]
 [-2.25e+00 -2.92e-01 -1.00e+00 -0.00e+00 -0.00e+00 -0.00e+00 -0.00e+00 ... ]
 [-5.33e+00 -7.01e-01 -1.00e+00 -0.00e+00 -0.00e+00 -0.00e+00 -0.00e+00 ... ]
 [-3.91e+00 -6.19e+00 -1.00e+00 -0.00e+00 -0.00e+00 -0.00e+00 -0.00e+00 ... ]
 [ 2.88e-01 -8.00e+00 -1.00e+00 -0.00e+00 -0.00e+00 -0.00e+00 -0.00e+00 ... ]
 [ 2.59e+00 -6.77e+00 -1.00e+00 -0.00e+00 -0.00e+00 -0.00e+00 -0.00e+00 ... ]
 [ 7.02e+00 -8.06e+00 -1.00e+00 -0.00e+00 -0.00e+00 -0.00e+00 -0.00e+00 ... ]
 [ 7.66e+00 -8.70e+00 -1.00e+00 -0.00e+00 -0.00e+00 -0.00e+00 -0.00e+00 ... ]
 [ 8.86e+00 -6.01e+00 -1.00e+00 -0.00e+00 -0.00e+00 -0.00e+00 -0.00e+00 ... ]
 [ 8.26e+00 -3.39e+00 -1.00e+00 -0.00e+00 -0.00e+00 -0.00e+00 -0.00e+00 ... ]
 [ 5.36e+00 -4.32e+00 -1.00e+00 -0.00e+00 -0.00e+00 -0.00e+00 -0.00e+00 ... ]
 [ 7.20e+00 -1.46e+00 -1.00e+00 -0.00e+00 -0.00e+00 -0.00e+00 -0.00e+00 ... ]
 [ 6.51e+00 -4.55e+00 -1.00e+00 -0.00e+00 -0.00e+00 -0.00e+00 -0.00e+00 ... ]
 [ 3.84e+00 -5.31e+00 -1.00e+00 -0.00e+00 -0.00e+00 -0.00e+00 -0.00e+00 ... ]
 [ 8.87e-01 -3.91e+00 -1.00e+00 -0.00e+00 -0.00e+00 -0.00e+00 -0.00e+00 ... ]
 [-1.42e+00 -3.85e+00 -1.00e+00 -0.00e+00 -0.00e+00 -0.00e+00 -0.00e+00 ... ]
 [-2.80e+00 -4.61e+00 -1.00e+00 -0.00e+00 -0.00e+00 -0.00e+00 -0.00e+00 ... ]
 [-4.92e+00 -6.60e+00 -1.00e+00 -0.00e+00 -0.00e+00 -0.00e+00 -0.00e+00 ... ]
 [-5.79e+00 -7.42e+00 -1.00e+00 -0.00e+00 -0.00e+00 -0.00e+00 -0.00e+00 ... ]
 [-7.64e+00 -7.94e+00 -1.00e+00 -0.00e+00 -0.00e+00 -0.00e+00 -0.00e+00 ... ]
 [-5.43e+00 -5.02e+00 -1.00e+00 -0.00e+00 -0.00e+00 -0.00e+00 -0.00e+00 ... ]
 [-1.27e-01  8.18e-01 -1.00e+00 -0.00e+00 -0.00e+00 -0.00e+00 -0.00e+00 ... ]
 [-1.23e+00  1.46e+00 -1.00e+00 -0.00e+00 -0.00e+00 -0.00e+00 -0.00e+00 ... ]
 [-3.03e+00  1.64e+00 -1.00e+00 -0.00e+00 -0.00e+00 -0.00e+00 -0.00e+00 ... ]
 [ 7.49e-01  2.04e+00 -1.00e+00 -0.00e+00 -0.00e+00 -0.00e+00 -0.00e+00 ... ]
 [ 2.32e+00  4.15e+00 -1.00e+00 -0.00e+00 -0.00e+00 -0.00e+00 -0.00e+00 ... ]
 [ 1.76e+00  5.61e+00 -1.00e+00 -0.00e+00 -0.00e+00 -0.00e+00 -0.00e+00 ... ]
 [ 1.58e+00  6.77e+00 -1.00e+00 -0.00e+00 -0.00e+00 -0.00e+00 -0.00e+00 ... ]
 [ 2.13e+00  8.64e+00 -1.00e+00 -0.00e+00 -0.00e+00 -0.00e+00 -0.00e+00 ... ]
 [ 3.65e+00  8.82e+00 -1.00e+00 -0.00e+00 -0.00e+00 -0.00e+00 -0.00e+00 ... ]
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 [ 7.95e-01  8.82e+00 -1.00e+00 -0.00e+00 -0.00e+00 -0.00e+00 -0.00e+00 ... ]
 [-2.19e-01  8.47e+00 -1.00e+00 -0.00e+00 -0.00e+00 -0.00e+00 -0.00e+00 ... ]
 [ 3.93e+00  8.00e+00 -1.00e+00 -0.00e+00 -0.00e+00 -0.00e+00 -0.00e+00 ... ]
 [ 5.82e+00  5.26e+00 -1.00e+00 -0.00e+00 -0.00e+00 -0.00e+00 -0.00e+00 ... ]
 [ 3.56e+00 -3.09e+00 -1.00e+00 -0.00e+00 -0.00e+00 -0.00e+00 -0.00e+00 ... ]
 [-6.80e-01 -6.13e+00 -1.00e+00 -0.00e+00 -0.00e+00 -0.00e+00 -0.00e+00 ... ]
 [ 2.88e-01 -2.57e+00 -1.00e+00 -0.00e+00 -0.00e+00 -0.00e+00 -0.00e+00 ... ]
 [-4.80e+00 -9.23e+00  1.00e+00 -0.00e+00 -0.00e+00 -0.00e+00 -0.00e+00 ... ]
 [-4.16e+00 -6.72e+00  1.00e+00 -0.00e+00 -0.00e+00 -0.00e+00 -0.00e+00 ... ]
 [-3.65e+00 -5.14e+00  1.00e+00 -0.00e+00 -0.00e+00 -0.00e+00 -0.00e+00 ... ]
 [-2.41e+00 -4.44e+00  1.00e+00 -0.00e+00 -0.00e+00 -0.00e+00 -0.00e+00 ... ]
 [-1.39e+00 -2.63e+00  1.00e+00 -0.00e+00 -0.00e+00 -0.00e+00 -0.00e+00 ... ]
 [ 2.19e-01 -1.17e+00  1.00e+00 -0.00e+00 -0.00e+00 -0.00e+00 -0.00e+00 ... ]
 [ 7.72e-01  3.50e-01  1.00e+00 -0.00e+00 -0.00e+00 -0.00e+00 -0.00e+00 ... ]
 [ 1.74e+00  1.93e+00  1.00e+00 -0.00e+00 -0.00e+00 -0.00e+00 -0.00e+00 ... ]
