Chicago

September 26, 2018

1 Chicago: "we makin' cars"

Implement the Formula SAE contectualized design problem from Zurita et al

1.1 TO DO: CHECK UNITS

everywhere, esp when importing tables

```
In [1]: import numpy as np
        import pandas as pd
        from scipy.stats import chi
        # from opteval import benchmark_func as bf
        import matplotlib

        #for server:
        # matplotlib.use('Agg')

        #for retina display:
        %config InlineBackend.figure_format = 'retina'

        import matplotlib.pyplot as plt
        import copy
        import time as timer
        import threading

        from multiprocessing import Pool
        from playsound import playsound
        # from sklearn import linear_model
```

1.2 Helper Functions

```
In [2]: def cp(x): #make a copy instead of reference
            return copy.deepcopy(x)

        def isNumber(s):
            try:
                float(s)
```

```
            return True
        except ValueError:
            return False

    def isNaN(num):
        return num != num

    def mean(x):
        return np.mean(x)

    def norm(x):
        return float(np.linalg.norm(x))

    def dist(x,y):
        return np.linalg.norm(np.array(x)-np.array(y))

    def bounds(x,low,high):
        if x > high:
            return high
        if x < low:
            return low
        return x
```

In [3]:
```
    def makeAiScore():
        ai = np.random.normal(97,17)
        ai = bounds(ai, 40,150)
        return ai

    def makeIqScore(): #this IQ ranges from 0 to 1, bc it is basically efficiency
        iq = np.random.normal(0.5,0.2)
        iq = bounds(iq, 0.1,1.0)
        return iq

    def pickWorseScore(betterScore,worseScore,temperature):
        if temperature <=1E-6: #never pick worse answers, and avoid devide by 0
            return False
        if np.random.uniform(0,1) < np.exp((betterScore-worseScore)/temperature):  #
            return True
        return False

    def calculateDecay(steps,T0=1.0,Tf=0.01):
        if T0<=Tf or T0<=0:
            return 0
        return (Tf / float(T0) ) ** (1/steps)

    def calculateAgentDecay(agent, steps):
        E_N = normalizedE(agent.kai.E)
        E_transformed = np.exp((E_N*-1)+3.3)
```

```
            startEndRatio = bounds(1/E_transformed, 1E-10,1)
            T0 = agent.temp
            TF = T0 * startEndRatio
            return calculateDecay(steps,T0,TF)
```

In [4]:
```
def chaching():
    playsound("/Users/samlapp/SAE_ABM/missionComplete.wav")
```

1.3 constants and params

In [108]:
```
complexSharing = True #if False, shareBasic() is used, eg strictly-greedy one-dimens
commBonus = 10 #increasing the communication bonus makes successful communication mo
commRange = 180
selfBias = 0 #increasing self bias will make agents choose their solutions more over
startRange = 10
nDims = 56

SO_STRENGTH = 10
RG_STRENGTH = 10
TEAM_MEETING_COST = 1 #1 turn

VERBOSE = False
showViz = False

AVG_SPEED = 1
SD_SPEED = .5
MIN_SPEED = 1E-4
AVG_TEMP = 1
SD_TEMP = 0.5
```

1.4 Load Table of parameters

In [6]:
```
#FIRST TIME:
paramsDF = pd.read_csv("./SAE/paramDB.csv")
paramsDF.columns = ['paramID','name','variable','team','kind','minV','maxV','used']
# paramsDF.at[3,"maxV"] = np.pi/4
# paramsDF.at[10,"maxV"] = np.pi/4
paramsDF.at[17,"maxV"] = np.pi /4
paramsDF.used = pd.to_numeric(paramsDF.used)
paramsDF = paramsDF.drop(columns=["paramID"],axis=1)
#remove unused variables... print(len(paramsDF))
paramsDF = paramsDF.loc[paramsDF.used > 0 ]
paramsDF.to_csv("./SAE/paramDBreduced.csv")
paramsDF = pd.read_csv("./SAE/paramDBreduced.csv")
print(len(paramsDF))
paramsDF = paramsDF.drop(["used"],axis=1)
paramsDF.head()
```

56

Out[6]:

	Unnamed: 0	name	variable	team	kind	minV	maxV
0	0	rear wing height	hrw	rw	1	0.025	0.7
1	1	rear wing length	lrw	rw	1	0.05	0.25
2	2	rear wing width	wrw	rw	1	300	r_track-2*rear_wheel_r
3	3	rear wing angle of attack	arw	rw	1	0	0.7853981634
4	5	rear wing y position	yrw	rw	1	.500 + (h_rw)/2	1.200 - (h_rw)/2

In [7]:
```
paramsDF.loc[paramsDF.variable == "asw"]
```

Out[7]:

	Unnamed: 0	name	variable	team	kind	minV	maxV
15	17	side wings angle of attack	asw	sw	1	0	0.7853981633974483

In [8]:
```
#logical vector for parameters with fixed min/max (TRUE), or min/max as f(p) (FALSE)
hasNumericBounds = [True if isNumber(row.minV) and isNumber(row.maxV) else False for i
```

In [9]:
```
# materialsDF = pd.read_csv("/Users/samlapp/Documents/THRED Lab/SAE/materials.csv")
# materialsDF.q = [int(1 + np.random.uniform(0.98,1.02)*materialsDF.iloc[i]['q']) for
# materialsDF.to_csv("/Users/samlapp/Documents/THRED Lab/SAE/materialsTweaked.csv")
materialsDF = pd.read_csv("./SAE/materialsTweaked.csv")
materialsDF.head()
```

Out[9]:

	Unnamed: 0	Material	Code	q	E
0	0	Glass-filled epoxy (35%)	GFE	1890	1900000000
1	1	Glass-filled polyester (35%)	GFP	1989	2000000000
2	2	Glass-filled nylon (35%)	GFN	1607	1600000000
3	3	S-glass epoxy (45%)	SGE	1781	1800000000
4	4	Carbon epoxy (61%)	CE	1627	1600000000

In [10]:
```
tiresDF = pd.read_csv("./SAE/tires.csv")
tiresDF
```

Out[10]:

	ID	radius	mass
0	T1	0.22860	3.636
1	T2	0.22987	4.091
2	T3	0.23241	4.545
3	T4	0.24638	4.545

```
4  T5  0.24765  5.000
5  T6  0.26670  5.000
6  T7  0.26670  5.000
7  T8  0.26162  5.455
```

In [11]:
```
# motorsDF = pd.read_csv("/Users/samlapp/Documents/THRED Lab/SAE/motors.csv")
# # first time: we want to make motors with the same power slightly different:
# motorsDF.Power = [int(1 + np.random.uniform(0.98,1.02)*motorsDF.iloc[i]['Power']) f
# motorsDF.to_csv("/Users/samlapp/Documents/THRED Lab/SAE/motorsTweaked.csv")
enginesDF = pd.read_csv("./SAE/motorsTweaked.csv")
print("unique" if len(enginesDF)-len(np.unique(enginesDF.Power)) == 0 else "not uniuq
enginesDF.columns = ["ind","id","name","le","we","he","me","Phi_e","T_e"]
enginesDF.head()
```

```
unique
```

Out[11]:

	ind	id	name	le	we	he	me	Phi_e	T_e
0	0	M1	GX200	0.321	0.376	0.346	16.1	4157	912.4
1	1	M2	GX240	0.380	0.429	0.422	27.5	5980	18.3
2	2	M3	GX270	0.380	0.429	0.422	25.0	6208	19.1
3	3	M4	GX340	0.407	0.485	0.449	31.5	7866	26.4
4	4	M5	GXV340	0.433	0.382	0.406	32.3	6677	21.6

In [12]:
```
# susDF = pd.read_csv("/Users/samlapp/Documents/THRED Lab/SAE/suspension.csv")
# susDF.krsp = [int(np.random.uniform(0.98,1.02)*susDF.iloc[i]['krsp']) for i in rang
# susDF.kfsp = susDF.krsp
# susDF.to_csv("/Users/samlapp/Documents/THRED Lab/SAE/suspensionTweaked.csv")
susDF = pd.read_csv("./SAE/suspensionTweaked.csv")
print("unique" if len(susDF)-len(np.unique(susDF.krsp)) == 0 else "not uniuqe")
susDF = susDF.drop(columns=[susDF.columns[0]])
susDF.head()
```

```
unique
```

Out[12]:

	id	krsp	crsp	mrsp	kfsp	cfsp	mfsp
0	S1	3982	600	0.3	3982	600	0.3
1	S2	21189	2000	0.3	21189	2000	0.3
2	S3	20784	2000	0.3	20784	2000	0.3
3	S4	21231	2000	0.3	21231	2000	0.3
4	S5	20650	2000	0.3	20650	2000	0.3

