COLUMBIA UNIVERSITY

MECE 4510 EVOLUTIONARY COMPUTATION AND DESIGN AUTOMATION

Assignment3 Phase C

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Instructor:
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Grace Hour Used: 0
Grace Hour Gained: 0
Grace Hour Remaining: 92

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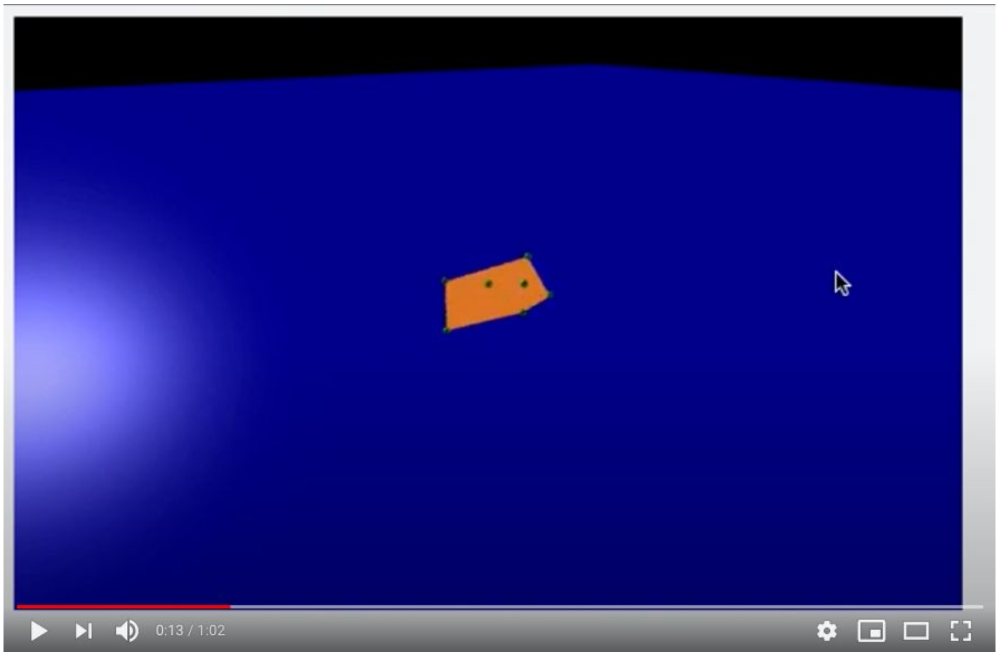
Result Summary