 [ 3.35e+00  2.28e+00  1.00e+00 -0.00e+00 -0.00e+00 -0.00e+00 -0.00e+00 ... ]
 [ 5.47e+00  3.33e+00  1.00e+00 -0.00e+00 -0.00e+00 -0.00e+00 -0.00e+00 ... ]
 [ 8.24e+00  4.44e+00  1.00e+00 -0.00e+00 -0.00e+00 -0.00e+00 -0.00e+00 ... ]
 [ 6.26e+00  1.69e+00  1.00e+00 -0.00e+00 -0.00e+00 -0.00e+00 -0.00e+00 ... ]
 [ 4.04e+00  1.17e+00  1.00e+00 -0.00e+00 -0.00e+00 -0.00e+00 -0.00e+00 ... ]
 [ 6.30e+00 -7.82e+00  1.00e+00 -0.00e+00 -0.00e+00 -0.00e+00 -0.00e+00 ... ]
 [ 7.41e+00 -7.94e+00  1.00e+00 -0.00e+00 -0.00e+00 -0.00e+00 -0.00e+00 ... ]
 [ 7.55e+00 -5.02e+00  1.00e+00 -0.00e+00 -0.00e+00 -0.00e+00 -0.00e+00 ... ]
 [ 8.33e+00 -6.54e+00  1.00e+00 -0.00e+00 -0.00e+00 -0.00e+00 -0.00e+00 ... ]
 [ 8.38e+00 -7.82e+00  1.00e+00 -0.00e+00 -0.00e+00 -0.00e+00 -0.00e+00 ... ]
 [ 9.21e+00 -6.37e+00  1.00e+00 -0.00e+00 -0.00e+00 -0.00e+00 -0.00e+00 ... ]
 [ 9.07e+00 -8.23e+00  1.00e+00 -0.00e+00 -0.00e+00 -0.00e+00 -0.00e+00 ... ]
 [ 6.44e+00 -8.82e+00  1.00e+00 -0.00e+00 -0.00e+00 -0.00e+00 -0.00e+00 ... ]
 [ 2.98e+00 -9.58e+00  1.00e+00 -0.00e+00 -0.00e+00 -0.00e+00 -0.00e+00 ... ]
 [ 2.38e+00 -8.00e+00  1.00e+00 -0.00e+00 -0.00e+00 -0.00e+00 -0.00e+00 ... ]
 [ 3.68e+00 -6.95e+00  1.00e+00 -0.00e+00 -0.00e+00 -0.00e+00 -0.00e+00 ... ]
 [ 6.26e+00 -2.69e+00  1.00e+00 -0.00e+00 -0.00e+00 -0.00e+00 -0.00e+00 ... ]
 [ 6.90e+00  5.84e-02  1.00e+00 -0.00e+00 -0.00e+00 -0.00e+00 -0.00e+00 ... ]
 [ 7.91e+00  2.63e+00  1.00e+00 -0.00e+00 -0.00e+00 -0.00e+00 -0.00e+00 ... ]
 [ 8.15e+00  4.55e+00  1.00e+00 -0.00e+00 -0.00e+00 -0.00e+00 -0.00e+00 ... ]
 [ 7.68e+00  5.49e+00  1.00e+00 -0.00e+00 -0.00e+00 -0.00e+00 -0.00e+00 ... ]
 [ 5.89e+00  5.14e+00  1.00e+00 -0.00e+00 -0.00e+00 -0.00e+00 -0.00e+00 ... ]
 [-1.03e+00 -2.92e-01  1.00e+00 -0.00e+00 -0.00e+00 -0.00e+00 -0.00e+00 ... ]
 [ 2.52e+00 -3.85e+00  1.00e+00 -0.00e+00 -0.00e+00 -0.00e+00 -0.00e+00 ... ]
 [ 4.32e+00 -6.25e+00  1.00e+00 -0.00e+00 -0.00e+00 -0.00e+00 -0.00e+00 ... ]
 [ 6.95e+00 -6.66e+00  1.00e+00 -0.00e+00 -0.00e+00 -0.00e+00 -0.00e+00 ... ]
 [ 7.64e+00 -4.38e+00  1.00e+00 -0.00e+00 -0.00e+00 -0.00e+00 -0.00e+00 ... ]
 [ 8.15e+00 -4.55e+00  1.00e+00 -0.00e+00 -0.00e+00 -0.00e+00 -0.00e+00 ... ]
 [ 8.42e+00 -2.16e+00  1.00e+00 -0.00e+00 -0.00e+00 -0.00e+00 -0.00e+00 ... ]
 [ 8.88e+00 -5.20e+00  1.00e+00 -0.00e+00 -0.00e+00 -0.00e+00 -0.00e+00 ... ]
 [ 7.59e+00 -9.52e+00  1.00e+00 -0.00e+00 -0.00e+00 -0.00e+00 -0.00e+00 ... ]
 [ 2.98e+00 -9.17e+00  1.00e+00 -0.00e+00 -0.00e+00 -0.00e+00 -0.00e+00 ... ]
 [ 1.28e+00 -9.28e+00  1.00e+00 -0.00e+00 -0.00e+00 -0.00e+00 -0.00e+00 ... ]
 [-2.42e-01 -8.93e+00  1.00e+00 -0.00e+00 -0.00e+00 -0.00e+00 -0.00e+00 ... ]
 [ 3.58e+00 -8.18e+00  1.00e+00 -0.00e+00 -0.00e+00 -0.00e+00 -0.00e+00 ... ]
 [ 4.78e+00 -8.23e+00  1.00e+00 -0.00e+00 -0.00e+00 -0.00e+00 -0.00e+00 ... ]
 [ 5.93e+00 -8.35e+00  1.00e+00 -0.00e+00 -0.00e+00 -0.00e+00 -0.00e+00 ... ]
 [ 8.05e+00 -8.64e+00  1.00e+00 -0.00e+00 -0.00e+00 -0.00e+00 -0.00e+00 ... ]
 [ 9.11e+00 -9.17e+00  1.00e+00 -0.00e+00 -0.00e+00 -0.00e+00 -0.00e+00 ... ]
 [ 9.30e+00 -1.81e+00  1.00e+00 -0.00e+00 -0.00e+00 -0.00e+00 -0.00e+00 ... ]
 [ 5.79e+00 -3.85e+00  1.00e+00 -0.00e+00 -0.00e+00 -0.00e+00 -0.00e+00 ... ]
 [ 6.53e+00 -5.31e+00  1.00e+00 -0.00e+00 -0.00e+00 -0.00e+00 -0.00e+00 ... ]
 [ 7.27e+00 -5.66e+00  1.00e+00 -0.00e+00 -0.00e+00 -0.00e+00 -0.00e+00 ... ]
 [ 0.00e+00  0.00e+00  0.00e+00 -1.00e+00 -0.00e+00 -0.00e+00 -0.00e+00 ... ]
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c): Output 4 plots & Explain your observations here:

In [263…

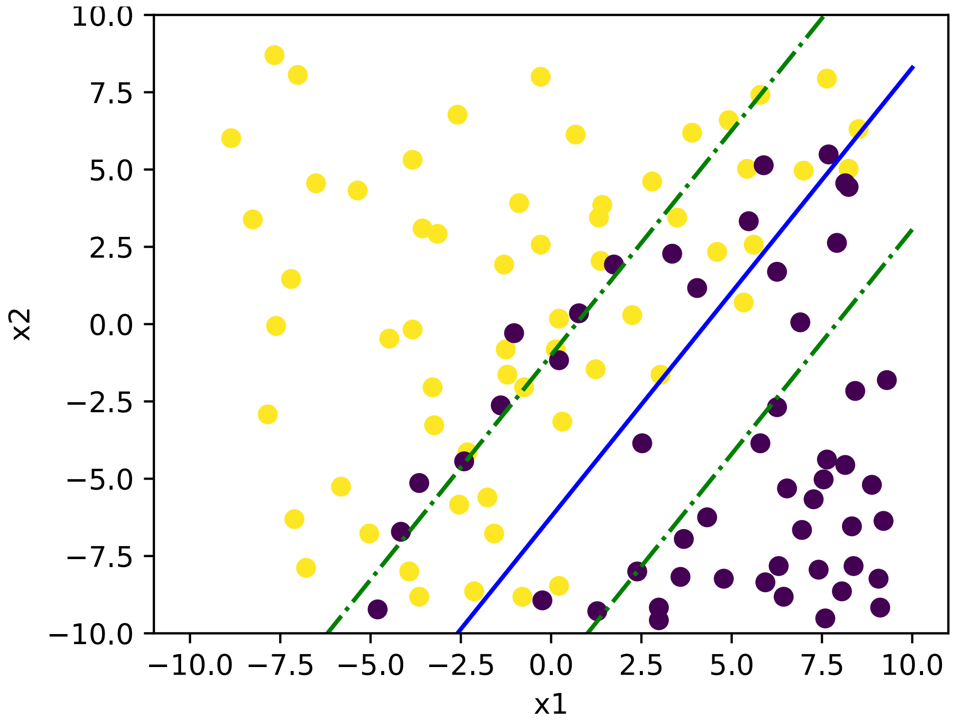
```python
def svm(data,C):
    x = data[:, 0:2]
    y = data[:, 2].reshape(-1,1)
    n = x.shape[0]
    Q = np.zeros((n+3,n+3))
    Q[0,0] = 1
    Q[1,1] = 1
    Q = matrix(Q,tc = "d")
    p = np.ones((n+3,1))
    p[0:3,:] = 0
    p = matrix(C*p,tc = "d")
    h = -np.ones((2*n,1))
    h[n:2*n,:] = 0
    h = matrix(h,tc = "d")
    ones = np.ones((n)).reshape(-1,1)
    G1 = (-y) * (np.hstack((x,ones)))
    G2 = -np.eye((n))
    G3 = np.zeros((n,3))
    Ga = np.hstack((G1,G2))
    Gb = np.hstack((G3,G2))
    G = np.vstack((Ga,Gb))
    G = matrix(G,tc = "d")
    sol = solvers.qp(Q, p, G, h)
    #print(sol['x'])
    z = sol['x']

    # Plot points
    x_point = np.linspace(-10,10,200)
    y_point = (-z[2]-z[0]* x_point) / z[1]
    y_point1 = (1-z[2]-z[0]* x_point) / z[1]
    y_point2 = (-1-z[2]-z[0]* x_point) / z[1]
    f, ax = plt.subplots(figsize=(5,4))
    ax.scatter(x[:,0],x[:,1],c = y)
    ax.set_xlabel("x1")
    ax.set_ylabel("x2")
    #legend1 = plt.legend(*scatter.legend_elements(),loc="upper right", title="Classes")
    ax.plot(x_point,y_point,c = "b")
    ax.plot(x_point,y_point1,c = "green",linestyle="-.")
    ax.plot(x_point,y_point2,c = "green",linestyle="-.")
    ax.set_ylim(-10,10)
    ax.set_title(f"c = {C}")
    return f
```

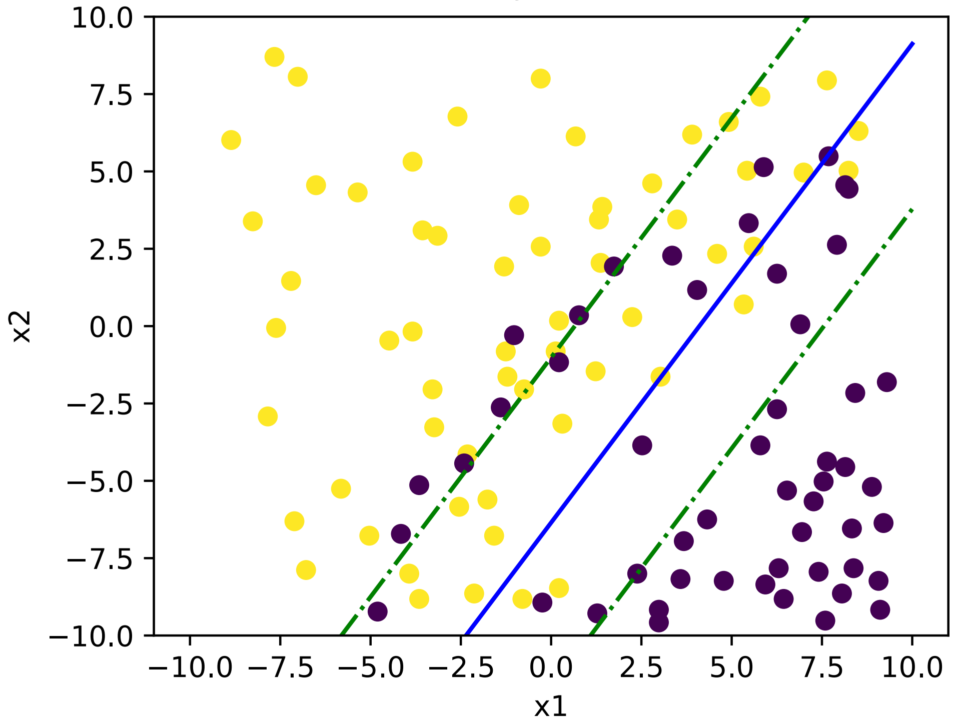
In [264…

```python
fig1 = svm(data,0.1)
fig2 = svm(data,1)
fig3 = svm(data,100)
fig4 = svm(data,1000000)
```