In [13]:
```
# brakesDF = pd.read_csv("/Users/samlapp/Documents/THRED Lab/SAE/brakes.csv")
# brakesDF.columns = [a.strip() for a in brakesDF.columns]
# brakesDF.rbrk = [np.random.uniform(0.98,1.02)*brakesDF.iloc[i]['rbrk'] for i in ran
# brakesDF.to_csv("/Users/samlapp/Documents/THRED Lab/SAE/brakesTweaked.csv")
brakesDF = pd.read_csv("./SAE/brakesTweaked.csv")
print("unique" if len(brakesDF)-len(np.unique(brakesDF['rbrk'])) == 0 else "not uniuq
brakesDF = brakesDF.drop(columns=[brakesDF.columns[0]])
brakesDF.head()
```

unique

Out[13]:

	brakeID	qbrk	lbrk	hbrk	wbrk	tbrk	rbrk
0	B1	0.4	0.10	0.0425	0.0200	0.350	0.025447
1	B2	0.4	0.14	0.0490	0.0175	0.350	0.024598
2	B3	0.4	0.14	0.0615	0.0175	0.350	0.027990
3	B4	0.5	0.10	0.0380	0.0160	0.350	0.030169
4	B5	0.5	0.10	0.0425	0.0200	0.355	0.031523

In [14]:
```
# paramsDF.variable
```

In [15]:
```
class Params:
    def __init__(self,v = paramsDF):
        self.vars = v.variable
        self.team = v.team
        for i, row in v.iterrows():
            setattr(self, row.variable.strip(),-1)
p = Params()
for v in p.vars:
    value = np.random.uniform()
    setattr(p,v,value)
paramsDF.loc[paramsDF.variable=="hrw"]["team"][0]

teams = np.unique(paramsDF.team)
teamDimensions = [[row.team == t for i, row in paramsDF.iterrows()] for t in teams]
teamDictionary = {}
for i in range(len(teams)):
    teamDictionary[teams[i]] = teamDimensions[i]
paramList = np.array(paramsDF.variable)
```

In [16]:
```
#convert parameter vector to Parameter object
pNames = paramsDF.variable
blankParameterObject = Params()
def asParameters(pList):
    p = cp(blankParameterObject)
    for i in range(len(pList)):
        setattr(p,pNames[i],pList[i])
    return p

numberParameters = len(paramsDF)
def asVector(params):
    r = np.zeros(numberParameters)
    for i in range(numberParameters):
        pName = pNames[i]
        r[i] = getattr(params,pName)
    return r
```

In [17]:
```
p = startParams()
v = asVector(p)
```

```
---------------------------------------------------------------------------

NameError                                 Traceback (most recent call last)

<ipython-input-17-72947ffea02e> in <module>()
----> 1 p = startParams()
      2 v = asVector(p)


NameError: name 'startParams' is not defined
```

```
In [18]: %timeit asParameters(v)
         %timeit asVector(p)
```

```
191 ţs ś 9.61 ţs per loop (mean ś std. dev. of 7 runs, 1000 loops each)
454 ţs ś 5.76 ţs per loop (mean ś std. dev. of 7 runs, 1000 loops each)
```

1.5 Objective Subfunctions

1.5.1 constants

The car's top velocity vcar is 26.8 m/s (60 mph).
The car's engine speed x_e is 3600 rpm.
The density of air q_air during the race is 1.225 kg/m3.
The track radio of curvature r_track is 9 m.
The pressure applied to the brakes Pbrk is 1x10^7 Pa

```
In [19]: #scale parameters to go between unit cube (approximately) and SI units
         paramMaxValues = []
```

```
In [20]: v_car = 26.8 #m/s (60 mph)
         w_e = 3600 * 60 * 2 *np.pi #rpm  to radians/sec
         rho_air = 1.225 #kg/m3.
         r_track = 9 #m
         P_brk = 10**7 #Pascals
         C_dc = 0.04 #drag coefficient of cabin
         gravity = 9.81 #m/s^2
```

```
In [21]: #mass (minimize)
         def mrw(p):
             return p.lrw * p.wrw *p.hrw * p.qrw
         def mfw(p):
             return p.lfw * p.wfw *p.hfw * p.qfw
         def msw(p):
             return p.lsw * p.wsw *p.hsw * p.qsw
         def mia(p):
```

```
        return p.lia * p.wia *p.hia * p.qia
    def mc(p):
        return 2*(p.hc*p.lc*p.tc + p.hc*p.wc*p.tc + p.lc*p.hc*p.tc)*p.qc
    def mbrk(p):
        #CHRIS missing parameters: how is mbrk calculated? assuming lrw*rho
        return p.lbrk * p.wbrk * p.hbrk * p.qbrk
    def mass(p): #total mass, minimize
        mass = mrw(p) + mfw(p) + 2 * msw(p) + 2*p.mrt + 2*p.mft + p.me + mc(p) + mia(p) +
        return mass
```

In [22]:
```
    #center of gravity height, minimize
    def cGy(p):
        t1 =  (mrw(p)*p.yrw + mfw(p)*p.yfw+ p.me*p.ye + mc(p)*p.yc + mia(p)*p.yia) / mass
        t2 = 2* (msw(p)*p.ysw + p.mrt*p.rrt + p.mft*p.rft + mbrk(p)*p.rft + p.mrsp*p.yrsp

        return t1 + t2
```

In [23]:
```
    #Drag (minimize) and downforce (maximize)
    def AR(w,alpha,l): #aspect ratio of a wing
        return w* np.cos(alpha) / l

    def C_lift(AR,alpha): #lift coefficient of a wing
        return 2*np.pi* (AR / (AR + 2)) * alpha

    def C_drag(C_lift, AR): #drag coefficient of wing
        return C_lift**2 / (np.pi * AR)

    def F_down_wing(w,h,l,alpha,rho_air,v_car): #total downward force of wing
        wingAR = AR(w,alpha,l)
        C_l = C_lift(wingAR, alpha)
        return 0.5 * alpha * h * w * rho_air * (v_car**2) * C_l

    def F_drag_wing(w,h,l,alpha,rho_air,v_car): #total drag force on a wing
        wingAR = AR(w,alpha,l)
    #     print(wingAR)
        C_l = C_lift(wingAR, alpha)
    #     print(C_l)
        C_d = C_drag(C_l,wingAR)
    #     print(C_d)
        return F_drag(w,h,rho_air,v_car,C_d)

    def F_drag(w,h,rho_air,v_car,C_d):
        return 0.5*w*h*rho_air*v_car**2*C_d

    def F_drag_total(p): #total drag on vehicle
        cabinDrag = F_drag(p.wc,p.hc,rho_air,v_car,C_dc)
        rearWingDrag = F_drag_wing(p.wrw,p.hrw,p.lrw,p.arw,rho_air,v_car)
        frontWingDrag = F_drag_wing(p.wfw,p.hfw,p.lfw,p.afw,rho_air,v_car)
```

```
        sideWingDrag = F_drag_wing(p.wsw,p.hsw,p.lsw,p.asw,rho_air,v_car)
        return rearWingDrag + frontWingDrag + 2* sideWingDrag + cabinDrag

    def F_down_total(p): #total downforce
        downForceRearWing = F_down_wing(p.wrw,p.hrw,p.lrw,p.arw,rho_air,v_car)
        downForceFrontWing = F_down_wing(p.wfw,p.hfw,p.lfw,p.afw,rho_air,v_car)
        downForceSideWing = F_down_wing(p.wsw,p.hsw,p.lsw,p.asw,rho_air,v_car)
        return downForceRearWing + downForceFrontWing + 2*downForceSideWing
```

In [24]:
```
#acceleration (maximize)
def rollingResistance(p,tirePressure,v_car):
    C = .005 + 1/tirePressure * (.01 + .0095 * (v_car**2))
    return C * mass(p) * gravity

def acceleration(p):
    mTotal = mass(p)
    tirePressure = p.Prt #CHRIS should it be front or rear tire pressure?
    total_resistance = F_drag_total(p) + rollingResistance(p, tirePressure,v_car)

    w_wheels = v_car / p.rrt #rotational speed of rear tires

    efficiency = total_resistance * v_car / p.Phi_e

    torque = p.T_e

    #converted units of w_e from rpm to rad/s !!!
    F_wheels = torque * efficiency * w_e /(p.rrt * w_wheels)

    return (F_wheels - total_resistance) / mTotal
# acceleration(p)
```

