In [13]:

```
########################################
### Name : Md Ziauddin Ridoy ###########
### Matriculation : 220100676 ####################
```

In [8]:

```
%matplotlib inline
import matplotlib.pylab as plt
import numpy as np
from matplotlib.ticker import MaxNLocator
from itertools import product
```

In [33]:

```
def Rosenbrock_f(x,y):
    return (1 - x)**2 + 100*(y - x**2)**2

def Grad_Rosenbrock_f(x,y):
    g1 = -400*x*y + 400*x**3 + 2*x -2
    g2 = 200*y -200*x**2
    return np.array([g1,g2])

def Hessian_Rosenbrock_f(x,y):
    h11 = -400*y + 1200*x**2 + 2
    h12 = -400 * x
    h21 = -400 * x
    h22 = 200
    return np.array([[h11,h12],[h21,h22]])
```

In [9]:

```
def Rosenbrock(X):
    x, y = X
    return (1 - x)**2 + 100*(y - x**2)**2

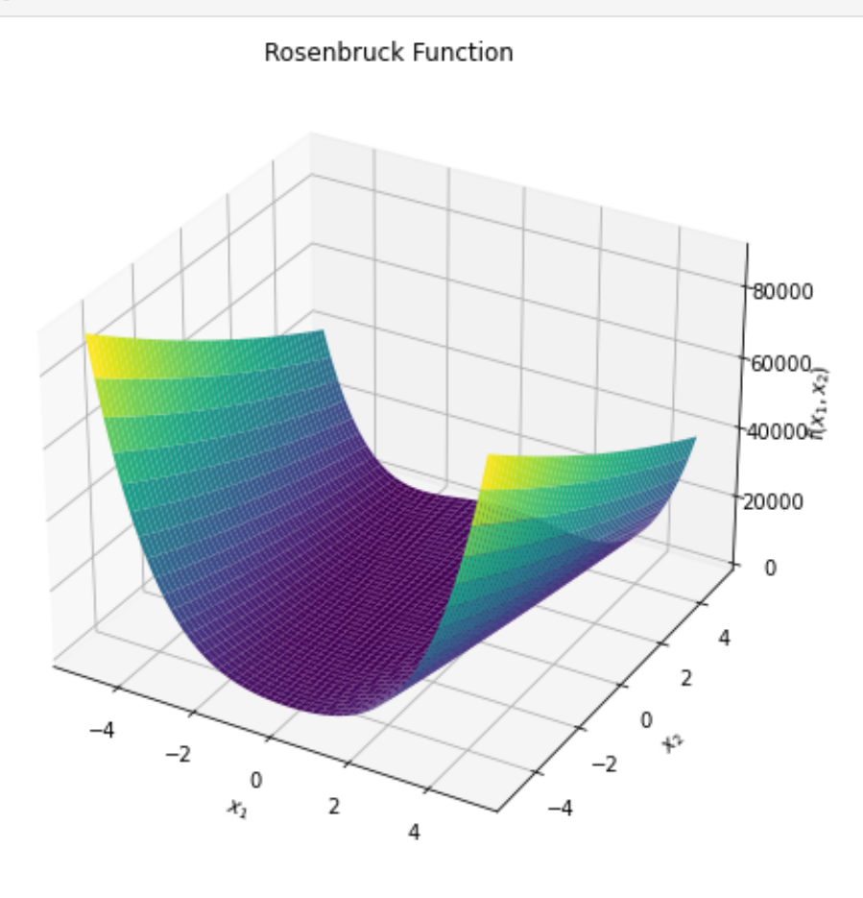
def Grad_Rosenbrock(X):
    x, y = X
    return np.array([
       -400*x*y + 400*x**3 + 2*x -2,
        200*y -200*x**2
    ])

def Hessian_Rosenbrock(X):
    x, y = X
    return np.matrix([
       [-400*y + 1200*x**2 + 2, -400*x],
        [-400*x, 200]
    ])
```

In [45]:

```
x = np.arange(-5, 5, 0.025)
y = np.arange(-5, 5, 0.025)
X, Y = np.meshgrid(x, y)
Z = np.zeros(X.shape)
mesh_size = range(len(X))
for i, j in product(mesh_size, mesh_size):
    x_coor = X[i][j]
    y_coor = Y[i][j]
    Z[i][j] = Rosenbrock(np.array([x_coor, y_coor]))

fig = plt.figure(figsize=(6,6))
ax = fig.gca(projection='3d')
ax.set_title('Rosenbruck Function')
ax.set_xlabel('$x_1$')
ax.set_ylabel('$x_2$')
ax.set_zlabel('$f(x_1, x_2)$')
ax.plot_surface(X, Y, Z, cmap='viridis')
plt.tight_layout()
plt.show()
```