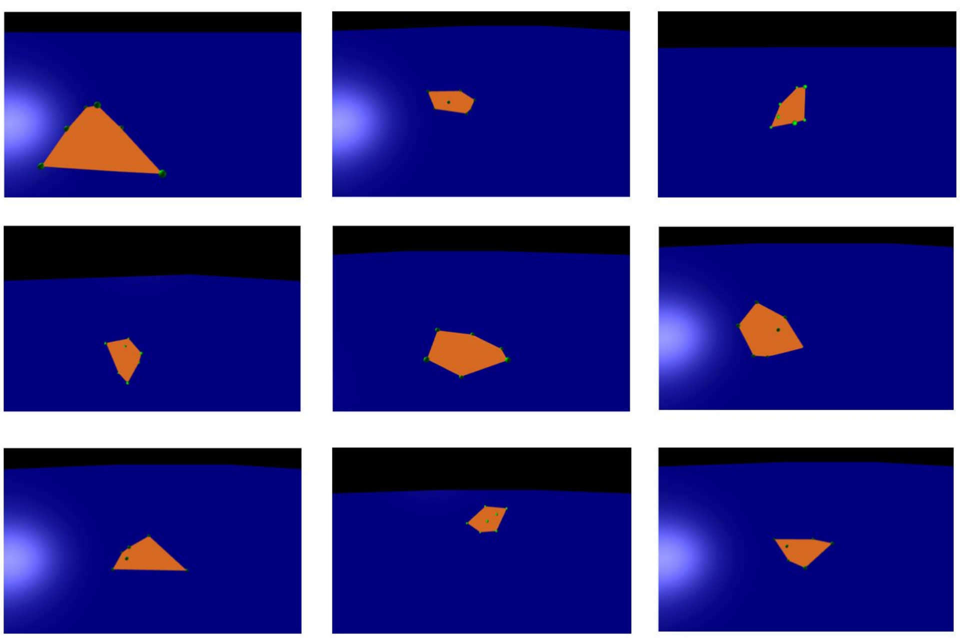
Fastest robot running cycles



Speed: 0.083 d/cy

https://www.youtube.com/watch?v=xKQb16Vvre0

Robot Zoo



Design parameters

Simulation parameters

- simulation time = 200s (frame time)
- time step = 0.001
- gravity = 9.81
- damping coefficient = 0.9
- ground restoration constant = 20000
- ground friction coefficient = 0.9

Robot parameters

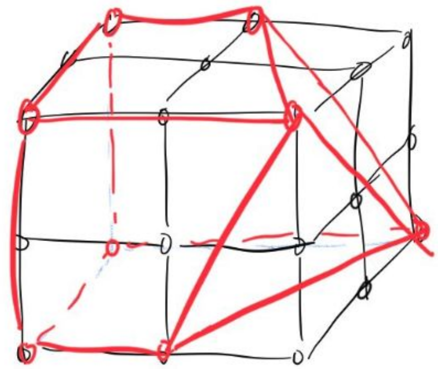
- mass = 0.5
- number of masses = 8 (selected from a 3x3x3 grid.)
- soft spring constant = 2000
- medium spring constant = 5000
- hard spring constant = 8000
- spring locomotion: $L = L_0 + A * sin(B * t + C)$

Evolutionary Parameters

- population size = 2000
- mutation rate = 0.3
- crossover rate = 0.5

Representation

Set up a 3x3x3 coordinate system as the following, using genetic algorithm to select 8 points from the 27 candidates and use them as masses. Different spring types are also distributed by algorithm to evolve with the purpose of generating the fastest moving robot.



Indirect encoding:

- distribute springs from 3 different types: soft, medium, hard
- generate spring locomotion parameters.

Selection: top 50% best solution
Crossover: single point crossover
Mutation:

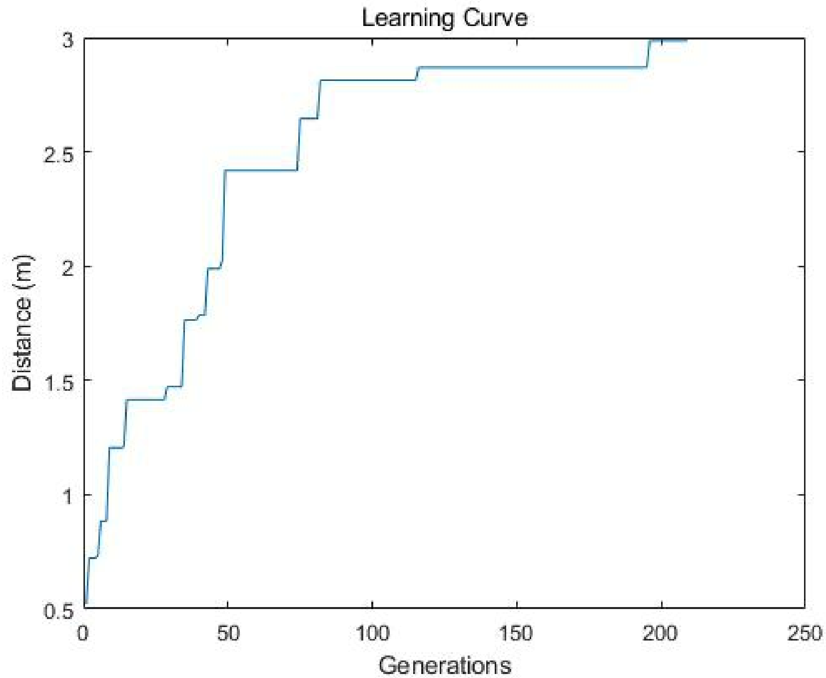
- spring type variation
- locomotion expression
- mass distribution