In [25]:
```
#crash force (minimize)
def crashForce(p):
    return np.sqrt(mass(p) * v_car**2 * p.wia * p.hia * p.Eia / (2*p.lia))
```

In [26]:
```
#impact attenuator volume (minimize)
def iaVolume(p):
    return p.lia*p.wia*p.hia
```

In [27]:
```
#corner velocity (maximize)
y_suspension = 0.05 # m
dydt_suspension = 0.025 #m/s
def suspensionForce(k,c):
    return k*y_suspension + c*dydt_suspension

def cornerVelocity(p):
    F_fsp = suspensionForce(p.kfsp,p.cfsp)
    F_rsp = suspensionForce(p.krsp,p.crsp)
    downforce = F_down_total(p)
```

```
        mTotal = mass(p)

        #CHRIS again, rear tire pressure?
        C = rollingResistance(p,p.Prt,v_car)
        forces = downforce+mTotal*gravity-2*F_fsp-2*F_rsp
        if forces < 0:
            return 0
        return np.sqrt( forces * C * r_track / mTotal )
    # cornerVelocity(p)
```

In [28]:
```
    #breaking distance (minimize)
    def breakingDistance(p):
        mTotal = mass(p)
        C = rollingResistance(p,p.Prt,v_car)

        #CHRIS need c_brk break friction coef, and A_brk (rectangle or circle?)
        #breaking torque
        A_brk = p.hbrk * p.wbrk
        c_brk = .37 #?   most standard brake pads is usually in the range of 0.35 to 0.42
        Tbrk = 2 * c_brk * P_brk * A_brk * p.rbrk

        #y forces:
        F_fsp = suspensionForce(p.kfsp,p.cfsp)
        F_rsp = suspensionForce(p.krsp,p.crsp)
        Fy = mTotal*gravity + F_down_total(p) - 2 * F_rsp - 2*F_fsp

        #breaking accelleration
        #CHRIS front and rear tire radius are same? (rrt and rft)
        a_brk = Fy * C / mTotal + 4*Tbrk*C/(p.rrt*mTotal)

        #breaking distance
        return v_car**2 / (2*a_brk)
    # breakingDistance(p)
```

In [29]:
```
    #suspension acceleration (minimize)
    def suspensionAcceleration(p):
        Ffsp = suspensionForce(p.kfsp,p.cfsp)
        Frsp = suspensionForce(p.krsp,p.crsp)
        mTotal = mass(p)
        Fd = F_down_total(p)
        return (2*Ffsp - 2*Frsp - mTotal*gravity - Fd)/mTotal
    # suspensionAcceleration(p)
```

In [30]:
```
    #pitch moment (minimize)
    def pitchMoment(p):
        Ffsp = suspensionForce(p.kfsp,p.cfsp)
        Frsp = suspensionForce(p.krsp,p.crsp)
```

```
    downForceRearWing = F_down_wing(p.wrw,p.hrw,p.lrw,p.arw,rho_air,v_car)
    downForceFrontWing = F_down_wing(p.wfw,p.hfw,p.lfw,p.afw,rho_air,v_car)
    downForceSideWing = F_down_wing(p.wsw,p.hsw,p.lsw,p.asw,rho_air,v_car)
    #CHRIS assuming lcg is lc? and lf is ?
    lcg = p.lc
    lf = 0.5
    return 2*Ffsp*lf + 2*Frsp*lf + downForceRearWing*(lcg - p.lrw) - downForceFrontWi
# pitchMoment(p)
```

1.6 Global Objective

In [31]:
```
#Global objective: linear sum of objective subfunctions
#sub-objectives to maximize will be mirrored *-1 to become minimizing

subObjectives = [mass,cGy,F_drag_total,F_down_total,acceleration,crashForce,iaVolume,
alwaysMinimize = [1,1,1,-1,-1,1,1,-1,1,1,1] #1 for minimizing, -1 for maximizing
weightsNull = np.ones(len(subObjectives)) / len(subObjectives)
weights1 = np.array([14,1,20,30,10,1,1,10,10,2,1])/100
weights2 = np.array([25,1,15,20,15,1,1,15,5,1,1])/100
weights3 = np.array([14,1,20,15,25,1,1,10,10,2,1])/100

weightsCustom = np.array([14,1,20,30,11,1,1,10,10,2,0])/100 #pitch moment is zero bc

def objectiveDetailedNonNormalized(p,weights):
    score = 0
    subscores = []
    for i in range(len(subObjectives)):
        obj = subObjectives[i]
        subscore = obj(p)
        subscores.append(subscore)
        score += weights[i]*alwaysMinimize[i]*subscore
    return score,subscores

# subscoreMean = np.zeros(len(subObjectives))
# subscoreSd = np.ones(len(subObjectives))

def objective(p,weights):
    score = 0
    for i in range(len(subObjectives)):
        obj = subObjectives[i]
        subscore= obj(p)
        normalizedSubscore = (subscore - subscoreMean[i]) / subscoreSd[i]
        score += weights[i]*alwaysMinimize[i]*normalizedSubscore
    return score

def objectiveDetailed(p,weights):
    score = 0
    subscores = []
```

```
        for i in range(len(subObjectives)):
            obj = subObjectives[i]
            subscore= obj(p)
            normalizedSubscore = (subscore - subscoreMean[i]) / subscoreSd[i]
            subscores.append(normalizedSubscore)
            score += weights[i]*alwaysMinimize[i]*normalizedSubscore
        return score, subscores
```

1.7 Constraints

1.8 constraints not done

I didnt actually do the constraint functions yet just bounds

```
In [32]: #a list with all the min-max functions (!) which can be called to return max and min
         minMaxParam = [None for i in range(len(paramsDF))]
         def wrw(p):
             minV = 0.300
             maxV = r_track - 2 * p.rrt

             return minV, maxV
         minMaxParam[paramsDF.loc[paramsDF.variable=="wrw"].index[0]] = wrw

         # def xrw(p):
         #     minV = p.lrw / 2
         #     maxV = .250 - minV
         #     return minV, maxV
         # minMaxParam[paramsDF.loc[paramsDF.variable=="xrw"].index[0]] = xrw

         def yrw(p):
             minV = .5 + p.hrw / 2
             maxV = 1.2 - p.hrw / 2
             return minV, maxV
         minMaxParam[paramsDF.loc[paramsDF.variable=="yrw"].index[0]] = yrw
         wheelSpace = .1 #?? don't have an equation for this rn, min is .075

         aConst = wheelSpace
         def lfw(p):
             minV = .05
             maxV = .7 - aConst
             return minV, maxV
         minMaxParam[paramsDF.loc[paramsDF.variable=="lfw"].index[0]] = lfw

         f_track = 3 # bounds: 3, 2.25 m
         def wfw(p):
             minV = .3
             maxV = f_track
             return minV, maxV
         minMaxParam[paramsDF.loc[paramsDF.variable=="wfw"].index[0]] = wfw
```

```
# def xfw(p):
#     minV = p.lrw + p.rrt + p.lc + p.lia + p.lfw/2
#     maxV = .25 + p.rrt + p.lc + p.lia + p.lfw/2
#     return minV, maxV
# minMaxParam[paramsDF.loc[paramsDF.variable=="xfw"].index[0]] = xfw

xConst = .030 #ground clearance 19 to 50 mm
def yfw(p):
    minV = xConst + p.hfw / 2
    maxV = .25 - p.hfw/2
    return minV, maxV
minMaxParam[paramsDF.loc[paramsDF.variable=="yfw"].index[0]] = yfw

# def xsw(p):
#     minV = p.lrw + 2*p.rrt + aConst + p.lsw / 2
#     maxV = .250 + 2*p.rrt + aConst + p.lsw / 2
#     return minV, maxV
# minMaxParam[paramsDF.loc[paramsDF.variable=="xsw"].index[0]] = xsw

def ysw(p):
    minV = xConst + p.hsw/2
    maxV = .250 - p.hsw/2
    return minV, maxV
minMaxParam[paramsDF.loc[paramsDF.variable=="ysw"].index[0]] = ysw

# def xrt(p):
#     minV = p.lrw + p.rrt
#     maxV = .250 + p.rrt
#     return minV, maxV
# minMaxParam[paramsDF.loc[paramsDF.variable=="xrt"].index[0]] = xrt

# def xft(p):
#     minV = p.lrw + p.rrt + p.lc
#     maxV = .250 + p.rrt  + p.lc
#     return minV, maxV
# minMaxParam[paramsDF.loc[paramsDF.variable=="xft"].index[0]] = xft

# def xe(p):
#     minV = p.lrw + p.rrt - p.le / 2
#     maxV = p.lrw + aConst + p.rrt - p.le / 2
#     return minV, maxV
# minMaxParam[paramsDF.loc[paramsDF.variable=="xe"].index[0]] = xe

def ye(p):
    minV = xConst + p.he / 2
    maxV = .5 - p.he / 2
    return minV, maxV
```

```
minMaxParam[paramsDF.loc[paramsDF.variable=="ye"].index[0]] = ye

def hc(p):
    minV = .500
    maxV = 1.200 - xConst
    return minV, maxV
minMaxParam[paramsDF.loc[paramsDF.variable=="hc"].index[0]] = hc

# def xc(p):
#     minV = p.lrw + p.rrt + p.lc / 2
#     maxV = .250 + p.rrt + p.lc / 2
#     return minV, maxV
# minMaxParam[paramsDF.loc[paramsDF.variable=="xc"].index[0]] = xc

def yc(p):
    minV = xConst + p.hc / 2
    maxV = 1.200 - p.hc / 2
    return minV, maxV
minMaxParam[paramsDF.loc[paramsDF.variable=="yc"].index[0]] = yc

def lia(p):
    minV = .2
    maxV = .7  - p.lfw # what is l_fr?
    return minV, maxV
minMaxParam[paramsDF.loc[paramsDF.variable=="lia"].index[0]] = lia

# def xia(p):
#     minV = p.lrw + p.rrt + p.lc + p.lia / 2
#     maxV = .250 + p.rrt + p.lc + p.lia/ 2
#     return minV, maxV
# minMaxParam[paramsDF.loc[paramsDF.variable=="xia"].index[0]] = xia

def yia(p):
    minV = xConst + p.hia / 2
    maxV = 1.200 - p.hia / 2
    return minV, maxV
minMaxParam[paramsDF.loc[paramsDF.variable=="yia"].index[0]] = yia

def yrsp(p):
    minV = p.rrt
    maxV = p.rrt * 2
    return minV, maxV
minMaxParam[paramsDF.loc[paramsDF.variable=="yrsp"].index[0]] = yrsp

def yfsp(p):
    minV = p.rft
    maxV = p.rft * 2
    return minV, maxV
```

```
        minMaxParam[paramsDF.loc[paramsDF.variable=="yfsp"].index[0]] = yfsp

        #test:
        # for f in minMaxParam:
        #     if f is not None:
        #         print(f(p))
```