In [46]:

```
def ArmijoLineSearch(f, xk, pk, gfk, phi0, alpha0, rho=0.5, c1=1e-4):
    """Minimize over alpha, the function ``f(xₖ + αpₖ)``.
    α > 0 is assumed to be a descent direction.

    Parameters
    --------------------
    f : callable
        Function to be minimized.
    xk : array
        Current point.
    pk : array
        Search direction.
    gfk : array
        Gradient of `f` at point `xk`.
    phi0 : float
        Value of `f` at point `xk`.
    alpha0 : scalar
        Value of `alpha` at the start of the optimization.
    rho : float, optional
        Value of alpha shrinkage factor.
    c1 : float, optional
        Value to control stopping criterion.

    Returns
    --------------------
    alpha : scalar
        Value of `alpha` at the end of the optimization.
    phi : float
        Value of `f` at the new point `x_{k+1}`.
    """
    derphi0 = np.dot(gfk, pk)
    phi_a0 = f(xk + alpha0*pk)

    while not phi_a0 <= phi0 + c1*alpha0*derphi0:
        alpha0 = alpha0 * rho
        phi_a0 = f(xk + alpha0*pk)

    return alpha0, phi_a0
```

In [55]:

```
def GradientDescent(f, f_grad, init, alpha=1, tol=1e-3, max_iter=100000):
    """Gradient descent method for unconstraint optimization problem.
    given a starting point x ∈ Rⁿ,
    repeat
        1. Define direction. p := −∇f(x).
        2. Line search. Choose step length α using Armijo Line Search.
        3. Update. x := x + αp.
    until stopping criterion is satisfied.

    Parameters
    --------------------
    f : callable
        Function to be minimized.
    f_grad : callable
        The first derivative of f.
    init : array
        initial value of x.
    alpha : scalar, optional
        the initial value of steplength.
    tol : float, optional
        tolerance for the norm of f_grad.
    max_iter : integer, optional
        maximum number of steps.

    Returns
    --------------------
    xs : array
        x in the learning path
    ys : array
        f(x) in the learning path
    """
    # initialize x, f(x), and f'(x)
    xk = init
    fk = f(xk)
    gfk = f_grad(xk)
    gfk_norm = np.linalg.norm(gfk)
    # initialize number of steps, save x and f(x)
    num_iter = 0
    curve_x = [xk]
    curve_y = [fk]
    print('Initial condition: y = {:.4f}, x = {} \n'.format(fk, xk))
    # take steps
    while gfk_norm > tol and num_iter < max_iter:
        # determine direction
        pk = -gfk
        #pk = np.linalg.inv(Hessian_Rosenbrock_f(x,y)) @ Grad_Rosenbrock_f(x,y)
        # calculate new x, f(x), and f'(x)
        alpha, fk = ArmijoLineSearch(f, xk, pk, gfk, fk, alpha0=alpha)
        xk = xk + alpha * pk
        gfk = f_grad(xk)
        gfk_norm = np.linalg.norm(gfk)
        # increase number of steps by 1, save new x and f(x)
        num_iter += 1
        curve_x.append(xk)
        curve_y.append(fk)
        print('Iteration: {} \t y = {:.4f}, x = {}, gradient = {:.4f}'.
              format(num_iter, fk, xk, gfk_norm))
    # print results
    if num_iter == max_iter:
        print('\nGradient descent does not converge.')
    else:
        print('\nSolution: \t y = {:.4f}, x = {}'.format(fk, xk))

    return np.array(curve_x), np.array(curve_y)
```

In [56]:

```
def plot(xs, ys):
    fig, (ax1, ax2) = plt.subplots(1, 2, figsize=(12, 6))
    plt.suptitle('Gradient Descent Method')

    ax1.plot(xs[:,0], xs[:,1], linestyle='--', marker='o', color='orange')
    ax1.plot(xs[-1,0], xs[-1,1], 'ro')
    ax1.set(
        title='Path During Optimization Process',
        xlabel='x1',
        ylabel='x2'
    )
    CS = ax1.contour(X, Y, Z)
    ax1.clabel(CS, fontsize='smaller', fmt='%1.2f')
    ax1.axis('square')

    ax2.plot(ys, linestyle='--', marker='o', color='orange')
    ax2.plot(len(ys)-1, ys[-1], 'ro')
    ax2.xaxis.set_major_locator(MaxNLocator(integer=True))
    ax2.set(
        title='Objective Function Value During Optimization Process',
        xlabel='Iterations',
        ylabel='Objective Function Value'
    )
    ax2.legend(['Armijo line search algorithm'])

    plt.tight_layout()
    plt.show()
```