Analysis

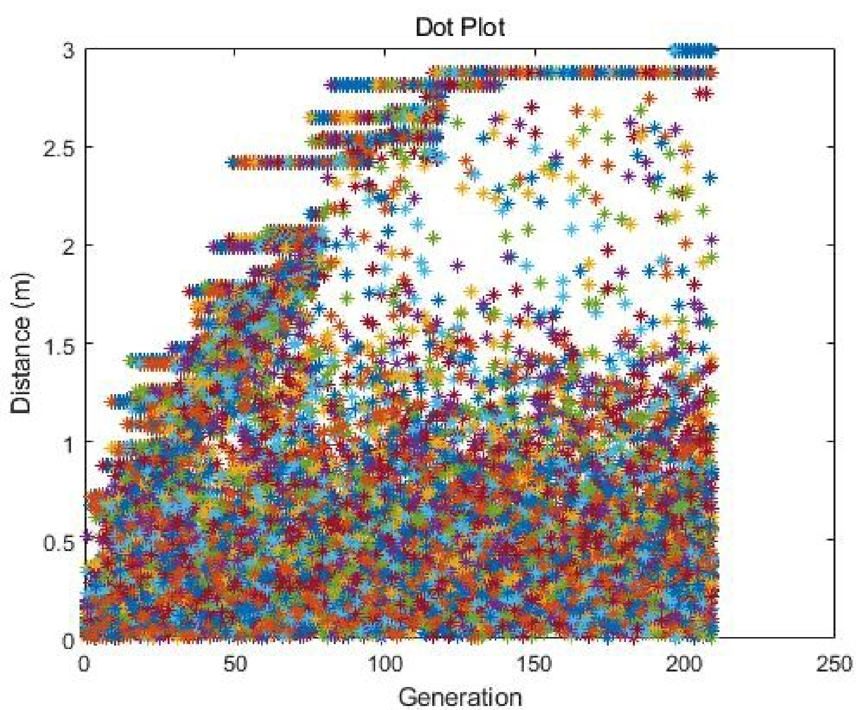
In this assignment, the Genetic Programming is implemented to find the optimal solution in the distribution of mass positions and spring locomotion expressions. In general, evolution in the mass position, which causes variations of morphologies of robots, has a greater influence on the moving speed of robots. The main challenge is to generate multiple cubes and connect them. If doing this by direct encoding, the implementation gets complicated when the morphology of robots goes wild and crazy, because there are lots of mass points coordinates to distribute and various types of springs to connect them.