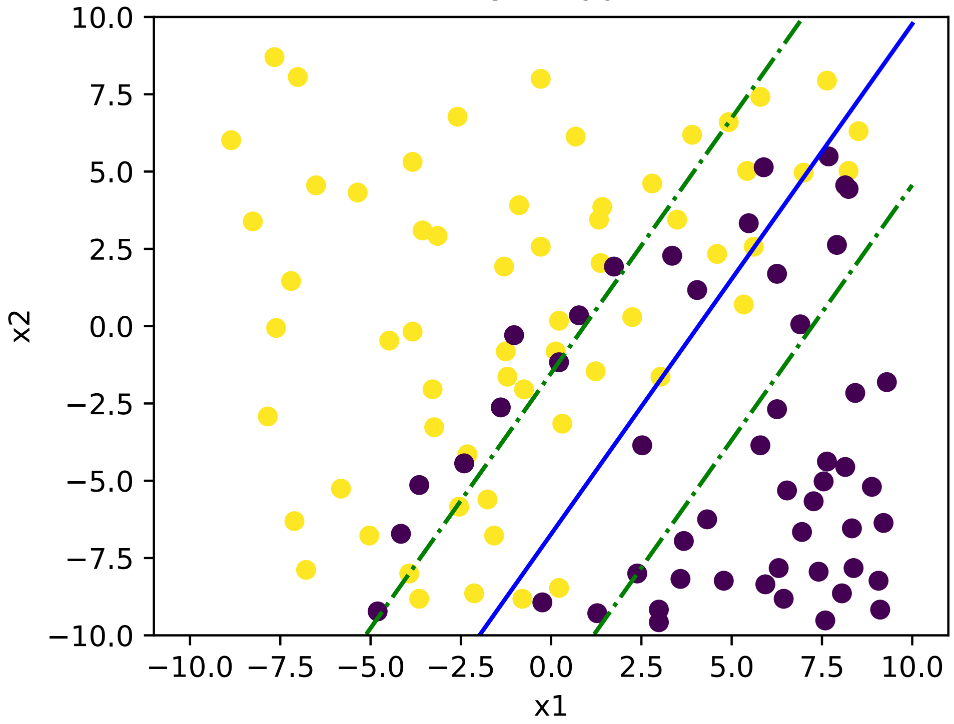
c = 0.1

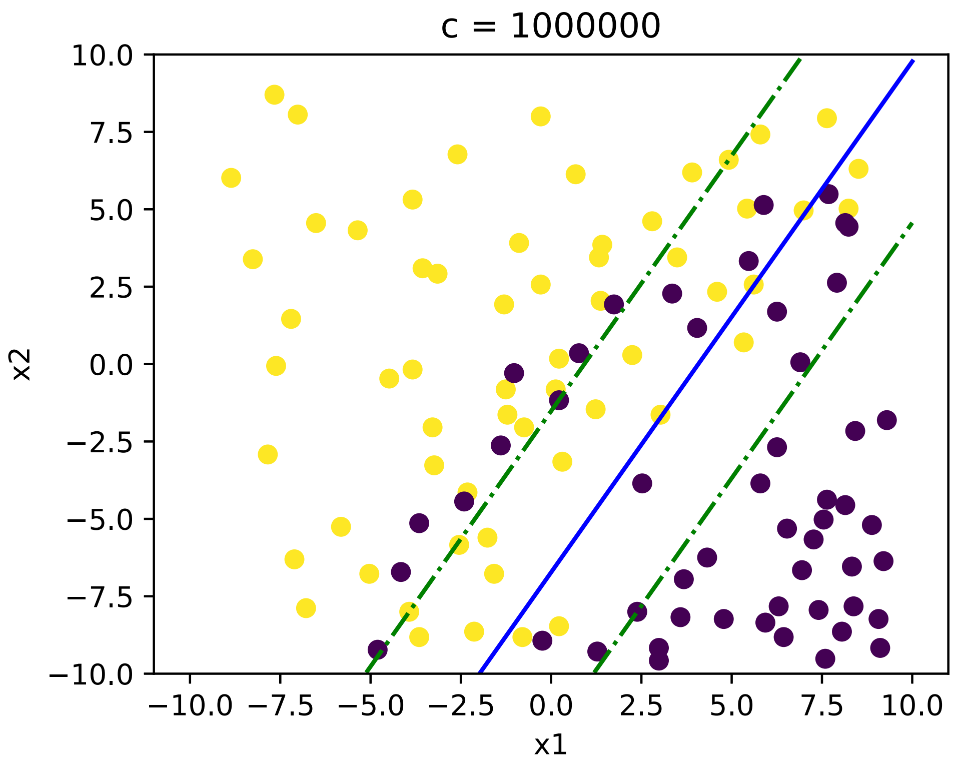


c = 1



c = 100





I think there are not huge differences between these four figures. Generally, with the increase of C, the constraints are harder to satisfy,the width between margins will become more narrow. However, this is a linearly non-separable case, no matter how hard the constraints are, these classes cannot be linearly separate, which means there aren't big differences between different C values.