In [57]:

```
x0 = np.array([-1.2, 1])
xs, ys = GradientDescent(Rosenbrock, Grad_Rosenbrock, init=x0)
plot(xs, ys)
```

```
Initial condition: y = 24.2000, x = [-1.2  1. ]

Iteration: 1     y = 5.1011, x = [-0.98945313  1.0859375 ], gradient = 43.8985
Iteration: 2     y = 4.1194, x = [-1.02689261  1.06505468], gradient = 2.1275
Iteration: 3     y = 4.1157, x = [-1.02716425  1.06299487], gradient = 1.7746
Iteration: 4     y = 4.1126, x = [-1.02638613  1.06144634], gradient = 1.7749
Iteration: 5     y = 4.1095, x = [-1.02562692  1.05988817], gradient = 1.7753
Iteration: 6     y = 4.1065, x = [-1.02486672  1.05833005], gradient = 1.7757
Iteration: 7     y = 4.1034, x = [-1.0241059   1.05677179], gradient = 1.7761
Iteration: 8     y = 4.1003, x = [-1.02334446  1.05521342], gradient = 1.7765
Iteration: 9     y = 4.0972, x = [-1.02258239  1.05365491], gradient = 1.7769
Iteration: 10    y = 4.0941, x = [-1.02181968  1.05209629], gradient = 1.7773
Iteration: 11    y = 4.0910, x = [-1.02105635  1.05053753], gradient = 1.7777
Iteration: 12    y = 4.0880, x = [-1.02029238  1.04897865], gradient = 1.7781
Iteration: 13    y = 4.0849, x = [-1.01952778  1.04741965], gradient = 1.7785
Iteration: 14    y = 4.0818, x = [-1.01876254  1.04586051], gradient = 1.7789
Iteration: 15    y = 4.0787, x = [-1.01799667  1.04430126], gradient = 1.7793
Iteration: 16    y = 4.0756, x = [-1.01723016  1.04274188], gradient = 1.7797
Iteration: 17    y = 4.0725, x = [-1.01646301  1.04118237], gradient = 1.7801
Iteration: 18    y = 4.0694, x = [-1.01569522  1.03962274], gradient = 1.7805
Iteration: 19    y = 4.0663, x = [-1.01492679  1.03806298], gradient = 1.7809
Iteration: 20    y = 4.0632, x = [-1.01415772  1.0365031 ], gradient = 1.7813
Iteration: 21    y = 4.0601, x = [-1.013388   1.0349431], gradient = 1.7817
Iteration: 22    y = 4.0570, x = [-1.01261763  1.03338297], gradient = 1.7821
Iteration: 23    y = 4.0539, x = [-1.01184662  1.03182272], gradient = 1.7825
Iteration: 24    y = 4.0508, x = [-1.01107496  1.03026234], gradient = 1.7829
Iteration: 25    y = 4.0477, x = [-1.01030264  1.02870184], gradient = 1.7834
Iteration: 26    y = 4.0446, x = [-1.00952968  1.02714121], gradient = 1.7838
Iteration: 27    y = 4.0415, x = [-1.00875606  1.02558046], gradient = 1.7842
Iteration: 28    y = 4.0384, x = [-1.00798179  1.02401959], gradient = 1.7846
Iteration: 29    y = 4.0353, x = [-1.00720686  1.02245859], gradient = 1.7850
Iteration: 30    y = 4.0322, x = [-1.00643128  1.02089747], gradient = 1.7854
Iteration: 31    y = 4.0290, x = [-1.00565503  1.01933623], gradient = 1.7858
Iteration: 32    y = 4.0259, x = [-1.00487813  1.01777487], gradient = 1.7862
Iteration: 33    y = 4.0228, x = [-1.00410056  1.01621338], gradient = 1.7867
Iteration: 34    y = 4.0197, x = [-1.00332233  1.01465177], gradient = 1.7871
Iteration: 35    y = 4.0166, x = [-1.00254343  1.01309003], gradient = 1.7875
Iteration: 36    y = 4.0135, x = [-1.00176387  1.01152818], gradient = 1.7879
Iteration: 37    y = 4.0103, x = [-1.00098364  1.0099662 ], gradient = 1.7883
Iteration: 38    y = 4.0072, x = [-1.00020274  1.0084041 ], gradient = 1.7887
Iteration: 39    y = 4.0041, x = [-0.99942117  1.00684188], gradient = 1.7892
Iteration: 40    y = 4.0010, x = [-0.99863893  1.00527954], gradient = 1.7896
Iteration: 41    y = 3.9978, x = [-0.99785602  1.00371707], gradient = 1.7900
Iteration: 42    y = 3.9947, x = [-0.99707243  1.00215449], gradient = 1.7904
Iteration: 43    y = 3.9916, x = [-0.99628816  1.00059178], gradient = 1.7909
Iteration: 44    y = 3.9884, x = [-0.99550321  0.99902895], gradient = 1.7913
Iteration: 45    y = 3.9853, x = [-0.99471759  0.997466  ], gradient = 1.7917
Iteration: 46    y = 3.9822, x = [-0.99393128  0.99590293], gradient = 1.7921
Iteration: 47    y = 3.9790, x = [-0.99314429  0.99433974], gradient = 1.7925
Iteration: 48    y = 3.9759, x = [-0.99235662  0.99277643], gradient = 1.7930
Iteration: 49    y = 3.9728, x = [-0.99156826  0.991213  ], gradient = 1.7934
Iteration: 50    y = 3.9696, x = [-0.99077921  0.98964945], gradient = 1.7938
Iteration: 51    y = 3.9665, x = [-0.98998948  0.98808578], gradient = 1.7943
Iteration: 52    y = 3.9633, x = [-0.98919905  0.98652199], gradient = 1.7947
Iteration: 53    y = 3.9602, x = [-0.98840793  0.98495808], gradient = 1.7951
Iteration: 54    y = 3.9570, x = [-0.98761612  0.98339405], gradient = 1.7955
Iteration: 55    y = 3.9539, x = [-0.98682362  0.9818299 ], gradient = 1.7960
Iteration: 56    y = 3.9507, x = [-0.98603041  0.98026563], gradient = 1.7964
Iteration: 57    y = 3.9476, x = [-0.98523651  0.97870125], gradient = 1.7968
Iteration: 58    y = 3.9444, x = [-0.98444191  0.97713674], gradient = 1.7973
Iteration: 59    y = 3.9413, x = [-0.98364661  0.97557212], gradient = 1.7977
Iteration: 60    y = 3.9381, x = [-0.9828506   0.97400738], gradient = 1.7981