Performance Plots

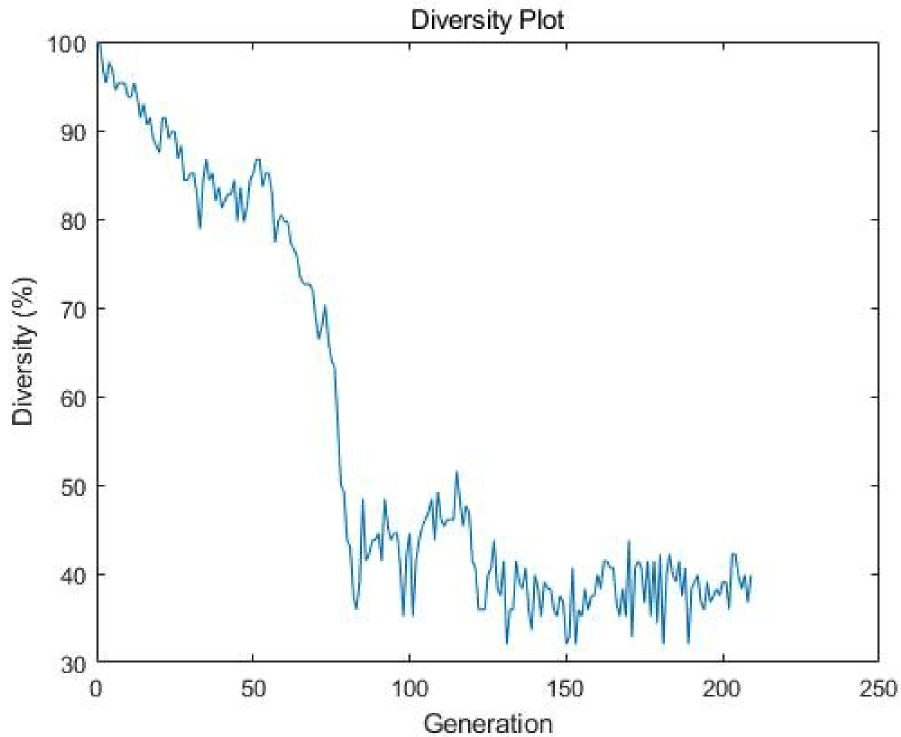
Learning Curve



Dot Plot



Diversity plot



Appendix

```
import vpython as vp
import itertools
import random
import numpy as np
from math import *
import matplotlib.pyplot as plt


scene = vp.canvas()
floor = vp.box(pos=vp.vector(0, 0, 0), length=100, height=0.001,
width=100, color=vp.color.blue)

ballname = ['b1','b2','b3','b4','b5','b6','b7','b8']
ballvectors = [vp.vector(0, 0, 0), vp.vector(0, 1, 0), vp.vector(0,
0, 1), vp.vector(1, 0, 0),vp.vector(1, 1, 0), vp.vector(0, 1, 1),
vp.vector(1, 0, 1), vp.vector(1, 1, 1), vp.vector(0, 2,
0),vp.vector(0, 0, 2),vp.vector(2, 0, 0),vp.vector(2, 2,
0),vp.vector(0, 2, 2),vp.vector(2, 0, 2),vp.vector(2, 2,
2),vp.vector(0, 3, 0),vp.vector(0, 0, 3),vp.vector(3, 0,
0),vp.vector(3, 3, 0),vp.vector(0, 3, 3),vp.vector(3, 0,
```

```
3),vp.vector(3, 0, 3),vp.vector(3, 3, 3)]


for i in range(8):
    masscoord = math.rand(ballvectors)

OriginalCOM = (ballvectors[0] + ballvectors[1] + ballvectors[2] +
ballvectors[3] +ballvectors[4] +
               ballvectors[5] + ballvectors[6] + ballvectors[7]) / 8


triangles = []
for z in itertools.combinations(ballvectors,3):
    triangles.append(z)

T = list(range(56))
for i in range(len(triangles)):
    T[i] = vp.triangle(v0 = vp.vertex(pos = triangles[i][0]),v1 =
vp.vertex(pos = triangles[i][1]),
                        v2 = vp.vertex(pos = triangles[i][2]),
texture = "texture.jpg" )   # texture


springvecs = []
for i in range(len(ballname)):
    ballname[i] = vp.sphere(pos = ballvectors[i], radius = 0.05,
color = vp.color.green)
velocity = vp.vector(0,0,0)
for i in itertools.combinations(ballvectors,2):
    springvecs.append(i)

spring = ['s1', 's2', 's3', 's4', 's5', 's6', 's7', 's8', 's9',
's10', 's11', 's12','s13', 's14', 's15',
          's16','s17', 's18', 's19', 's20', 's21', 's22', 's23',
's24', 's25', 's26', 's27','s28']

v = 0
dt = 0.001
mass = 0.1
g = 9.81

g_vector = vp.vector(0,g,0)
for i in range(len(ballname)):
    ballname[i].velocity = vp.vector(0,0,0)
F_c = vp.vector(0,1000,0)
```

```python
def getCOM(v):
    COM = (v[0].pos + v[1].pos + v[2].pos + v[3].pos + v[4].pos + 
v[5].pos + v[6].pos + v[7].pos)/ 16
    return COM

pa1 = [[-0.0999684941118836, -2.436063476356824, 2296.7581897299874],
    [-0.07967391969199222, -0.08634880798548794, 2361.5826862217555],
    [0.09067974114260546, -0.21159318157779383, 4755.324973113422],
    [0.18380205176538172, -2.0565408755726033, 4409.3898116994515],