In [33]:
```
def getAttr(obj):
    return [a for a in dir(obj) if not a.startswith('__')]
```

In [34]:
```
def findMaterialByDensity(rho):
    differences = abs(np.array(materialsDF.q) - rho)
    material = materialsDF.iloc[np.argmin(differences)]
    return material.Code, material.q, material.E
def findTireByRadius(radius):
    differences = abs(np.array(tiresDF.radius) - radius)
    tire = tiresDF.iloc[np.argmin(differences)]
    return tire.ID, tire.radius, tire.mass

def findEngineByPower(power):
    differences = abs(np.array(enginesDF.Phi_e) - power)
    engine = enginesDF.loc[np.argmin(differences)]
    return engine

def findSuspensionByK(k):
    differences = abs(np.array(susDF.krsp) - k)
    sus = susDF.loc[np.argmin(differences)]
    return sus

def findBrakesByR(r): #what is the driving variable for brakes??? r?
    differences = abs(np.array(brakesDF.rbrk) - r)
    brakes = brakesDF.loc[np.argmin(differences)]

    return brakes
```

In [35]:
```
def constrain(p,dimsToConstrain=np.ones(len(paramsDF))):
#     p_attribute = getAttr(p)
    paramIndices = [i for i in range(len(dimsToConstrain)) if dimsToConstrain[i] ==1]
    for i in paramIndices: #range(len(paramsDF)): # we need to do the equations bound
#         if not dimsToConstrain[i]: #we don't need to check this dimension, it didn'
#             continue
        param = paramsDF.loc[i]
        variable = param.variable
        value = getattr(p,variable)
        if param.kind == 1: #continuous param with min and max
            if hasNumericBounds[i]:
                newValue = bounds(value,float(param["minV"]),float(param["maxV"]))
                setattr(p,variable,newValue)
```

```
            #do the equation ones after setting all other parameters

        elif param.kind == 2: #choose a material based on density
            materialID,density,modulusE = findMaterialByDensity(value)
            setattr(p,variable,density)
            #find other variables that are driven by this one:
            for i, otherParam in paramsDF[paramsDF.team == variable].iterrows():#dime
                setattr(p,otherParam.variable,modulusE)
        elif param.kind == 3: #choose tires
            tireID,radius,weight = findTireByRadius(value)
            setattr(p,variable,radius)
            #find other variables that are driven by this one:
            for i, otherParam in paramsDF[paramsDF.team == variable].iterrows():
                setattr(p,otherParam.variable,weight)
        elif param.kind == 4: #choose motor
            tableRow= findEngineByPower(value) #Phi_e,l_e,w_e,h_e,T_e,m_e
            setattr(p,variable,tableRow[variable])
            #find other variables that are driven by this one:
            for i, otherParam in paramsDF[paramsDF.team == variable].iterrows():
                setattr(p,otherParam.variable,tableRow[otherParam.variable])
        elif param.kind == 5: #choose brakes
            tableRow = findBrakesByR(value) # r is driving variable

            setattr(p,variable,tableRow[variable]) #df columns need to be same as var
            #find other variables that are driven by this one:
            for i, otherParam in paramsDF[paramsDF.team == variable].iterrows():
            #their "team" is THIS VAR: dimension is driven by this
                setattr(p,otherParam.variable,tableRow[otherParam.variable])

        elif param.kind == 6: #choose suspension
            tableRow = findSuspensionByK(value) #kfsp, cfsp, mfsp
            setattr(p,variable,tableRow[variable])
            #find other variables that are driven by this one:
            for i, otherParam in paramsDF[paramsDF.team == variable].iterrows():#thei
                setattr(p,otherParam.variable,tableRow[otherParam.variable])

    #now we can do the ones that depend on other variables
    for i in paramIndices:
        param = paramsDF.loc[i]
        variable = param.variable
        value = getattr(p,variable)
        if param.kind == 1 and not hasNumericBounds[i]:
            f = minMaxParam[i] #list of minMax functions for each variable
            minV, maxV = f(p)
            newValue = bounds(value,minV,maxV)
            setattr(p,variable,newValue)
    return p
```

1.9 create the scaling vector

```
In [36]: pVmax = asParameters([1e30 for i in range(len(paramsDF))])
         maxVals = pVmax
         maxVals = constrain(pVmax)
         scalingVector = asVector(maxVals) #this acts as a scaling vector to map SI unit value
         # paramsDF.iloc[11]
```

1.10 create realistic starting values

```
In [37]: def startParams(returnParamObject=True):
             nParams = len(paramsDF)
             pV = np.random.uniform(0,1,nParams) * scalingVector
             p = constrain(asParameters(pV))
         #     print(asVector(p))
             return p if returnParamObject else asVector(p)
         # objective(p,weightsCustom)

In [38]: # p = startParams()
         # constrained = asVector(p)
         # # constrained/ scalingVector
         # for i, row in paramsDF.iterrows():
         #     print(row[1] + " : \t"+str(constrained[i]))
```

1.10.1 run random possible start values through objectives to get distribution of outputs

```
In [39]: # subscores = []
         # for i in range(2000):
         #     p = startParams()
         #     _,ss = objectiveDetailedNonNormalized(p,weightsNull)
         #     subscores.append(ss)
         # s = np.array(subscores)

In [40]: # x = s[:,7]
         # s[:,7 ] = [3000 if isNaN(x[i]) else x[i] for i in range(len(x)) ]
```

1.10.2 capture the mean and standard deviations of subscores

so that we can normalize them assuming Normal dist. Now, the objective function will fairly weight sub-objectives using custom weights

```
In [41]: # #FIRST TIME, need to run this if we don't have the file with saved values
         # subscoreMean = []
         # subscoreSd = []
         # for i in range(len(subscores[0])):
         #     subscoreMean.append(np.mean(s[:,i]))
         #     subscoreSd.append(np.std(s[:,i]))

         # subscoreStatsDF = pd.DataFrame(columns=["subscoreMean","subscoreSD"],data=np.transp
```

```
        # subscoreStatsDF.to_csv("./SAE/subscoreStatsDF.csv")

        # #     plt.hist((np.array(s[:,i]) - subscoreMean[i])/subscoreSd[i])
        # #     plt.show()
```

```
In [42]: subscoreStatsDF = pd.read_csv("./SAE/subscoreStatsDF.csv")
         subscoreMean = list(subscoreStatsDF.subscoreMean)
         subscoreSd = list(subscoreStatsDF.subscoreSD)
```

```
In [46]: objective(startParams(),weightsCustom)
```

```
Out[46]: -1.2512569551431818
```