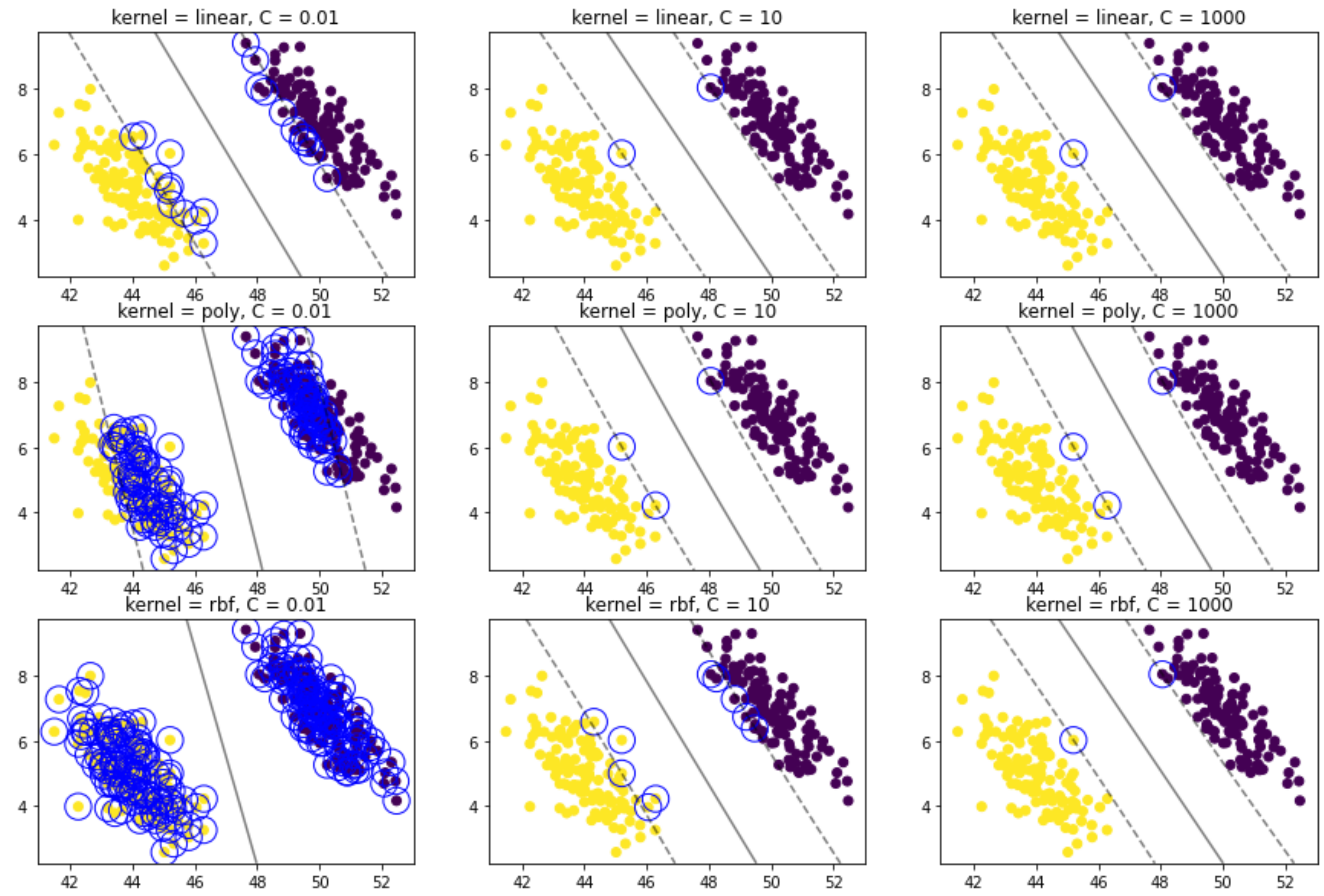
Problem 2: Support Vector Machine Experiments with sklearn

(a)

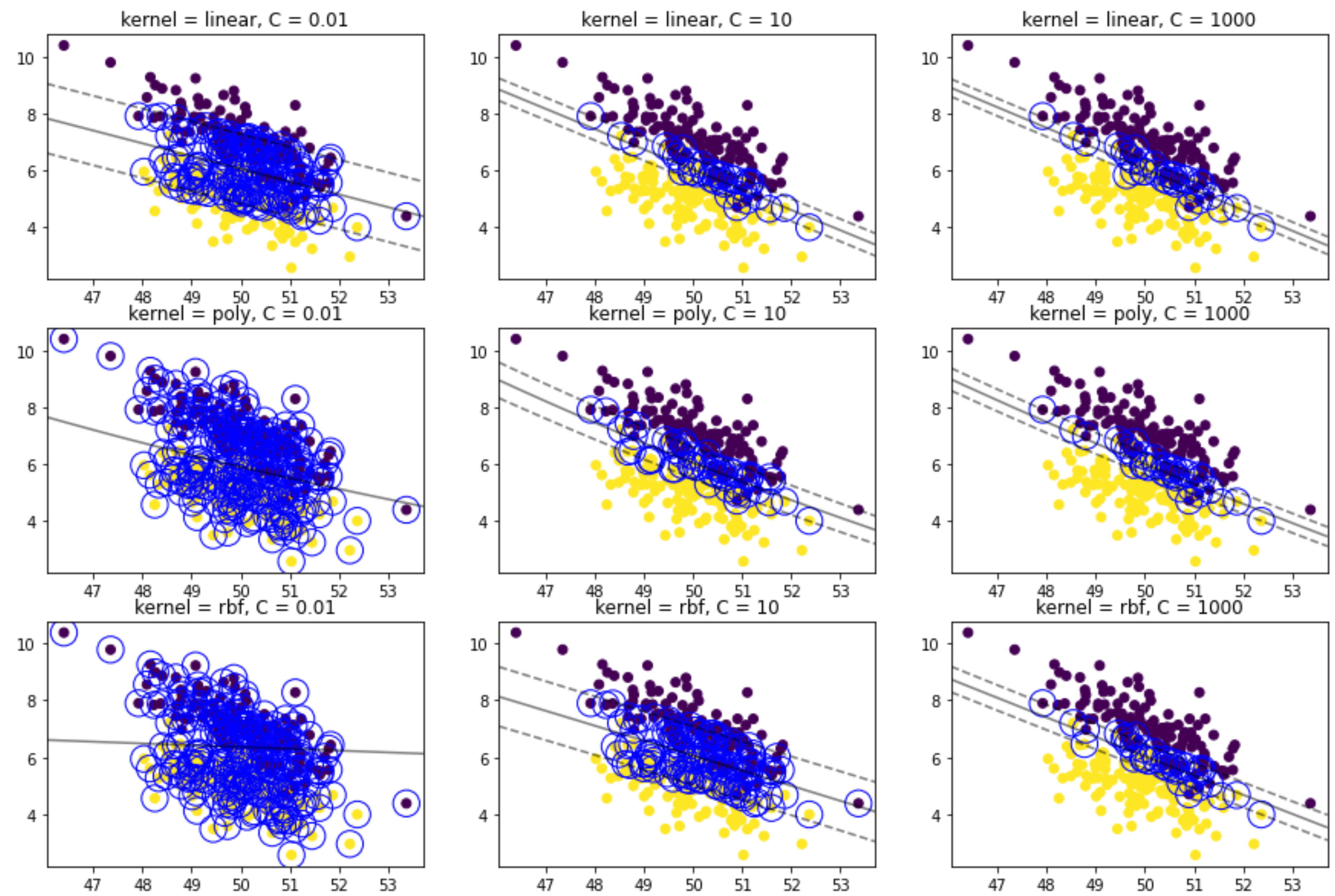
In [1]:
```
from sklearn.svm import SVC
from plot_svc_decision_function import plot_svc_decision_function
```