    [-0.09146751801551414, -1.1488912489420897, 1828.5235061201834],
    [0.12405268447947199, -2.813723875627788, 4433.034537634187],
    [0.11126570634985072, 2.9781789480327108, 1536.2099136022057],
    [0.17140895971224107, 3.0375520686516975, 4274.469299579441],
    [0.03410203251472729, 0.3029379290102514, 1816.8271542650991],
    [-0.042351202453747266, 1.3271962303422749, 4865.486843841038],
    [-0.12401891611004096, -1.455914399642346, 2241.1865101427006],
    [0.16860887015307674, 2.3914072461699805, 2474.754155099656],
    [-0.11773307676195617, -0.3926900646112008, 1067.4545888208283],
    [0.1889606677054101, 1.5196174154857083, 5192.421195053015],
    [0.035816105198113485, -2.1041344746790127, 4666.689845214234],
    [-0.010549926384152558, -1.3311801212100072, 1236.6327877338986],
    [-0.10281383568907182, -0.6452025562267107, 1809.5808026975737],
    [-0.13964559177630298, 1.0742302809635627, 4488.763201981452],
    [0.13159014364690885, -1.6264225015119274, 1043.3984921278495],
    [-0.15788353962765111, 2.445306398612243, 4962.665844610705],
    [-0.10355923252096791, -2.0136708324532977, 3816.315590216662],
    [0.10326981592129303, -0.9756094020324113, 2285.446390155172],
    [-0.051793601473909684, -2.0312235905388243, 2908.6840001433184],
    [-0.0443805533814709, -1.7160858876498892, 4580.86053237835],
    [0.14274328807395192, 0.5766512368889116, 4898.871085132674],
    [-0.1280887144442297, 0.32902508167789923, 5017.558774143425],
    [-0.15039361389519904, -2.2832635644031134, 4323.8339489367545],
    [0.10632846454515804, 1.6343248793719205, 3613.8574144730146]]


L0 = np.zeros((8, 8))
for i in range(8):
    for j in range(8):
        if i == j:
            L0[j][i] = 0
        else:
            position = ballname[j].pos - ballname[i].pos
            L0[j][i] = vp.mag(position)
L0rate = np.zeros((8,8))
```

```
t = 0.001
c = 1
w = 10 * np.pi
eta = 1
while True:
    vp.rate(100)
    floor =
vp.box(pos=vp.vector(ballvectors[5].x,0,ballvectors[1].z),length=5,he
ight = 0.001,width=5,color=vp.color.blue)
    scene.forward = vp.vector(-1,-1,1.5)
    scene.center.y = ballvectors[1].y
    scene.center.z = ballvectors[1].z
    L0rate[0][1] = L0[0][1] + pa1[0][0] * sin(w * t + pa1[0][1])
    L0rate[1][0] = L0[1][0] + pa1[0][0] * sin(w * t + pa1[0][1])
    L0rate[0][2] = L0[0][2] + pa1[1][0] * sin(w * t + pa1[1][1])
    L0rate[2][0] = L0[2][0] + pa1[1][0] * sin(w * t + pa1[1][1])
    L0rate[0][3] = L0[0][3] + pa1[2][0] * sin(w * t + pa1[2][1])