2 Create Virtual Population with represntative KAI scores

based on KAI score and subscore dataset provided by Dr. J

```
In [77]: kaiDF_DATASET = pd.read_csv("./KAI/KAI_DATA_2018_07_09.csv")
         kaiDF_DATASET.columns = ["KAI","SO","E","RG"]
         def makeKAI(n=1,asDF=True):
             pop = np.random.multivariate_normal(kaiDF_DATASET.mean(),kaiDF_DATASET.cov(),n)
             if asDF:
                 popDF = pd.DataFrame(pop)
                 popDF.columns = kaiDF_DATASET.columns
                 return popDF if n>1 else popDF.loc[0]
             else:
                 return pop if n>1 else pop[0]

         # def makeSubscores(kai,n=1,asDF=True):
         #     pop = np.random.multivariate_normal(kaiDF_DATASET.mean(),kaiDF_DATASET.cov(),n)
         kaiPopulation = makeKAI(100000)
         kaiPopulation=kaiPopulation.round()
```

```
In [78]: def findAiScore(kai):
             kai = int(kai)
             a = kaiPopulation.loc[kaiPopulation['KAI'] == kai]
             ind = np.random.choice(a.index)
             me = kaiPopulation.loc[ind]
             return KAIScore(me) #this is a KAIScore object
```

```
In [79]: def normalizedAI(ai):
             return (ai - kaiDF_DATASET.mean().KAI)/kaiDF_DATASET.std().KAI
         def normalizedRG(rg):
             return (rg - kaiDF_DATASET.mean().RG)/kaiDF_DATASET.std().RG
         def normalizedE(E):
             return (E - kaiDF_DATASET.mean().E)/kaiDF_DATASET.std().E
         def normalizedSO(SO):
             return (SO - kaiDF_DATASET.mean().SO)/kaiDF_DATASET.std().SO
```

```
In [80]: kaiDF_DATASET.mean().E
         kaiDF_DATASET.std().E

Out[80]: 5.251845955448993

In [81]: def dotNorm(a,b): #return normalized dot product (how parallel 2 vectors are, -1 to 1
             if norm(a) <= 0 or norm(b)<= 0:
         #         print("uh oh, vector was length zero")
                 return 0
             a = np.array(a)
             b = np.array(b)
             dotAB = np.sum(a*b)
             normDotAB = dotAB / (norm(a)*norm(b))
             return normDotAB

In [82]: def plotCategoricalMeans(x,y):
             categories = np.unique(x)
             means = []
             sds = []
             for c in categories:
                 yc = [y[i] for i in range(len(y)) if x[i] == c]
                 means.append(np.mean(yc))
                 sds.append(np.std(yc))
             plt.errorbar(categories,means,yerr=sds,marker='o',ls='none')

             return means

In [83]: #speed distributions:
         dfConstant=1.9
         def travelDistance(speed): #how far do we go? chi distribution, but at least go 0.1 *
             r = np.max([chi.rvs(dfConstant),0.1])
             return r * speed

In [84]: def memoryWeightsPrimacy(n):
             if n==1:
                 return np.array([1])
             weights = np.arange(n-1,-1,-1)**3*0.4 + np.arange(0,n,1)**3
             weights = weights / np.sum(weights)
             return weights

In [85]: def aiColor(ai): #red for innovators, blue for adaptors
             ai01 = bounds((ai - 40)/ 120,0,1)
             red = ai01
             blue = 1 - ai01
             return (red,0,blue)

In [86]: def makeParamString():
             s= ""
             s+= "steps: "+ str(steps) + " \n"
```

```
        s+= "self-bias: " +str(selfBias)+ " \n"
        s+= "num agents: " +str(nAgents)+ " \n"
        s+= "rg strength: " +str(RG_STRENGTH)+ " \n"
        s+= "so strength: " +str(SO_STRENGTH)+ " \n"
        s+= "repeats: " +str(reps)+ " \n"
        s+= "avg speed: " +str(AVG_SPEED) + " \n"
        s+= "sd speed: " + str(SD_SPEED)+ " \n"
        s+= "min speed: " +str(MIN_SPEED)+ " \n"
        s+= "avg temp: "+ str(AVG_TEMP)+ " \n"
        s+= "sd temp: " +str(SD_TEMP)+ " \n"
        return s
```