Iteration: 61    y = 3.9350, x = [-0.98205389  0.97244252], gradient = 1.7986
Iteration: 62    y = 3.9318, x = [-0.98125647  0.97087754], gradient = 1.7990
Iteration: 63    y = 3.9286, x = [-0.98045835  0.96931245], gradient = 1.7995
Iteration: 64    y = 3.9255, x = [-0.97965951  0.96774724], gradient = 1.7999
Iteration: 65    y = 3.9223, x = [-0.97885997  0.96618191], gradient = 1.8003
Iteration: 66    y = 3.9191, x = [-0.97805971  0.96461647], gradient = 1.8008
Iteration: 67    y = 3.9160, x = [-0.97725873  0.9630509 ], gradient = 1.8012
Iteration: 68    y = 3.9128, x = [-0.97645705  0.96148523], gradient = 1.8016
Iteration: 69    y = 3.9096, x = [-0.97565464  0.95991943], gradient = 1.8021
Iteration: 70    y = 3.9065, x = [-0.97485151  0.95835352], gradient = 1.8025
Iteration: 71    y = 3.9033, x = [-0.97404767  0.9567875 ], gradient = 1.8030
Iteration: 72    y = 3.9001, x = [-0.9732431   0.95522136], gradient = 1.8034
Iteration: 73    y = 3.8969, x = [-0.9724378  0.9536551], gradient = 1.8039
Iteration: 74    y = 3.8938, x = [-0.97163178  0.95208873], gradient = 1.8043
Iteration: 75    y = 3.8906, x = [-0.97082503  0.95052224], gradient = 1.8048
Iteration: 76    y = 3.8874, x = [-0.97001756  0.94895564], gradient = 1.8052
Iteration: 77    y = 3.8842, x = [-0.96920935  0.94738893], gradient = 1.8057
Iteration: 78    y = 3.8810, x = [-0.96840041  0.9458221 ], gradient = 1.8061
Iteration: 79    y = 3.8779, x = [-0.96759073  0.94425515], gradient = 1.8066
Iteration: 80    y = 3.8747, x = [-0.96678032  0.9426881 ], gradient = 1.8070
Iteration: 81    y = 3.8715, x = [-0.96596917  0.94112093], gradient = 1.8075
Iteration: 82    y = 3.8683, x = [-0.96515728  0.93955365], gradient = 1.8079
Iteration: 83    y = 3.8651, x = [-0.96434465  0.93798625], gradient = 1.8084
Iteration: 84    y = 3.8619, x = [-0.96353128  0.93641874], gradient = 1.8088
Iteration: 85    y = 3.8587, x = [-0.96271716  0.93485112], gradient = 1.8093
Iteration: 86    y = 3.8555, x = [-0.96190229  0.93328339], gradient = 1.8097
Iteration: 87    y = 3.8523, x = [-0.96108668  0.93171554], gradient = 1.8102
Iteration: 88    y = 3.8491, x = [-0.96027032  0.93014759], gradient = 1.8106
Iteration: 89    y = 3.8459, x = [-0.9594532   0.92857952], gradient = 1.8111
Iteration: 90    y = 3.8427, x = [-0.95863533  0.92701134], gradient = 1.8115
Iteration: 91    y = 3.8395, x = [-0.95781671  0.92544305], gradient = 1.8120
Iteration: 92    y = 3.8363, x = [-0.95699733  0.92387465], gradient = 1.8125
Iteration: 93    y = 3.8331, x = [-0.95617718  0.92230614], gradient = 1.8129
Iteration: 94    y = 3.8299, x = [-0.95535628  0.92073752], gradient = 1.8134
Iteration: 95    y = 3.8267, x = [-0.95453462  0.91916879], gradient = 1.8139
Iteration: 96    y = 3.8234, x = [-0.95371219  0.91759995], gradient = 1.8143
Iteration: 97    y = 3.8202, x = [-0.95288899  0.91603101], gradient = 1.8148
Iteration: 98    y = 3.8170, x = [-0.95206503  0.91446195], gradient = 1.8152
Iteration: 99    y = 3.8138, x = [-0.9512403   0.91289278], gradient = 1.8157
Iteration: 100   y = 3.8106, x = [-0.95041479  0.91132351], gradient = 1.8162
Iteration: 101   y = 3.8074, x = [-0.94958852  0.90975413], gradient = 1.8166
Iteration: 102   y = 3.8041, x = [-0.94876146  0.90818464], gradient = 1.8171
Iteration: 103   y = 3.8009, x = [-0.94793363  0.90661505], gradient = 1.8176
Iteration: 104   y = 3.7977, x = [-0.94710502  0.90504534], gradient = 1.8181
Iteration: 105   y = 3.7944, x = [-0.94627563  0.90347553], gradient = 1.8185
Iteration: 106   y = 3.7912, x = [-0.94544546  0.90190562], gradient = 1.8190
Iteration: 107   y = 3.7880, x = [-0.9446145  0.9003356], gradient = 1.8195
Iteration: 108   y = 3.7848, x = [-0.94378275  0.89876547], gradient = 1.8199
Iteration: 109   y = 3.7815, x = [-0.94295022  0.89719524], gradient = 1.8204
Iteration: 110   y = 3.7783, x = [-0.94211689  0.8956249 ], gradient = 1.8209
Iteration: 111   y = 3.7750, x = [-0.94128277  0.89405446], gradient = 1.8214
Iteration: 112   y = 3.7718, x = [-0.94044786  0.89248391], gradient = 1.8218
Iteration: 113   y = 3.7686, x = [-0.93961216  0.89091326], gradient = 1.8223
Iteration: 114   y = 3.7653, x = [-0.93877565  0.88934251], gradient = 1.8228
Iteration: 115   y = 3.7621, x = [-0.93793834  0.88777165], gradient = 1.8233
Iteration: 116   y = 3.7588, x = [-0.93710023  0.88620069], gradient = 1.8238
Iteration: 117   y = 3.7556, x = [-0.93626132  0.88462963], gradient = 1.8242
Iteration: 118   y = 3.7523, x = [-0.9354216   0.88305846], gradient = 1.8247
Iteration: 119   y = 3.7491, x = [-0.93458108  0.8814872 ], gradient = 1.8252
Iteration: 120   y = 3.7458, x = [-0.93373974  0.87991583], gradient = 1.8257
Iteration: 121   y = 3.7426, x = [-0.93289759  0.87834436], gradient = 1.8262
Iteration: 122   y = 3.7393, x = [-0.93205463  0.87677279], gradient = 1.8267
Iteration: 123   y = 3.7361, x = [-0.93121085  0.87520112], gradient = 1.8271