    L0rate[3][0] = L0[3][0] + pa1[2][0] * sin(w * t + pa1[2][1])
    L0rate[0][4] = L0[0][4] + pa1[3][0] * sin(w * t + pa1[3][1])
    L0rate[4][0] = L0[4][0] + pa1[3][0] * sin(w * t + pa1[3][1])
    L0rate[0][5] = L0[0][5] + pa1[4][0] * sin(w * t + pa1[4][1])
    L0rate[5][0] = L0[5][0] + pa1[4][0] * sin(w * t + pa1[4][1])
    L0rate[0][6] = L0[0][6] + pa1[5][0] * sin(w * t + pa1[5][1])
    L0rate[6][0] = L0[6][0] + pa1[5][0] * sin(w * t + pa1[5][1])
    L0rate[0][7] = L0[0][7] + pa1[6][0] * sin(w * t + pa1[6][1])
    L0rate[7][0] = L0[7][0] + pa1[6][0] * sin(w * t + pa1[6][1])
    L0rate[1][2] = L0[1][2] + pa1[7][0] * sin(w * t + pa1[7][1])
    L0rate[2][1] = L0[2][1] + pa1[7][0] * sin(w * t + pa1[7][1])
    L0rate[1][3] = L0[1][3] + pa1[8][0] * sin(w * t + pa1[8][1])
    L0rate[3][1] = L0[3][1] + pa1[8][0] * sin(w * t + pa1[8][1])
    L0rate[1][4] = L0[1][4] + pa1[9][0] * sin(w * t + pa1[9][1])
    L0rate[4][1] = L0[4][1] + pa1[9][0] * sin(w * t + pa1[9][1])
    L0rate[1][5] = L0[1][5] + pa1[10][0] * sin(w * t + pa1[10][1])
    L0rate[5][1] = L0[5][1] + pa1[10][0] * sin(w * t + pa1[10][1])
    L0rate[1][6] = L0[1][6] + pa1[11][0] * sin(w * t + pa1[11][1])
    L0rate[6][1] = L0[6][1] + pa1[11][0] * sin(w * t + pa1[11][1])
    L0rate[1][7] = L0[1][7] + pa1[12][0] * sin(w * t + pa1[12][1])
    L0rate[7][1] = L0[7][1] + pa1[12][0] * sin(w * t + pa1[12][1])
    L0rate[2][3] = L0[2][3] + pa1[13][0] * sin(w * t + pa1[13][1])
    L0rate[3][2] = L0[3][2] + pa1[13][0] * sin(w * t + pa1[13][1])
    L0rate[2][4] = L0[2][4] + pa1[14][0] * sin(w * t + pa1[14][1])
    L0rate[4][2] = L0[4][2] + pa1[14][0] * sin(w * t + pa1[14][1])
    L0rate[2][5] = L0[2][5] + pa1[15][0] * sin(w * t + pa1[15][1])
    L0rate[5][2] = L0[5][2] + pa1[15][0] * sin(w * t + pa1[15][1])
    L0rate[2][6] = L0[2][6] + pa1[16][0] * sin(w * t + pa1[16][1])
```

```
    L0rate[6][2] = L0[6][2] + pa1[16][0] * sin(w * t + pa1[16][1])
    L0rate[2][7] = L0[2][7] + pa1[17][0] * sin(w * t + pa1[17][1])
    L0rate[7][2] = L0[7][2] + pa1[17][0] * sin(w * t + pa1[17][1])
    L0rate[3][4] = L0[3][4] + pa1[18][0] * sin(w * t + pa1[18][1])
    L0rate[4][3] = L0[4][3] + pa1[18][0] * sin(w * t + pa1[18][1])
    L0rate[3][5] = L0[3][5] + pa1[19][0] * sin(w * t + pa1[19][1])
    L0rate[5][3] = L0[5][3] + pa1[19][0] * sin(w * t + pa1[19][1])
    L0rate[3][6] = L0[3][6] + pa1[20][0] * sin(w * t + pa1[20][1])
    L0rate[6][3] = L0[6][3] + pa1[20][0] * sin(w * t + pa1[20][1])
    L0rate[3][7] = L0[3][7] + pa1[21][0] * sin(w * t + pa1[21][1])
