```python
############   CaseStudyCplex.py #############
##  Program running the bi-objective model for
##  "Designing Spatially Cohesive Nature Reserves With Backup Coverage (IJGIS)
##  Authors: Delmelle, Desjardins, Deng
##  Inputs: Study area, distance between parcels/patches
##      weareGrass_Area.txt: information on each patch, including ID, location and area
##      weareGrass_weight.txt: information of biodiversity for each patch
##      weareGrass_Dist.txt: distance between each patch, using vertices
##  Outputs: LP file
##  Contact: delmelle@gmail.com
###########################################################


#import modules
import random, string, os, math, time

#define distance function
def distance(x1, y1, x2, y2):
    dx = x2 - x1
    dy = y2 - y1
    d = math.sqrt(dx**2 + dy**2)
    return d

####  INPUTS  ####

#extent of study area; for predefined grid
left = 947994
right = 991752
bottom = 187782
top = 237660

alpha = .95 #weighting scheme; equation 1
K=3 #number of clusters (K); equation 6
interval=20000 #discretization level
S = 10000 #separation distance; equation 7
M=50000000 #a very large number
A=.5 #percentage (ratio) of total area to set aside (A); equation 9
F=.16 #minimum percentage (ratio) of total area to set aside (F-note that F * K cannot exceed A); equation 8


####  OUTPUT  ####
outputFileName = "C:\\temp\\casestudy_weareAlpha" + str(alpha) +".lp" #naming convention: concatenate alpha value.
outputFile = open(outputFileName,"w")


#### INFORMATION ON PARCELS (or PATCHES) ####
##creating empty vectors
areaList =[]
parcelID = []
parcelAREA=[]
parcelX=[]
parcelY=[]

##Read and store information on area, coordinates and ID of parcels
areaFile = open("weareGrass_Area.txt",'r')
for line in areaFile:
    areaList.append(line.strip("\n").split("\t"))
for row in areaList:
    parcelID.append(int(row[0]))
    parcelAREA.append(float(row[1])+0.0001) #in case some parcels area are = 0
    parcelX.append(float(row[2]))
    parcelY.append(float(row[3]))
print "area read"

##Read and store information on biodiversity within each parcel
weightID=[]
weightVALUE=[]
weightFile = open ("weareGrass_weight.txt",'r')
for line in weightFile:
    a = line.strip("\n")
    b = a.split("\t")
    weightID.append(int(b[0]))
    weightVALUE.append(float(b[1]))
#Normalize biodiversity
NormBio=[]
for i in weightVALUE:
    bioVal = ((i-min(weightVALUE))/(max(weightVALUE)-min(weightVALUE))+0.00001)
    NormBio.append(bioVal)
print "biodiversity read and normalized"

## Reading distances between parcels  (distance must be pre-calculated)
distanceFile = open("weareGrass_Dist.txt",'r')
oriID = []
desID =[]

## Storing distances between parcels  (average, minimum and maximum)
avgDist =[0] * len(parcelID)
minDist =[0] * len(parcelID)
maxDist = [0] * len(parcelID)
for i in range(0,408,1):
    avgDist[i] =[0] * len(parcelID)
    minDist[i] =[0] * len(parcelID)
    maxDist[i] =[0] * len(parcelID)

for line in distanceFile:
    a = line.strip("\n")
    b = a.split("\t")
    oriID.append(int(b[0]))
    desID.append(int(b[1]))
    minDist[int(b[0])][int(b[1])]=float(b[2])
    maxDist[int(b[0])][int(b[1])]=float(b[3])
    avgDist[int(b[0])][int(b[1])]=float(b[4])
print "distances between patches read"


#### INFORMATION ON RESERVES (or CLUSTERS) ####
##creating empty vectors and store ID, location (generated on a grid)
clusterList = []
centerX = []
centerY = []
centerID = []
counter = 0
for i in range(left,right,interval):
    for j in range(bottom,top,interval):
        centerID.append(counter)
        centerX.append(int(i))
        centerY.append(int(j))
        counter+=1

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### DISTANCE COMPUTATION ####