Iteration: 124   y = 3.7328, x = [-0.93036626  0.87362935], gradient = 1.8276
Iteration: 125   y = 3.7295, x = [-0.92952084  0.87205748], gradient = 1.8281
Iteration: 126   y = 3.7263, x = [-0.9286746   0.87048551], gradient = 1.8286
Iteration: 127   y = 3.7230, x = [-0.92782754  0.86891344], gradient = 1.8291
Iteration: 128   y = 3.7197, x = [-0.92697965  0.86734127], gradient = 1.8296
Iteration: 129   y = 3.7165, x = [-0.92613093  0.86576901], gradient = 1.8301
Iteration: 130   y = 3.7132, x = [-0.92528139  0.86419664], gradient = 1.8306
Iteration: 131   y = 3.7099, x = [-0.92443101  0.86262418], gradient = 1.8311
Iteration: 132   y = 3.7066, x = [-0.9235798   0.86105163], gradient = 1.8316
Iteration: 133   y = 3.7034, x = [-0.92272775  0.85947897], gradient = 1.8321
Iteration: 134   y = 3.7001, x = [-0.92187486  0.85790622], gradient = 1.8326
Iteration: 135   y = 3.6968, x = [-0.92102113  0.85633338], gradient = 1.8331
Iteration: 136   y = 3.6935, x = [-0.92016656  0.85476044], gradient = 1.8336
Iteration: 137   y = 3.6902, x = [-0.91931114  0.8531874 ], gradient = 1.8341
Iteration: 138   y = 3.6870, x = [-0.91845488  0.85161427], gradient = 1.8346
Iteration: 139   y = 3.6837, x = [-0.91759777  0.85004105], gradient = 1.8351
Iteration: 140   y = 3.6804, x = [-0.9167398   0.84846773], gradient = 1.8356
Iteration: 141   y = 3.6771, x = [-0.91588099  0.84689432], gradient = 1.8361
Iteration: 142   y = 3.6738, x = [-0.91502132  0.84532082], gradient = 1.8366
Iteration: 143   y = 3.6705, x = [-0.91416079  0.84374722], gradient = 1.8371
Iteration: 144   y = 3.6672, x = [-0.9132994   0.84217353], gradient = 1.8376
Iteration: 145   y = 3.6639, x = [-0.91243715  0.84059976], gradient = 1.8381
Iteration: 146   y = 3.6606, x = [-0.91157403  0.83902589], gradient = 1.8386
Iteration: 147   y = 3.6573, x = [-0.91071005  0.83745193], gradient = 1.8391
Iteration: 148   y = 3.6540, x = [-0.9098452   0.83587788], gradient = 1.8396
Iteration: 149   y = 3.6507, x = [-0.90897948  0.83430374], gradient = 1.8401
Iteration: 150   y = 3.6474, x = [-0.90811288  0.83272951], gradient = 1.8406
Iteration: 151   y = 3.6441, x = [-0.90724542  0.83115519], gradient = 1.8411
Iteration: 152   y = 3.6408, x = [-0.90637707  0.82958079], gradient = 1.8417
Iteration: 153   y = 3.6375, x = [-0.90550784  0.8280063 ], gradient = 1.8422
Iteration: 154   y = 3.6341, x = [-0.90463773  0.82643172], gradient = 1.8427
Iteration: 155   y = 3.6308, x = [-0.90376674  0.82485705], gradient = 1.8432
Iteration: 156   y = 3.6275, x = [-0.90289486  0.8232823 ], gradient = 1.8437
Iteration: 157   y = 3.6242, x = [-0.9020221   0.82170746], gradient = 1.8442
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Iteration: 680   y = 1.4987, x = [-0.22331582  0.05454965], gradient = 2.2341
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Iteration: 1972          y = 0.0863, x = [0.70663151 0.49794301], gradient = 0.3389
Iteration: 1973          y = 0.0861, x = [0.70682217 0.49821353], gradient = 0.3386
Iteration: 1974          y = 0.0860, x = [0.70701265 0.49848386], gradient = 0.3383
Iteration: 1975          y = 0.0859, x = [0.70720293 0.49875398], gradient = 0.3381
Iteration: 1976          y = 0.0858, x = [0.70739302 0.4990239 ], gradient = 0.3378
Iteration: 1977          y = 0.0857, x = [0.70758291 0.49929362], gradient = 0.3375
Iteration: 1978          y = 0.0856, x = [0.70777262 0.49956315], gradient = 0.3372
Iteration: 1979          y = 0.0855, x = [0.70796214 0.49983247], gradient = 0.3369
Iteration: 1980          y = 0.0854, x = [0.70815146 0.50010159], gradient = 0.3367
Iteration: 1981          y = 0.0853, x = [0.7083406  0.50037052], gradient = 0.3364
Iteration: 1982          y = 0.0851, x = [0.70852955 0.50063925], gradient = 0.3361
Iteration: 1983          y = 0.0850, x = [0.7087183  0.50090778], gradient = 0.3358
Iteration: 1984          y = 0.0849, x = [0.70890687 0.50117611], gradient = 0.3356
Iteration: 1985          y = 0.0848, x = [0.70909525 0.50144424], gradient = 0.3353
Iteration: 1986          y = 0.0847, x = [0.70928344 0.50171218], gradient = 0.3350
Iteration: 1987          y = 0.0846, x = [0.70947144 0.50197991], gradient = 0.3347
Iteration: 1988          y = 0.0845, x = [0.70965925 0.50224746], gradient = 0.3345
Iteration: 1989          y = 0.0844, x = [0.70984688 0.5025148 ], gradient = 0.3342
Iteration: 1990          y = 0.0843, x = [0.71003432 0.50278195], gradient = 0.3339
Iteration: 1991          y = 0.0842, x = [0.71022157 0.5030489 ], gradient = 0.3336
Iteration: 1992          y = 0.0840, x = [0.71040863 0.50331565], gradient = 0.3334
Iteration: 1993          y = 0.0839, x = [0.71059551 0.50358221], gradient = 0.3331
Iteration: 1994          y = 0.0838, x = [0.7107822  0.50384857], gradient = 0.3328
Iteration: 1995          y = 0.0837, x = [0.71096871 0.50411474], gradient = 0.3325