In [3]:
```
def svm(data):
    data = np.loadtxt(data)
    x = data[:, 0:2]
    y = data[:, 2]
    fig, axs = plt.subplots(3,3,figsize = (15,10))
    kernel = ["linear","poly","rbf"]
    C = [0.01,10,1000]
    for i in range(3):
        for j in range(3):
            model = SVC(kernel = kernel[i],C = C[j])
            model.fit(x,y)
            axs[i,j].scatter(x[:,0],x[:,1],c = y)
            axs[i,j].set_title(f"kernel = {kernel[i]}, C = {C[j]}")
            plot_svc_decision_function(model,axs[i,j])
```

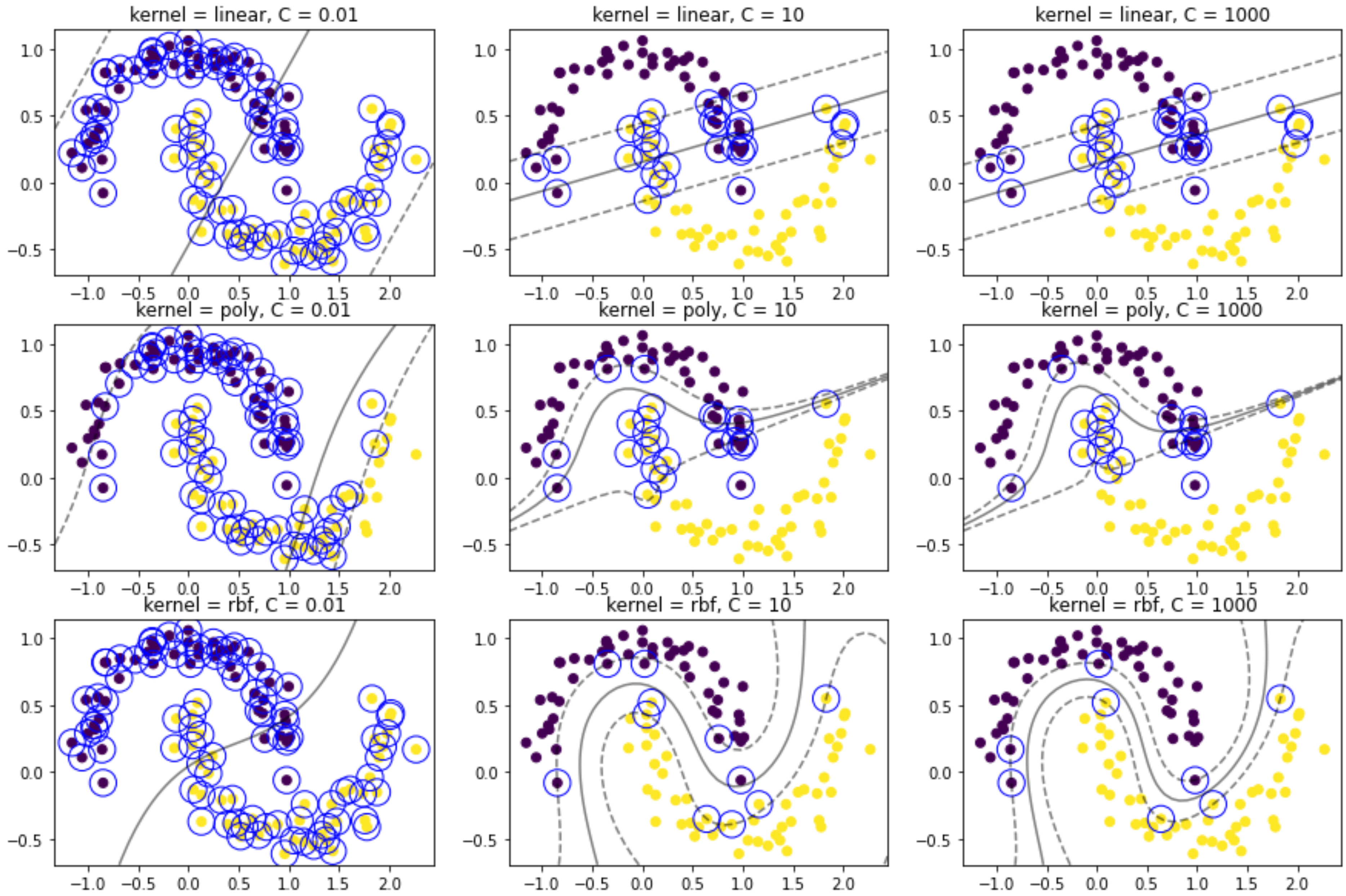
In [4]:
```
svm('binary_linsep_yes_n240.txt')
```