    L0rate[7][3] = L0[7][3] + pa1[21][0] * sin(w * t + pa1[21][1])
    L0rate[4][5] = L0[4][5] + pa1[22][0] * sin(w * t + pa1[22][1])
    L0rate[5][4] = L0[5][4] + pa1[22][0] * sin(w * t + pa1[22][1])
    L0rate[4][6] = L0[4][6] + pa1[23][0] * sin(w * t + pa1[23][1])
    L0rate[6][4] = L0[6][4] + pa1[23][0] * sin(w * t + pa1[23][1])
    L0rate[4][7] = L0[4][7] + pa1[24][0] * sin(w * t + pa1[24][1])
    L0rate[7][4] = L0[7][4] + pa1[24][0] * sin(w * t + pa1[24][1])
    L0rate[5][6] = L0[5][6] + pa1[25][0] * sin(w * t + pa1[25][1])
    L0rate[6][5] = L0[6][5] + pa1[25][0] * sin(w * t + pa1[25][1])
    L0rate[5][7] = L0[5][7] + pa1[26][0] * sin(w * t + pa1[26][1])
    L0rate[7][5] = L0[7][5] + pa1[26][0] * sin(w * t + pa1[26][1])
    L0rate[6][7] = L0[6][7] + pa1[27][0] * sin(w * t + pa1[27][1])
    L0rate[7][6] = L0[7][6] + pa1[27][0] * sin(w * t + pa1[27][1])
    ks = np.zeros((8, 8))
    ks[0][1] = pa1[0][2]
    ks[1][0] = pa1[0][2]
    ks[0][2] = pa1[1][2]
    ks[2][0] = pa1[1][2]
    ks[0][3] = pa1[2][2]
    ks[3][0] = pa1[2][2]
    ks[0][4] = pa1[3][2]
    ks[4][0] = pa1[3][2]
    ks[0][5] = pa1[4][2]
    ks[5][0] = pa1[4][2]
    ks[0][6] = pa1[5][2]
    ks[6][0] = pa1[5][2]
    ks[0][7] = pa1[6][2]
    ks[7][0] = pa1[6][2]
    ks[1][2] = pa1[7][2]
    ks[2][1] = pa1[7][2]
    ks[1][3] = pa1[8][2]
    ks[3][1] = pa1[8][2]
    ks[1][4] = pa1[9][2]
    ks[4][1] = pa1[9][2]
    ks[1][5] = pa1[10][2]
```

```
    ks[5][1] = pa1[10][2]
    ks[1][6] = pa1[11][2]
    ks[6][1] = pa1[11][2]
    ks[1][7] = pa1[12][2]
    ks[7][1] = pa1[12][2]
    ks[2][3] = pa1[13][2]
    ks[3][2] = pa1[13][2]
    ks[2][4] = pa1[14][2]
    ks[4][2] = pa1[14][2]
    ks[2][5] = pa1[15][2]
    ks[5][2] = pa1[15][2]
    ks[2][6] = pa1[16][2]
    ks[6][2] = pa1[16][2]
    ks[2][7] = pa1[17][2]
    ks[7][2] = pa1[17][2]
    ks[3][4] = pa1[18][2]
    ks[4][3] = pa1[18][2]
    ks[3][5] = pa1[19][2]
    ks[5][3] = pa1[19][2]
    ks[3][6] = pa1[20][2]
    ks[6][3] = pa1[20][2]
    ks[3][7] = pa1[21][2]
    ks[7][3] = pa1[21][2]
    ks[4][5] = pa1[22][2]
    ks[5][4] = pa1[22][2]
    ks[4][6] = pa1[23][2]
    ks[6][4] = pa1[23][2]
    ks[4][7] = pa1[24][2]
    ks[7][4] = pa1[24][2]
    ks[5][6] = pa1[25][2]
    ks[6][5] = pa1[25][2]
    ks[5][7] = pa1[26][2]
    ks[7][5] = pa1[26][2]
    ks[6][7] = pa1[27][2]
    ks[7][6] = pa1[27][2]

    t += 0.001
    for i in range(8):
        ballvectors[i] = ballname[i].pos
    springvecs = []
    for z in itertools.combinations(ballvectors, 2):