2.1 Agent and Team Classes

```
In [87]: class Agent:
             def __init__(self, id=-1):
                 self.id = id
                 self.score = np.inf
                 self.params = startParams()
                 self.r = asVector(self.params)
                 self.rNorm = self.r / scalingVector
                 self.nmoves = 0
                 self.kai = KAIScore()
                 self.speed = bounds(AVG_SPEED + normalizedAI(self.kai.KAI) * SD_SPEED, MIN_SPI
                 self.temp = bounds(AVG_TEMP + normalizedE(self.kai.E) * SD_TEMP, 0 ,np.inf)
                 self.iq = 1 #makeIqScore()
                 self.memory = [Solution(self.r,self.score,self.id,type(self))]
                 self.team = -1
                 self.decay = calculateAgentDecay(self,100)
                 self.startTemp = self.temp
                 self.startSpeed = self.speed

             def move(self,soBias=False,groupConformityBias=False,teamPosition=None):
                 if np.random.uniform()>self.iq: #I'm just thinking this turn
                     return False

         #         print("my dimensions:" +str(self.myDims))
                 #pick a new direction
                 d = np.random.uniform(-1,1,nDims)
                 d = d * self.myDims #project onto the dimensions I can move
                 dn = np.linalg.norm(d)
                 if dn==0: print("divide by zero (dn)")
                 #distance moved should be poisson distribution, rn its just my speed
                 distance = travelDistance(self.speed) * nDims
                 d = d / dn * distance
         #         print('considering moving '+str(d) + ' from '+str(self.r))
                 candidateSolution = asParameters((self.rNorm + d)*scalingVector)
                 candidateSolution = constrain(candidateSolution,self.myDims)
```

```
        acceptsNewSolution = self.evaluate(candidateSolution,soBias,groupConformityBia
        if acceptsNewSolution:
            self.moveTo(asVector(candidateSolution))
            return True
        self.score = self.f()
        return False

    def moveTo(self, r):
        self.r = r
        self.rNorm = self.r / scalingVector
        self.params = asParameters(self.r)
        self.score = self.f()
        self.memory.append(Solution(self.r,self.score,self.id,type(self)))
        self.nmoves += 1

    def startAt(self,position):
        self.r = position
        self.rNorm = self.r / scalingVector
        self.params = asParameters(self.r)
        self.memory = [Solution(r=self.r,score=self.f(),owner_id=self.id,agent_class=t

    def wantsToTalk(self,pComm):
        if(np.random.uniform() < pComm):
            return True
        return False

    def getBestScore(self):
        bestScore = self.score
        for s in self.memory:
            if s.score < bestScore:
                bestScore = s.score
        return bestScore

    def getBestSolution(self):
        bestSolution = self.memory[0]
        for m in self.memory:
            if m.score < bestSolution.score:
                bestSolution = m
        return bestSolution

    def soBias(self,currentPosition,candidatePosition): #influences preference for ne
        #positions should be given as NORMALIZED positions on unit cube!
        soNorm = normalizedSO(self.kai.SO) #normalized score for Sufficiency of Origi
        memSize = len(self.memory)
        if memSize < 2: return 0 #we don't have enough places be sticking around them

        candidateDirection = candidatePosition - currentPosition #in unit cube space
```

```
        memDirection = 0 # what is the direction of past solns from current soln?
        weights = memoryWeightsPrimacy(memSize) #weights based on temporal order, Rec
        for i in range(memSize-1): #don't include current soln
            past_soln = self.memory[i]
            pairwiseDiff = past_soln.rNorm - currentPosition
            memDirection += pairwiseDiff * weights[i]
        #now we see if the new solution is in the direction of the memories or away f
        paradigmRelatedness = dotNorm(memDirection, candidateDirection)
        raw_PR_score = soNorm * (paradigmRelatedness + 0) #shifting the x intercept #
        sufficiency_of_originality = raw_PR_score*SO_STRENGTH #the agent should have

        return sufficiency_of_originality

    def groupConformityBias(self,teamPosition,currentPosition,candidatePosition): #in
        rgNorm = normalizedRG(self.kai.RG) #normalized score for Rule/Group Conformit
        candidateDirection = candidatePosition - currentPosition

        #all teammates have equal weight
        teamDirection = teamPosition - currentPosition

        #now we see if the new solution is in the direction of the team or away from
        groupConformity = dotNorm(teamDirection, candidateDirection)
        nominalGC = 0 #can change intercept with -0 (using dot product of direction,s
        groupConformityBias = (groupConformity-nominalGC)*rgNorm*RG_STRENGTH
        return groupConformityBias

    def evaluate(self,candidateSolution,soBias=False,groupConformityBias=False,teamPos
        candidateSolutionNorm = asVector(candidateSolution) / scalingVector
        candidateScore = self.fr(candidateSolution)
        if soBias:
            candidateScore += self.soBias(self.rNorm,candidateSolutionNorm)
        if groupConformityBias:
            gcB = self.groupConformityBias(teamPosition,self.rNorm,candidateSolutionN
            candidateScore += gcB
        #if better solution, accept
        if candidateScore < self.score:
            return True
        #accept worse solution with some probability, according to exp((old-new )/tem
        elif pickWorseScore(self.score,candidateScore,self.temp):
            self.score = candidateScore #(its worse, but we go there anyways)
            return True
        return False


#Solutions are objects
class Solution():
    def __init__(self, r,  score, owner_id=None, agent_class=None):
```

```
        self.r = cp(r)
        self.rNorm = self.r / scalingVector
        self.score = cp(score)
        self.owner_id = cp(owner_id)
        self.agent_class = cp(agent_class)

#KAI scores are objects
class KAIScore():
    def __init__(self,subscores=None):
        if subscores is None:
            subscores = makeKAI(1,True)
        self.KAI = subscores.KAI
        self.SO = subscores.SO
        self.E = subscores.E
        self.RG = subscores.RG

#subclasses (Types) of Agents
class carDesigner(Agent):
    def __init__(self, id=-1):
        Agent.__init__(self,id)
        self.myDims = [1 for t in paramsDF.team ] #owns all dimensions by default
#         self.params = startParams() ##these already set in class Agent()
#         self.r = asVector(params)
#         self.rNorm = self.r / scalingVector

    def f(self):
        return objective(self.params,weightsCustom)
    def fr(self,params):
        return objective(params,weightsCustom)

class cabinPerson(Agent):
    def __init__(self, id=-1):
        Agent.__init__(self,id)
        self.myDims = [( 1 if t == "c" else 0 ) for t in paramsDF.team ]
#         self.r = np.random.uniform(-1*startRange,startRange,nDims)
        self.params = startParams() # asParameters(self.r)

    def f(self):
        return objective(self.params,weightsCustom)
    def fr(self,params):
        return objective(params,weightsCustom)

# class Steinway(Agent): #tuneable roughness
#     def __init__(self, id=-1):
#         Agent.__init__(self,id)
#         self.myDims = np.ones(nDims)
#         self.r = np.random.uniform(-1*startRange,startRange,nDims)
```

```
#     def f(self):
#         return testy(self.r,ROUGHNESS)
#     def fr(self,r):
#         return testy(r,ROUGHNESS)

# class LewisMultiDim(Agent): #objective is beauty
#     def __init__(self,id=-1):
#         Agent.__init__(self,id)
#         self.myDims = np.ones(nDims) #logical vector, LewD controls/varies x0 AND x

#     def f(self):
#         return ellipsoid(self.r)
#     def fr(self,r):
#         return ellipsoid(r)

def tryToShare(a1,a2):
    deltaAi = abs(a1.kai.KAI - a2.kai.KAI) #harder to communicate above 20, easy belo
    successful =  tryComm(deltaAi)
    if successful: #in share(), agents might adopt a better solution depending on the
        share(a1,a2) if complexSharing else shareBasic(a1,a2)
        return True
    return False

# def softShare(a1,a2): #share position with some error
#     deltaAi = abs(a1.ai - a2.ai) #hard to communicate above 20, easy below 10
#     #the higher the deltaAi, the more noise in sharing position
#     e = np.random.normal(10,10)
#         return True
#     return False

# def shareBasic(a1,a2): #always share
#     for i in range(len(a1.myDims)):
#         if(a1.myDims[i]>0):
#             #a1 controls this dimension, but a2 only follows if it helps them
#             candidateSoln = a2.params #other dimensions won't change
#             candidateSoln[i] = a1.r[i] #tells a1 where to go in This [i] dimension
#             if(a2.fr(candidateSoln)<a2.score): #self-bias goes here
#                 a2.r = candidateSoln
#                 a2.params = asParameters(a2.r)
#                 a2.score = a2.f()
# #                 print('shared')

#         elif(a2.myDims[i]>0):
#             #a1.r[i]=a2.r[i] #for naive follow
#             candidateSoln = a1.r
#             candidateSoln[i] = a2.r[i]
#             if(a1.fr(candidateSoln)<a1.score):
#                 a1.r = candidateSoln
```

```
#                 a1.params = asParameters(a1.r)
#                 a1.score = a1.f()
# #                 print('shared')
#     return True

def share(a1,a2): #agent chooses whether to accept new solution or not, holistic NOTT
    copyOfA1 = cp(a1)
    considerSharedSoln(a1,a2)
    considerSharedSoln(a2,copyOfA1) #so they could theoretically swap positions...
    return True

def considerSharedSoln(me,sharer): #,dim): #will only move (jump) in the dimensions t
#         candidateSoln = me.r #other dimensions won't change
#         candidateSoln[dim] = sharer.r[dim] #tells a1 where to go in This [i] dimens
        candidateSolution = sharer.params
        candidateScore = me.fr(candidateSolution)
        myScore = me.score - selfBias #improve my score by selfBias
        #Quality Bias Reduction? would go here
        if(candidateScore<myScore):
            if not pickWorseScore(candidateScore,myScore,me.temp): #sometimes choose
                me.moveTo(asVector(candidateSolution))  #(but never take a worse scor
#                 me.speed = me.startSpeed
#                 me.temp = me.startTemp # !! CHRIS trying somethign new here: restar
constructor = carDesigner
```

In [88]:
```
# commBonus = 0
# commRange = 200
def tryComm(deltaAi):
    c = np.random.uniform(commBonus,commBonus+commRange) #increasing commBonus makes
    return (deltaAi < c )
```

In [89]:
```
class Team(): #a group of agents working on the same dimension and objective function
    def __init__(self, nAgents, agentConstructor, dimensions = np.ones(nDims), specia
        self.agents = []
        self.dimensions = dimensions
        if (aiScore is not None) and (aiRange is not None):
            minScore = np.max([40, aiScore-aiRange/2.0])
            maxScore = np.min([150,aiScore+aiRange/2.0])
            aiScores = np.linspace(minScore,maxScore,nAgents)
            np.random.shuffle(aiScores) #randomly assign these to agents, not in orde
            #or we could try putting them in subteams according to a rule:

        for i in range(nAgents):
            a = agentConstructor(id = i)
            if startPositions is not None:
                a.startAt(startPositions[i])
            if (aiScore is not None) and (aiRange is not None):
                aiScore = aiScores[i]
```

```
                a.kai = findAiScore(aiScore)
                a.speed = bounds(AVG_SPEED + normalizedAI(a.kai.KAI) * SD_SPEED, MIN_S
                a.temp = bounds(AVG_TEMP + normalizedE(a.kai.E) * SD_TEMP, 0 ,np.inf)
            if speed is not None:
                a.speed = speed
            if temp is not None:
                a.temp = temp
            a.startSpeed = a.speed
            a.startTemp = a.temp
            a.myDims = dimensions #default: all dimensions owned by every agent
            self.agents.append(a)
        self.nAgents = nAgents
        aiScores = [a.kai.KAI for a in self.agents]
        self.dAI = np.max(aiScores)- np.min(aiScores)
        self.nMeetings = 0
        self.nTeamMeetings = 0
        self.subTeamMeetings = 0

        self.scoreHistory = []

        #if there are subteams owning certain dimensions, each subteams dimensions ar
        self.specializations = specializations

#         #we should give them same position in the dimensions they don't control
#         a0 = self.agents[0]
#         for i in range(len(a0.myDims)):
#             if not a0.myDims[i]:  #this isn't our dimension to control
#                 for a in self.agents:
#                     a.r[i] = a0.r[i]

    def getSharedPosition(self): #this is in the normalized space
        positions = np.array([a.rNorm for a in self.agents])
        return [np.mean(positions[:,i]) for i in range(len(positions[0]))]

    def getSubTeamPosition(self,team): #this is in the normalized space
        positions = np.array([a.rNorm for a in self.agents if a.team == team])
        return [np.mean(positions[:,i]) for i in range(len(positions[0]))]

    def getBestScore(self):
        return np.min([a.getBestScore() for a in self.agents])

    def getBestSolution(self):
        allSolns = [a.getBestSolution() for a in self.agents]
        allScores = [s.score for s in allSolns]
        return allSolns[np.argmin(allScores)]

    def getBestTeamSolution(self,team=-1): #returns a Solution object
        bestIndividualSolns = [a.getBestSolution() for a in self.agents if a.team ==
```