Iteration: 1996          y = 0.0836, x = [0.71115503 0.50438071], gradient = 0.3323
Iteration: 1997          y = 0.0835, x = [0.71134117 0.50464648], gradient = 0.3320
Iteration: 1998          y = 0.0834, x = [0.71152712 0.50491206], gradient = 0.3317
Iteration: 1999          y = 0.0833, x = [0.71171288 0.50517745], gradient = 0.3314
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Iteration: 2012          y = 0.0819, x = [0.71411116 0.50860983], gradient = 0.3279
Iteration: 2013          y = 0.0818, x = [0.71429437 0.50887251], gradient = 0.3277
Iteration: 2014          y = 0.0817, x = [0.7144774 0.509135 ], gradient = 0.3274
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Iteration: 2018          y = 0.0813, x = [0.71520773 0.51018304], gradient = 0.3264
Iteration: 2019          y = 0.0812, x = [0.71538986 0.51044457], gradient = 0.3261
Iteration: 2020          y = 0.0811, x = [0.71557181 0.51070592], gradient = 0.3258
Iteration: 2021          y = 0.0810, x = [0.71575359 0.51096707], gradient = 0.3256
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Iteration: 2023          y = 0.0808, x = [0.71611661 0.51148881], gradient = 0.3250
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Iteration: 2026          y = 0.0805, x = [0.71665981 0.51226999], gradient = 0.3242
Iteration: 2027          y = 0.0804, x = [0.71684052 0.51253001], gradient = 0.3240
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Iteration: 2029          y = 0.0802, x = [0.71720141 0.51304948], gradient = 0.3235
Iteration: 2030          y = 0.0800, x = [0.7173816  0.51330893], gradient = 0.3232
Iteration: 2031          y = 0.0799, x = [0.7175616  0.51356819], gradient = 0.3229
Iteration: 2032          y = 0.0798, x = [0.71774144 0.51382726], gradient = 0.3227
Iteration: 2033          y = 0.0797, x = [0.71792109 0.51408615], gradient = 0.3224
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Iteration: 2036          y = 0.0794, x = [0.71845902 0.51486169], gradient = 0.3216
Iteration: 2037          y = 0.0793, x = [0.71863798 0.51511983], gradient = 0.3214
Iteration: 2038          y = 0.0792, x = [0.71881677 0.51537778], gradient = 0.3211
Iteration: 2039          y = 0.0791, x = [0.71899538 0.51563555], gradient = 0.3209
Iteration: 2040          y = 0.0790, x = [0.71917382 0.51589313], gradient = 0.3206
Iteration: 2041          y = 0.0789, x = [0.71935209 0.51615052], gradient = 0.3204
Iteration: 2042          y = 0.0788, x = [0.71953018 0.51640773], gradient = 0.3201
Iteration: 2043          y = 0.0787, x = [0.7197081  0.51666475], gradient = 0.3198
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Iteration: 2045          y = 0.0785, x = [0.72006343 0.51717824], gradient = 0.3193
Iteration: 2046          y = 0.0784, x = [0.72024084 0.51743471], gradient = 0.3191
Iteration: 2047          y = 0.0783, x = [0.72041807 0.51769099], gradient = 0.3188
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Iteration: 2049          y = 0.0781, x = [0.72077203 0.518203  ], gradient = 0.3183
Iteration: 2050          y = 0.0780, x = [0.72094876 0.51845872], gradient = 0.3181
Iteration: 2051          y = 0.0779, x = [0.72112531 0.51871427], gradient = 0.3178
Iteration: 2052          y = 0.0778, x = [0.72130169 0.51896963], gradient = 0.3175
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Iteration: 2061          y = 0.0770, x = [0.72288154 0.52125963], gradient = 0.3153
Iteration: 2062          y = 0.0769, x = [0.72305624 0.52151317], gradient = 0.3150
Iteration: 2063          y = 0.0768, x = [0.72323077 0.52176652], gradient = 0.3148
Iteration: 2064          y = 0.0767, x = [0.72340513 0.52201969], gradient = 0.3145
Iteration: 2065          y = 0.0766, x = [0.72357933 0.52227268], gradient = 0.3143
Iteration: 2066          y = 0.0765, x = [0.72375336 0.52252548], gradient = 0.3140
Iteration: 2067          y = 0.0764, x = [0.72392723 0.52277811], gradient = 0.3138
Iteration: 2068          y = 0.0763, x = [0.72410093 0.52303056], gradient = 0.3135
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Iteration: 2070          y = 0.0761, x = [0.72444783 0.52353491], gradient = 0.3130
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Iteration: 2077          y = 0.0754, x = [0.7256568  0.52529447], gradient = 0.3113
Iteration: 2078          y = 0.0753, x = [0.72582886 0.52554512], gradient = 0.3111
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Iteration: 2080          y = 0.0751, x = [0.72617248 0.52604588], gradient = 0.3106
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Iteration: 2088          y = 0.0744, x = [0.72754048 0.52804183], gradient = 0.3086
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Iteration: 2095          y = 0.0737, x = [0.72872904 0.529779  ], gradient = 0.3069
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Iteration: 2878          y = 0.0304, x = [0.82588479 0.68131368], gradient = 0.1803
```