        springvecs.append(z)


    triangles = []
```

```
    for i in itertools.combinations(ballvectors, 3):
        triangles.append(i)

    for i in range(len(triangles)):
        T[i].v0.pos = triangles[i][0]
        T[i].v1.pos = triangles[i][1]
        T[i].v2.pos = triangles[i][2]
    dampening = 1




    F_mat = np.zeros((8, 8))
    F_vec = []
    F_v = []
    a = np.array(np.zeros((8, 8)))
    for i in range(8):
        for k in range(8):
            if k == i:
                L = 0
                F_mat[i][k] = 0
                F_vec.append(vp.vector(0, 0, 0))
            else:
                L = vp.mag(ballname[k].pos - ballname[i].pos) -
L0rate[k][i]
                # E_s.append(1/2*k_sp*L**2)
                F_mat[i][k] = L * ks[k][i]
                pf0 = ballname[k].pos - ballname[i].pos
                # a[i,k] = vp.norm(pf0)*L*k_sp
                F_vec.append(vp.norm(pf0) * L * ks[k][i])
                # E_S.append(sum(E_s)/2)
    a= np.array(F_vec).reshape(8, 8)
    F = a.sum(axis=0)
    for i in range(8):
        F[i] = F[i] + g_vector * mass
        if ballname[i].pos.y < floor.pos.y:
            F_N = ((floor.pos.y - ballname[i].pos.y) ** 2) * 800
            F[i].y = F[i].y - F_N
            mu = 1
            F_st = mu * F_N
            F_horiz = (F[i].x ** 2 + F[i].z ** 2) ** 0.5
            v_xz= (ballname[i].velocity.x ** 2 +
ballname[i].velocity.z ** 2) ** 0.5
            vx = ballname[i].velocity.x / v_xz
            vz = ballname[i].velocity.z / v_xz
```

```
            if F_st < F_horiz:
                F[i].x += F_horiz * vx - F_N * vx
                F[i].z += F_horiz * vz - F_N * vz
            else:
                F[i].x = F_horiz * vx
                F[i].z = F_horiz * vz
                ballname[i].velocity.x = 0
                ballname[i].velocity.z = 0
    for i in range(8):
        ballname[i].velocity -= (F[i] / mass * dt) * dampening
        ballname[i].pos += ballname[i].velocity * dt
    c+= 1
    if c == 3000:
        break

"""
# Calculating COM
   COM = getCOM(ballname)
   dvec = COM - OriginalCOM
   dis = sqrt(dvec.x ** 2 + dvec.z ** 2)
 # print(dis)
   total_dis.append(dis)
dis_index = np.argsort(total_dis)
sorted_dis = []
sorted_pa1 = []
for i in range(10):
    sorted_dis.append(total_dis[dis_index[i]])
    sorted_pa1.append(pa1[dis_index[i]])
good_dis = sorted_dis[-10:]
dots.append(good_dis)
print('GOODDIS', good_dis[-1])
best_dis.append(good_dis[-1])
pa1 = sorted_pa1[-10:]
print('PA1END', len(pa1))
"""
```