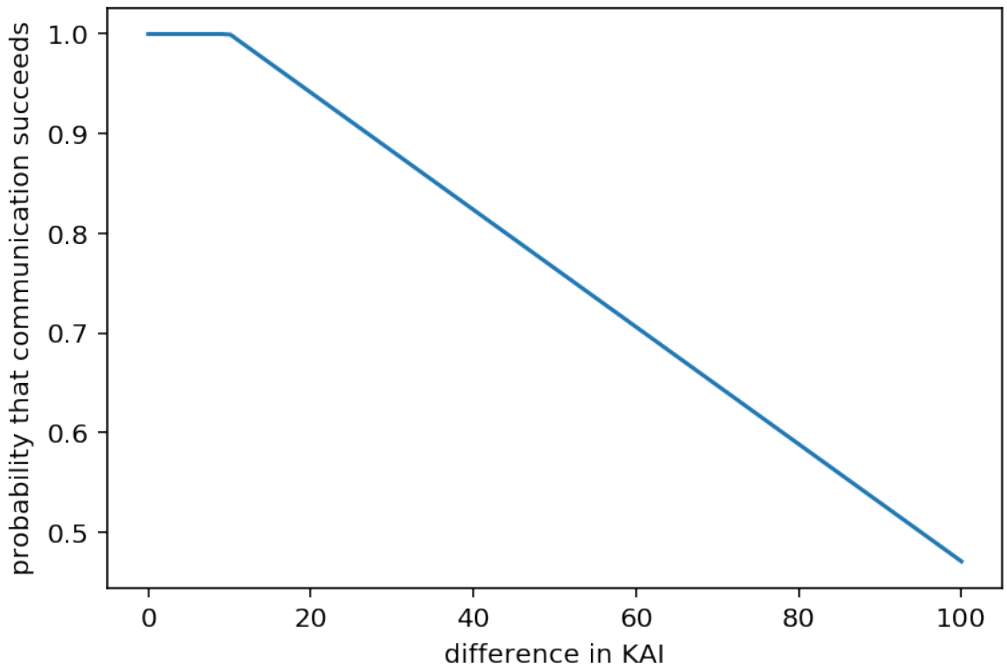
```
        bestScoreLocation = np.argmin([s.score for s in bestIndividualSolns])
        return bestIndividualSolns[bestScoreLocation]

    def haveMeetings(self,talkers):
        nMeetings = 0
        for i in np.arange(0,len(talkers)-1,2):
            #if you don't have a partner, you don't talk to anyone?
            #this needs to be adjusted
            a1 = talkers[i]
            a2 = talkers[i+1]
            didShare = tryToShare(a1,a2)
            if didShare:
#                 print(str(a1.id) + ' and '+str(a2.id)+' shared!')
                nMeetings +=1
        self.nMeetings += nMeetings
        return nMeetings

    def haveTeamMeeting(self):
        #they all go to the best position of the group
        bestSolution = self.agents[0].getBestSolution()
        for a in self.agents:
            agentBest = a.getBestSolution()
            if agentBest.score < bestSolution.score:
                bestSolution = agentBest
        #now move all agents to this position
        for a in self.agents:
            a.moveTo(bestSolution.r)

        return bestSolution

    def haveSubTeamMeeting(self,team,gap=False):
        #they all go to the best position of their specialized team
        teamAgents = [a for a in self.agents if a.team == team]
        if gap: #the meeting might fail if the cognitive style gap is large
            #take the KAI differences of the team into account
            kaiScores = [a.kai.KAI for a in teamAgents]
            deltaAi = max(kaiScores) - min(kaiScores) #hard to communicate above 20,
            successful =  tryComm(deltaAi)
            if not successful: #in share(), agents might adopt a better solution depe
                return None  #our cognitive style gap caused the meeting to fail (onl
        #ok, phew, we have a successful meeting despite any cognitive gap:
        bestSolution = teamAgents[0].getBestSolution()
        for a in teamAgents:
            agentBest = a.getBestSolution()
            if agentBest.score < bestSolution.score:
                bestSolution = agentBest
        #now move all agents to this position
        for a in teamAgents:
```

```
            a.moveTo(bestSolution.r)

        return bestSolution

    def haveInterTeamMeeting(self): #when you have teams of teams
        consensusPosition = np.zeros(nDims)
        #get the best solution from each specialized subteam, and extract their speci
        for team in range(len(self.specializations)):
            bestTeamSoln = self.getBestTeamSolution(team)
            specializedInput = bestTeamSoln.r * self.specializations[team]
            consensusPosition += specializedInput
        consensusPositionP = constrain(asParameters(consensusPosition))
        consensusPosition = asVector(consensusPositionP)
        consensusScore = self.agents[0].fr(consensusPositionP)
        #now move all agents to this position
        for a in self.agents:
            a.moveTo(consensusPosition)

        self.nTeamMeetings += 1
        return [consensusScore, consensusPosition]


    def step(self,pComm,showViz=False,soBias=False,groupConformityBias=False):
        #what happens during a turn for the team?
        #each agents can problem solve or interact (for now, inside team)
        talkers = []
        for a in self.agents:
            if a.wantsToTalk(pComm):
                talkers.append(a)
            else: #CHANGE: #CHRIS I'm going to make getSharedPosition look only at yo
                teamPosition = self.getSubTeamPosition(a.team) if groupConformityBias
                didMove = a.move(soBias=soBias,groupConformityBias = groupConformityBi
        if len(talkers)%2>0: #odd number, have last one explore instead of share
            a = talkers.pop()
            didMove = a.move(soBias=soBias,groupConformityBias = groupConformityBias,
        nMeetings = self.haveMeetings(talkers)
#         print("number of successful meetings: "+str(nMeetings))

#         if showViz:
#             self.plotPositions()

        self.updateTempSpeed()

        return nMeetings

    def updateTempSpeed(self):
        for a in self.agents:
            a.temp *= a.decay
```

```
                a.speed *= a.decay


    def plotPositions(self):
        xs = [a.r[0] for a in self.agents]
        ys = [a.r[1] for a in self.agents]
        cs = [aiColor(a.kai.KAI) for a in self.agents]
        plt.scatter(xs,ys, c=cs)
#         teamPosition = self.getSharedPosition()
#         plt.scatter(teamPosition[0],teamPosition[1],c='orange')
```

2.2 Tune Comm Bonus

```
In [90]: deltaAis = np.linspace(0,100,100)
         # pSuccess = []
         # for deltaAi in deltaAis: #hard to communicate above 20, easy below 10
         #     successful = []
         #     for i in range(1000):
         #         successful.append(tryComm(deltaAi))
         #     pSuccess.append(np.mean(successful))
         theoreticalP = [min(1 - (d-10)/170,1) for d in deltaAis]
         plt.plot(deltaAis,theoreticalP)
         # plt.plot(deltaAis,pSuccess)
         plt.xlabel("difference in KAI")
         plt.ylabel("probability that communication succeeds")
         plt.savefig("./figs/successfullP.pdf")
```



In [91]:
```
# nAgents = 22
# steps = 1
# teamDims, agentTeams = saeTeams(nAgents)
# team = teamWorkSpecialized(nAgents,constructor,teamDims,agentTeams,showViz=showViz,

# print(team.agents[0].score)
# print(team.agents[11].score)
# print(team.getBestScore())
# team.haveSubTeamMeeting(0)
# print(team.agents[0].score)
# print(team.agents[11].score)
# print(team.getBestScore())
```