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Iteration: 3793          y = 0.0123, x = [0.88905222 0.78993952], gradient = 0.1088
Iteration: 3794          y = 0.0123, x = [0.88910419 0.79003216], gradient = 0.1087
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Iteration: 4005          y = 0.0101, x = [0.89945313 0.80858868], gradient = 0.0977
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Iteration: 4015          y = 0.0100, x = [0.8999147  0.80942131], gradient = 0.0972
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Iteration: 4022          y = 0.0100, x = [0.90023634 0.81000174], gradient = 0.0969
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Iteration: 15134         y = 0.0000, x = [0.99887852 0.99775381], gradient = 0.0010
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Iteration: 15137         y = 0.0000, x = [0.99887983 0.99775644], gradient = 0.0010
Iteration: 15138         y = 0.0000, x = [0.99888027 0.99775731], gradient = 0.0010
Iteration: 15139         y = 0.0000, x = [0.99888071 0.99775819], gradient = 0.0010
Iteration: 15140         y = 0.0000, x = [0.99888115 0.99775906], gradient = 0.0010
Iteration: 15141         y = 0.0000, x = [0.99888158 0.99775994], gradient = 0.0010
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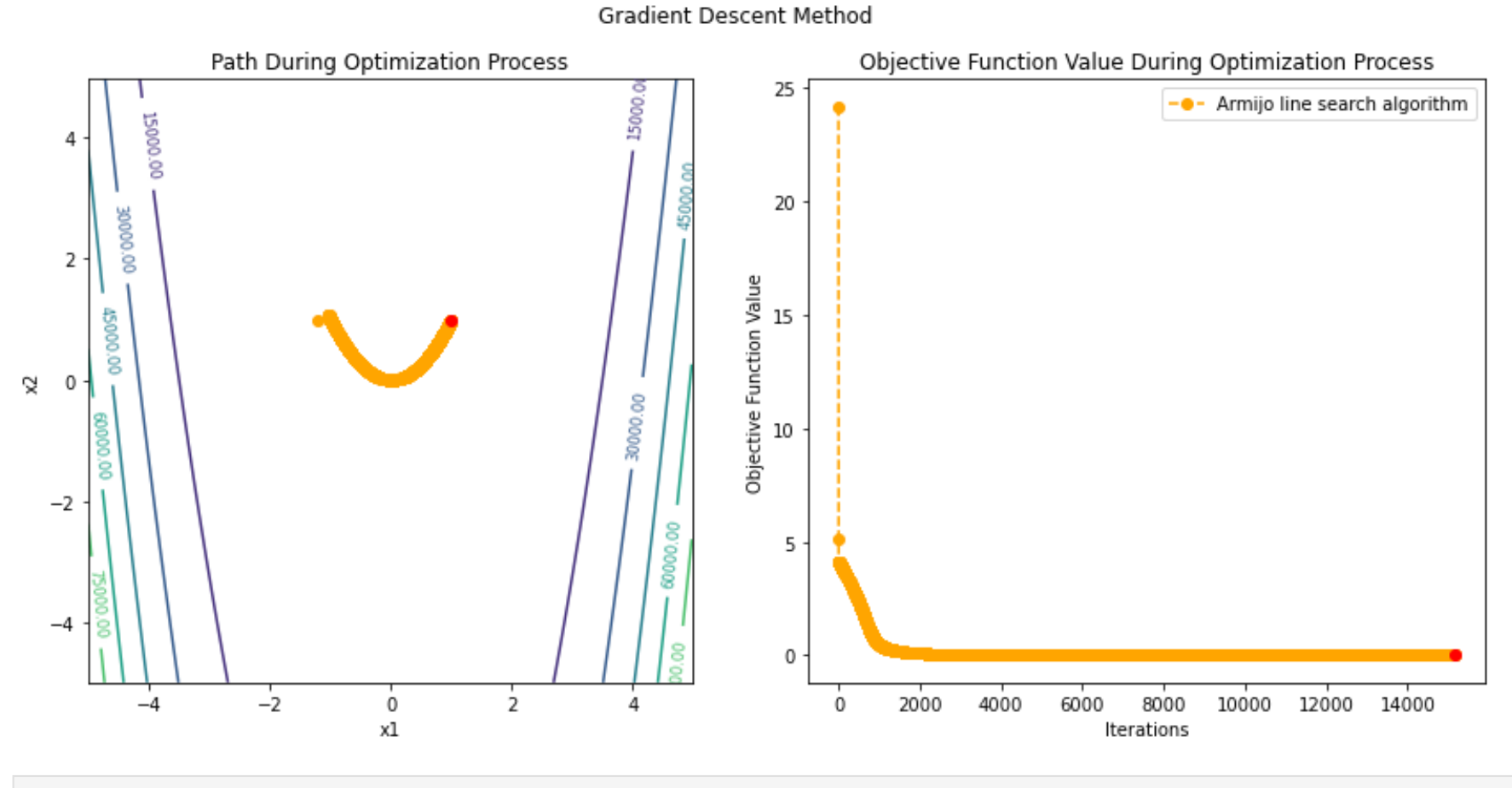
Iteration: 15143         y = 0.0000, x = [0.99888246 0.99776169], gradient = 0.0010
Iteration: 15144         y = 0.0000, x = [0.99888289 0.99776256], gradient = 0.0010
Iteration: 15145         y = 0.0000, x = [0.99888333 0.99776344], gradient = 0.0010