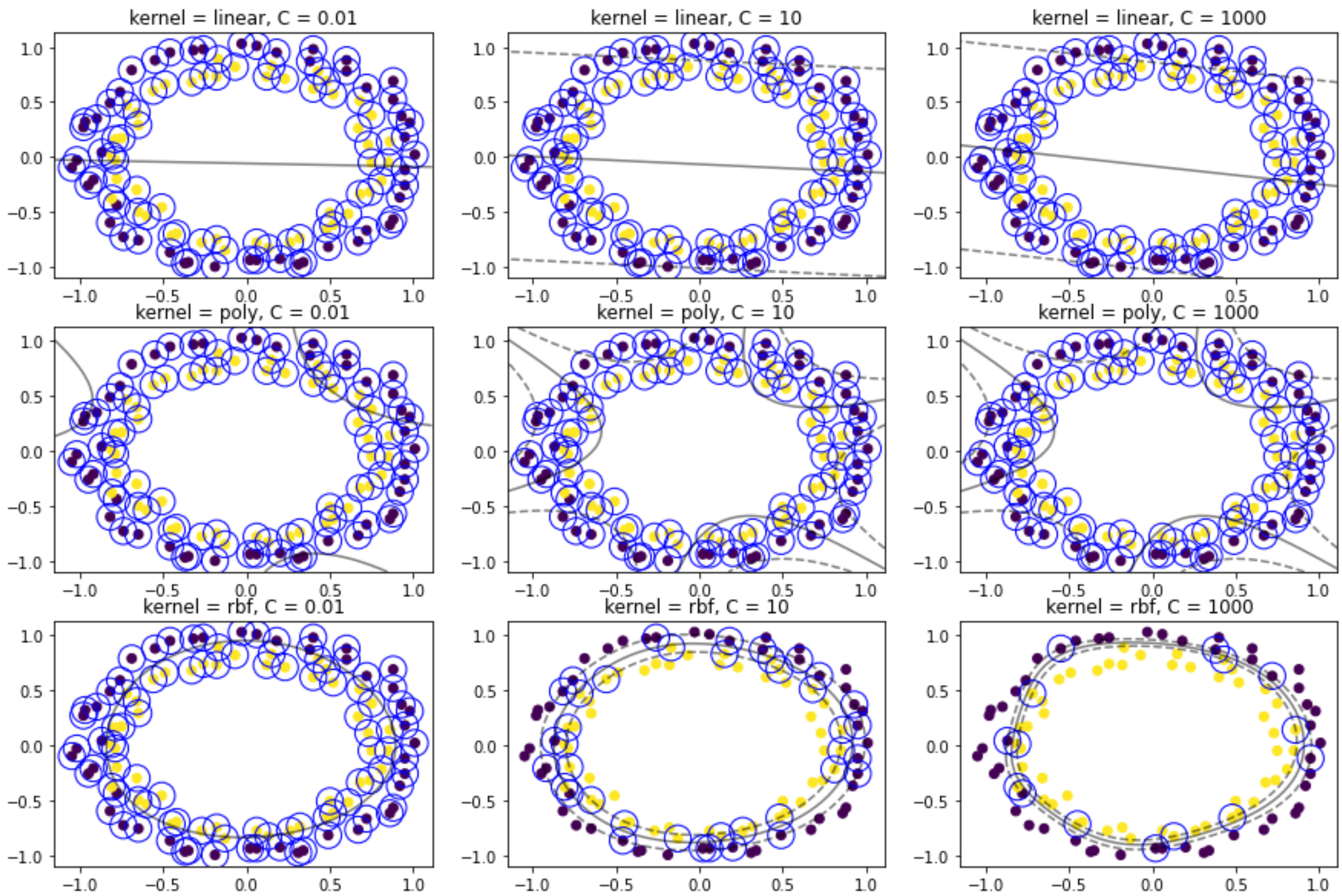
In [5]:
```
svm('binary_linsep_no_n240.txt')
```



In [6]:
```
svm('binary_moons_linsep_no_n100.txt')
```



In [7]:
```
svm('concentriccircles_binary.txt')
```



In [8]:
```
data = np.loadtxt('binary_moons_linsep_no_n100.txt')
x = data[:, 0:2]
y = data[:, 2]
model = SVC(kernel = "rbf",C = 1000)
model.fit(x,y)
model.support_vectors_
```

Out[8]:
```
array([[-0.86,  0.17],
       [ 0.02,  0.81],
       [ 0.98, -0.06],
       [-0.85, -0.08],
       [ 0.64, -0.35],
       [ 0.09,  0.52],
       [ 1.83,  0.55],
       [ 1.16, -0.24]])
```

(b)

Kernel:

for the first datasets, linear kernel is better because it takes less time.

for the second datasets, three types of kernel can't linearly separate the datasets. Therefore, I think the simple one is better.

for the third and fourth datasets, RBF did better.

Conclusion: I think we should choose different kernel according to different datasets.

C value:

The larger the C, the greater punishment SVM receives when it commits a misclassification. As a result, the decision boundary will rely on fewer support vectors as the margin becomes narrower.

Moons dataset

I think the model with 5 support vectors is better. Because these two models have identical classification accurary, more support vectors means it's more expensive to train model. Therefore, less support vectors model is better.

Problem 3: Support Vector Regression

(a)

In [246…
```
from sklearn.svm import SVR
data = np.loadtxt('train.txt')
test = np.loadtxt("test.txt")
x = data[:, 0:2]
y = data[:, 2]
test_x = test[:,0:2]
test_y = test[:,2]
mu_x = np.mean(x,axis = 0)
std_x = np.std(x,axis = 0)
x_new = (x - mu_x)/std_x
test_new = (test_x - mu_x)/std_x
model = SVR(kernel = "rbf",C = 1, epsilon = 0.0001)
model.fit(x_new,y)
y_pred = model.predict(test_new)
rmse = np.sqrt(np.mean((y_pred.reshape(-1,1)-test_y.reshape(-1,1))**2,axis = 0))
rmse
```

Out[246…
```
array([24.03386007])
```

(b)

In [236…
```
def svr(C,epsilon):
    model = SVR(kernel = "rbf",C = C, epsilon = epsilon)
    model.fit(x_new,y)
    y_pred = model.predict(test_new)
    rmse = np.sqrt(np.mean((y_pred.reshape(-1,1)-test_y.reshape(-1,1))**2,axis = 0))
    return rmse
```

In [242…
```
print("C = 0.01, epsilon = 0.0001, RMSE = ",svr(0.01,0.0001))
print("C = 0.01, epsilon = 0.01, RMSE = ",svr(0.01,0.01))
print("C = 0.01, epsilon = 1, RMSE = ",svr(0.01,1))
print("C = 10, epsilon = 0.0001, RMSE = ",svr(10,0.0001))
print("C = 10, epsilon = 0.01, RMSE = ",svr(10,0.01))
print("C = 10, epsilon = 1, RMSE = ",svr(10,1))
print("C = 100, epsilon = 0.0001, RMSE = ",svr(100,0.0001))
print("C = 100, epsilon = 0.01, RMSE = ",svr(100,0.01))
print("C = 100, epsilon = 1, RMSE = ",svr(100,1))
```

```
C = 0.01, epsilon = 0.0001, RMSE =  [49.86230822]
C = 0.01, epsilon = 0.01, RMSE =  [49.86230822]
C = 0.01, epsilon = 1, RMSE =  [49.71919847]
C = 10, epsilon = 0.0001, RMSE =  [7.2066139]
C = 10, epsilon = 0.01, RMSE =  [7.20308351]
C = 10, epsilon = 1, RMSE =  [7.19590857]
C = 100, epsilon = 0.0001, RMSE =  [4.35615181]
C = 100, epsilon = 0.01, RMSE =  [4.35497666]
C = 100, epsilon = 1, RMSE =  [4.18971781]
```

C value

From these number, I can figure out when C becomes bigger, RMSE will decrease. But this doesn't mean that bigger C is better. When C is too big, the model might be overfitted.