## Computing euclidean distances between parcels/patches and centers of cluster/reserve
Dist =[]
i=0
while i< len(parcelX):
    j=0
    while j<len(centerX):
        Dist.append(float(distance(parcelX[i], parcelY[i], centerX[j], centerY[j])))
        j=j+1
    i=i+1

##Normalize Distances
print "minDist=" + str(min(Dist))
print "maxDist=" + str(max(Dist))
NormDist=[]
for i in range(0,len(Dist), 1):
    NormVal =(float(Dist[i])-float(min(Dist)))/(float(max(Dist))-float(min(Dist))+0.001)
    NormDist.append(NormVal)
print "distances between clusters and patches read and normalized"


#### WRITING LP FORM ####
# 1. Objective function (equations 1, 2 and 3)
outputFile.write("Minimize\n")

for i in range(0,len(parcelX), 1):
    for r in range(0,len(centerX), 1):
       b = math.pow(float(NormDist[(i*len(centerID))+r]), 1) #change power here
       b = float(b*alpha)
       if b<0.000001:
           b=0.000001
       outputFile.write(" +" + str(b)+" X")
       outputFile.write(str(int(parcelID[i]))+"_"+str(int(centerID[r])))


    b = (float(NormBio[i]*(1-alpha)))
    if b<0.000001:
        b=0.00001
    outputFile.write(" - " + str(b)+" B")
    outputFile.write(str(int(parcelID[i])))
print "objective function done"


# 2. Constraints
outputFile.write("\nSubject to")
outputFile.write("\n")

#\ keep track of f1
for i in range(0,len(parcelX), 1):
   for r in range(0,len(centerX), 1):
       b = math.pow(float(NormDist[(i*len(centerID))+r]), 1) #change power here
       outputFile.write(" +" + str(b)+" X")
       outputFile.write(str(int(parcelID[i]))+"_"+str(int(centerID[r])))
outputFile.write(" -f1 = 0\n")

#\ keep track of f2
for i in range(0,len(parcelX), 1):
    b = NormBio[i]
    if b<0.000001:
        b=0.0001
    outputFile.write(" +" + str(b)+" B")
    outputFile.write(str(int(parcelID[i])))
outputFile.write(" - f2 = 0\n")
print "tracking f1 and f2 done"

outputFile.write("f1 > 0 \n")
outputFile.write("f2 > 0 \n")
print "f1 and f2 must be greater than zero"


# definition of state variables
outputFile.write("\n")
outputFile.write("\ define state variable Z\n")
r=0   #cluster r
while r < len(centerID):
    s = 0 #cluster s, s=r+1
    while s<len(centerID):
        i=0 #parcel i
        while i< len(parcelID):
            j=i #parcel j
            while j< len(parcelID):
                if (r != s) and (j != i):
                    outputFile.write("Z" + str(int(parcelID[i]))+"_"+str(int(centerID[r])) + "_" + str(int(parcelID[j]))+"_"+str(int(centerID[s])))
                    outputFile.write(" + X" + str(int(parcelID[i]))+"_"+str(int(centerID[r])) + " + X" + str(int(parcelID[j]))+"_"+str(int(centerID[s])))
                    outputFile.write("=2\n")
                j+=1
            i+=1
        s+=1
    r+=1
    #print i


# Equation 4: when a patch i is selected, it can belong to at most one reserve
i=0
while i< len(parcelID):
    r=0
    while r < len(centerID):
        outputFile.write("+")
        outputFile.write("X")
        outputFile.write(str(int(parcelID[i]))+"_"+str(r))
        r+=1
    outputFile.write("-B")
    outputFile.write(str(int(parcelID[i])))
    outputFile.write("=0\n")
    i+=1
outputFile.write("\n")

# equation 5: Each parcel must be assigned to only one cluster
outputFile.write("\n")
outputFile.write("\ parcel be assigned to a cluster iff cluster exist \n")
i=0
while i< len(parcelID):
    r=0
    while r < len(centerID):
        outputFile.write("X")
        outputFile.write(str(int(parcelID[i]))+"_"+str(int(centerID[r])) + ' - ')
        outputFile.write("Y"+str(int(centerID[r])) +"<=0\n")
        r=r+1
    i=i+1
print "constraint that each parcel must be assigned to only one cluster/reserve... done"


## equation 6: Number of clusters (reserves) should equal to K (p in the formulation)
outputFile.write("\n")