Solution:        y = 0.0000, x = [0.99888333 0.99776344]
```

Gradient Descent Method


Path During Optimization Process
x1
x2
Objective Function Value During Optimization Process
Armijo line search algorithm
Objective Function Value
Iterations

```
In [40]: def Newton_Raphson_Optimize(Grad, Hess, x,y, epsilon=1e-3, nMax = 1000):
             #Initialization
             i = 0
             iter_x, iter_y, iter_count = np.empty(0),np.empty(0), np.empty(0)
             error = 10
             X = np.array([x,y])

             #Looping as long as error is greater than epsilon
             while np.linalg.norm(error) > epsilon and i < nMax:
                 i +=1
                 iter_x = np.append(iter_x,x)
                 iter_y = np.append(iter_y,y)
                 iter_count = np.append(iter_count ,i)
                 print(X)

                 X_prev = X
                 X = X - np.linalg.inv(Hess(x,y)) @ Grad(x,y)
                 error = X - X_prev
                 x,y = X[0], X[1]

             return X, iter_x,iter_y, iter_count

         root,iter_x,iter_y, iter_count = Newton_Raphson_Optimize(Grad_Rosenbrock_f,Hessian_Rosenbrock_f,-1.2,1)
```

```
[-1.2  1. ]
[-1.1752809   1.38067416]
[ 0.76311487 -3.17503385]
[0.76342968 0.58282478]
[0.99999531 0.94402732]
[0.9999957  0.99999139]
```

```
In [41]: x = np.linspace(-3,3,250)
         y = np.linspace(-9,8,350)
         X, Y = np.meshgrid(x, y)
         Z = Rosenbrock_f(X, Y)

         #Angles needed for quiver plot
         anglesx = iter_x[1:] - iter_x[:-1]
         anglesy = iter_y[1:] - iter_y[:-1]

         %matplotlib inline
         fig = plt.figure(figsize = (16,8))

         #Surface plot
         ax = fig.add_subplot(1, 2, 1, projection='3d')
         ax.plot_surface(X,Y,Z,rstride = 5, cstride = 5, cmap = 'jet', alpha = .4, edgecolor = 'none' )
         ax.plot(iter_x,iter_y, Rosenbrock_f(iter_x,iter_y),color = 'r', marker = '*', alpha = .4)

         #Rotate the initialization to help viewing the graph
         ax.view_init(45, 280)
         ax.set_xlabel('x')
         ax.set_ylabel('y')

         #Contour plot
         ax = fig.add_subplot(1, 2, 2)
         ax.contour(X,Y,Z, 60, cmap = 'jet')
         #Plotting the iterations and intermediate values
         ax.scatter(iter_x,iter_y,color = 'r', marker = '*')
         ax.quiver(iter_x[:-1], iter_y[:-1], anglesx, anglesy, scale_units = 'xy', angles = 'xy', scale = 1, color = 'r'
         ax.set_title('Newton method with {} iterations'.format(len(iter_count)))

         plt.show()
```