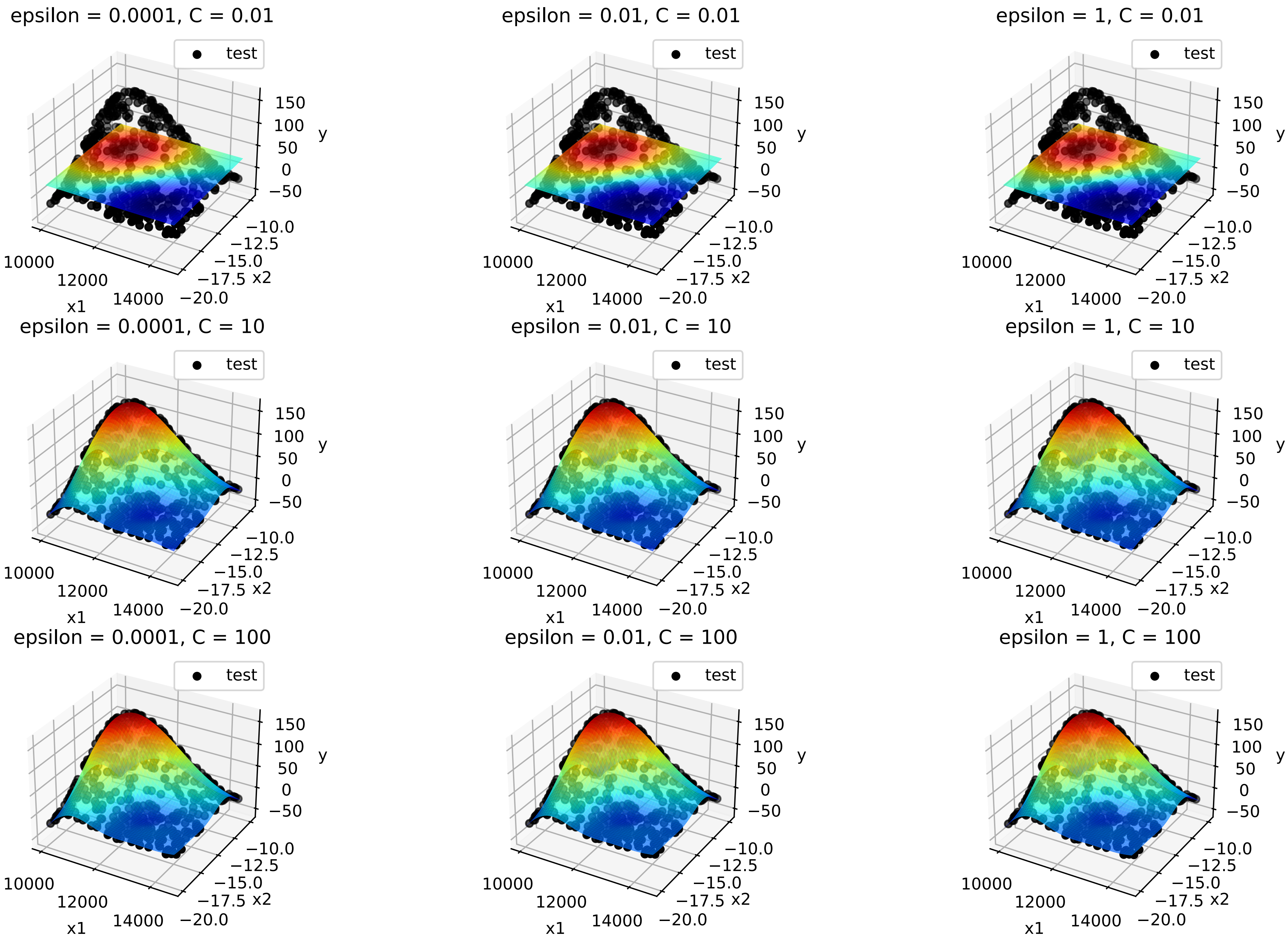
Epsilon

The value of epsilon defines a margin of tolerance where no penalty is given to errors. From numbers above, I can see there is no huge difference between the models which have the same C value.

(c)

In [256…
```
#from mpl_toolkits.mplot3d import Axes3D
x1 = np.linspace(np.min(test_x[:,0]),np.max(test_x[:,0]),100)
x2 = np.linspace(np.min(test_x[:,1]),np.max(test_x[:,1]),100)
x1_new, x2_new = np.meshgrid(x1,x2)
std_x1 = ((x1_new.ravel()).reshape(-1,1)-mu_x[0])/std_x[0]
std_x2 = ((x2_new.ravel()).reshape(-1,1)-mu_x[1])/std_x[1]
X_new = np.hstack((std_x1,std_x2))
```

In [255…
```
fig = plt.figure(figsize=(15,10))
epsilon = [0.0001,0.01,1]
C = [0.01,10,100]
for i in range(3):
    for j in range(3):
        model = SVR(kernel = "rbf",C = C[i], epsilon = epsilon[j])
        model.fit(x_new,y)
        y_pred = model.predict(X_new)
        #axs[i,j] = Axes3D(fig)
        ax = fig.add_subplot(3,3,3*i+j+1, projection='3d')
        ax.scatter(test_x[:,0].reshape(-1,1),test_x[:,1].reshape(-1,1),test_y.reshape(-1,1),c='black',label="test"
        ax.plot_surface(x1_new,x2_new,y_pred.reshape(x1_new.shape),cmap='jet',alpha = 0.7)
        ax.set(xlabel="x1",ylabel="x2",zlabel="y")
        ax.legend()
        ax.set_title(f"epsilon = {epsilon[j]}, C = {C[i]}")
```


epsilon = 0.0001, C = 0.01
epsilon = 0.01, C = 0.01
epsilon = 1, C = 0.01
epsilon = 0.0001, C = 10
epsilon = 0.01, C = 10
epsilon = 1, C = 10
epsilon = 0.0001, C = 100
epsilon = 0.01, C = 100
epsilon = 1, C = 100
test
150
100
50
0
−50
y
−10.0
−12.5
−15.0
−17.5
−20.0
x2
10000
12000
14000
x1

```
In [ ]:
```