outputFile.write("\ total number of clusters \n")
r=0
while r < len(centerID):
    outputFile.write("+")
    outputFile.write("Y"+str(int(centerID[r])))
    r=r+1
outputFile.write("=" + str(K))
print "constraint stipulating the number of clusters/reserves... done"


# equation 7: If a parcel i belongs to cluster r and parcel i' belongs to cluster r', then
# i and i' must be separated by a minimum distance S. d(i,i',r,r') >= S-(2-Xi-Xi') * M
outputFile.write("\n")
outputFile.write("\ minimum distance between parcels\n")

r=0   #cluster r
while r < len(centerID):
    s = 0 #cluster s, s=r+1
    while s<len(centerID):
        i=0 #parcel i
        while i< len(parcelID):
            j=i #parcel j
            while j< len(parcelID):
                if (r != s) and (j != i):
                    b = round(float(minDist[i][j]), 2)
                    outputFile.write(str(M) + " Z" + str(int(parcelID[i]))+"_"+str(int(centerID[r])) + "_" + str(int(parcelID[j]))+"_"+str(int(centerID[s])))
                    outputFile.write(">=" + str(S-b) + "\n")
                j+=1
            i+=1
        s+=1
    r+=1


# equation 8: cluster (reserve) should contain at least a certain percentage (F) of the total area
outputFile.write("\n \ a cluster/reserve should contain at least a percentage (F) of the total area")
outputFile.write("\n")
r=0
while r < len(centerID):
    i=0
    while i< len(parcelID):
        outputFile.write("+" + str(parcelAREA[i]))
        outputFile.write(" X")
        outputFile.write(str(int(parcelID[i]))+"_"+str(int(centerID[r])))
        i+=1
    outputFile.write("-" + str(float(F) * sum(parcelAREA)) +  " Y" + str(int(centerID[r])) + ">=0\n")
    r+=1
outputFile.write("\n")
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print "cluster should contain at least F parcels"



# equation 9: total area of parcels which are kept should be equal a percentage (A) of the total area
outputFile.write("\n \ total number of area set aside should be should be equal  a percentage (A) of the total area")
outputFile.write("\n")
i=0
while i< len(parcelID):
        outputFile.write("+" + str(parcelAREA[i]))
        outputFile.write(" B")
        outputFile.write(str(int(parcelID[i])))
        i+=1
outputFile.write(">=" + str(float(A) * sum(parcelAREA)) + "\n")
print "total area greater than A"



# equation 10: General constraints
outputFile.write("\n \n")
outputFile.write("GENERAL\n")

r=0   #cluster/reserve r
while r < len(centerID):
    s = 0 #cluster/reserve s, s=r+1
    while s<len(centerID):
        i=0 #parcel/patch i
        while i< len(parcelID):
            j=i #parcel/patch j
            while j< len(parcelID):
                if (r != s) and (j != i):
                    outputFile.write("Z" + str(int(parcelID[i]))+"_"+str(int(centerID[r])) + "_" + str(int(parcelID[j]))+"_"+str(int(centerID[s])))
                    outputFile.write("\n")
                j+=1
            i+=1
        s+=1
    r+=1
print "constraint: integer constraint...done"
outputFile.write("\n \n")



# equation 10: Binary constraints
outputFile.write("BINARY\n")
i=0
while i< len(parcelID):
    r=0
    while r < len(centerID):
        outputFile.write("X")
        outputFile.write(str(int(parcelID[i]))+"_"+str(int(centerID[r])))
        outputFile.write("\n")
        r +=1
    i=i+1
print "constraint: binary constraint...done"


i=0
while i< len(parcelID):
    outputFile.write("B"+str(int(parcelID[i]))+"\n")
    outputFile.write("\n")
    i=i+1
print "constraint: binary constraint...done"


r=0
while r < len(centerID):
    outputFile.write("Y")
    outputFile.write(str(int(centerID[r])))
    outputFile.write("\n")
    r +=1

outputFile.write("END\n")
outputFile.close()
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