3 Individual Exploration

In [92]:
```
# def work(AgentConstructor,steps=100,ai=None,temp=None, speed=None, showViz=False, s
#     a = AgentConstructor()
#     if ai is not None:
#         a.kai = findAiScore(ai)
#         self.speed = bounds(AVG_SPEED + normalizedAI(self.kai.KAI) * SD_SPEED, MIN_
#         self.temp = bounds(AVG_TEMP + normalizedE(self.kai.E) * SD_TEMP, 0 ,np.inf)
#     if startPosition is not None:
#         a.startAt(startPosition)
#     if temp is not None:
#         a.temp = temp
#     if speed is not None:
#         a.speed = speed

#     a.decay = calculateAgentDecay(a, steps)

#     scores = []
#     shareSuccess = []

#     for i in range(steps):
#         didMove = a.move(soBias=soBias,groupConformityBias = groupConformityBias,te
#         if didMove:
#             scores.append(copy.deepcopy(a.score))
#             if(showViz and a.nmoves>0):
# #                     plt.scatter(a.rNorm[0],a.rNorm[1],c=color)
#                 plt.scatter(a.rNorm[0],a.score,c=color)
#         a.speed *= a.decay
#         a.temp *= a.decay

#     return a
```

4 Team Work

In [144]:
```
# meetingTimes = 20
def teamWork(teamSize,agentConstructor, pComm, steps=100, soBias=False,groupConformit
    meetingTotals = []
    squad = Team(teamSize,agentConstructor,temp=temp,speed=speed,aiScore=aiScore,aiRa
    for a in squad.agents:
        a.decay = calculateAgentDecay(a,steps)

    meetingTotal = 0
    i = 0
    while i < steps:
        meetingTotal += squad.step(pComm,showViz,soBias,groupConformityBias)
#         if showViz:
#             rGroup = squad.getSharedPosition()
#             plt.scatter(rGroup[0],rGroup[1],marker='o',s=100,c='black')

        if (i+1)%meetingTimes == 0:
            squad.haveTeamMeeting()
            squad.nTeamMeetings +=1
            i += TEAM_MEETING_COST
            if(showViz):
                plt.show()
        i += 1
    if showViz: plt.show()
    meetingTotals.append(meetingTotal)

    return squad

# meetingTimes = 20
def teamWorkSpecialized(teamSize,agentConstructor,teamSpecializations,agentTeams, pC
    np.random.seed()
    meetingTotals = []
    squad = Team(teamSize,agentConstructor,temp=temp,speed=speed,aiScore=aiScore,aiRa
    for i in range(len(squad.agents)):
        a = squad.agents[i]
        aTeam = agentTeams[i]
        a.team = aTeam
        a.myDims = teamSpecializations[aTeam]
        a.decay = calculateAgentDecay(a,steps)

    meetingTotal = 0
    i = 0 #not for loop bc we need to increment custom ammounts inside loop
    while i < steps:
#                 pCi = pComm #*(i/steps) #we can make them wait until later to comm
        meetingTotal += squad.step(0,showViz,soBias,groupConformityBias)  #putting 0
        score = squad.getBestScore()
        squad.scoreHistory.append(score)
```

```
            if showViz:
                plt.scatter(i,score,marker='o',s=100,c='black')

            if (i+1)%meetingTimes == 0:
                squad.haveInterTeamMeeting()
                squad.nTeamMeetings +=1
                i += TEAM_MEETING_COST
#                 if showViz:
#                     plt.show()

            #use pComm for subTeam meetings instead of pair meetings
            for team in range(len(squad.specializations)):
                if pComm > np.random.uniform(): #on any step there is some chance of hav
                    squad.haveSubTeamMeeting(team,gap=complexSharing)
                    squad.subTeamMeetings += 1
            i += 1
        if showViz: plt.show()
        meetingTotals.append(meetingTotal)

        return squad

    def teamWorkSharing(teamSize,agentConstructor,teamSpecializations,agentTeams, pComm,
        np.random.seed()
        squad = Team(teamSize,agentConstructor,temp=temp,speed=speed,aiScore=aiScore,aiRa

        for i in range(len(squad.agents)):
            a = squad.agents[i]
            aTeam = agentTeams[i]
            a.team = aTeam
            a.myDims = teamSpecializations[aTeam]
            a.decay = calculateAgentDecay(a,steps)
        if curatedTeams:
            for team in range(len(teamSpecializations)):
                teamAgents=[a for a in squad.agents if a.team == team]
                for i in range(len(teamAgents)):
                    myKai = aiScore - aiRange/2.0 + aiRange*(float(i)/(len(teamAgents)-1)
                    a= teamAgents[i]
                    a.kai = findAiScore(myKai)

        i = 0 #not for loop bc we need to increment custom ammounts inside loop
        while i < steps:
#                     pCi = pComm #*(i/steps) #we can make them wait until later to comm
            squad.nMeetings += squad.step(pComm,showViz,soBias,groupConformityBias)
            score = squad.getBestScore()
            squad.scoreHistory.append(score)
            if showViz:
                plt.scatter(i,score,marker='o',s=100,c='black')
```

```
                if (i+1)%meetingTimes == 0:
                    squad.haveInterTeamMeeting()
                    squad.nTeamMeetings +=1
                    i += TEAM_MEETING_COST
            #             if showViz:
            #                 plt.show()
                i += 1
        if showViz: plt.show()

        return squad
```

In [175]:
```
#define the team specializations and assign agents to teams
def specializedTeams(nAgents,nDims,nTeams):
    teamDimensions = np.array([[1 if t%nTeams == dim%nTeams else 0 for dim in range(n
    agentTeams = np.array([a%nTeams for a in range(nAgents)])
    return teamDimensions, agentTeams

teams = ['brk', 'c', 'e', 'ft', 'fw', 'ia','fsp','rsp', 'rt', 'rw', 'sw']
teamsDict = { i:teams[i] for i in range(10)}
paramTeams = paramsDF.team
nTeams = len(teams)
teamDimensions_CONST = [[ 1 if paramTeam == thisTeam else 0 for paramTeam in paramTea

def saeTeams(nAgents):
    for i in range(nAgents):
        agentTeams = np.array([a%nTeams for a in range(nAgents)])
    return agentTeams
```

In [95]:
```
def showScoreHistory(agent):
    mem = agent.memory
    for i in range(len(mem)):
        m = mem[i]
        plt.scatter(i,m.score,c='b')
    plt.show()
def showPath(agents):
    for agent in agents:
        mem = agent.memory
        dims = [i for i in range(len(agent.myDims)) if agent.myDims[i]>0]
        x = []
        y = []
        for i in range(len(mem)):
            m = mem[i]
            x.append(m.r[dims[0]])
            y.append(m.r[dims[1]])
        plt.scatter(x,y,c=aiColor(agent.kai.KAI))
        plt.xlabel(paramsDF.name[dims[0]])
        plt.ylabel(paramsDF.name[dims[1]])
        plt.scatter(agent.r[dims[0]],agent.r[dims[1]],marker='x',s=100,c=aiColor(agent
```

```
            plt.show()
        # a0 = team.agents[9]
        # showScoreHistory(a0)
        # a0.myDims
```

```
In [171]: #set standard Parameters
          def resetDefaultParameters():
              steps = 500 #0 #100
              nAgents = 33
              constructor = carDesigner
              teamDims = [[ 1 if paramTeam == thisTeam else 0 for paramTeam in paramTeams] for
              agentTeams = saeTeams(33)#[[ 1 if paramTeam == thisTeam else 0 for paramTeam in

              RG_STRENGTH = 10
              SO_STRENGTH = 10
              commBonus = 10
              commRange = 180

              AVG_SPEED = 0.7E-2
              SD_SPEED = 0.7E-3
              MIN_SPEED = 1.0E-4
              AVG_TEMP = 1
              SD_TEMP = 0.8

              pComm = 0.2
              meetingTimes = steps #have one meeting at the end
              TEAM_MEETING_COST = 1

              VERBOSE = False
              showViz = False
              pairSharingOn = True
              complexSharing = True
              nDims = len(paramsDF)

              aiScoresMeans = [None]#np.linspace(80,120,3)
              aiRanges = [None] # np.linspace(0,30,2)
```

5 visualize the solution?

```
In [181]: # team0 = teamWorkSharing(nAgents,constructor,teamDims,agentTeams,showViz=showViz,sp
          s0 = team0.getBestSolution()
          carDesign = asParameters(s0.r)
```

```
divide by zero (dn)


/anaconda3/lib/python3.6/site-packages/ipykernel_launcher.py:31: RuntimeWarning: invalid value
```

```
---------------------------------------------------------------------------

TypeError                                 Traceback (most recent call last)

<ipython-input-181-45609b9e64fe> in <module>()
----> 1 team0 = teamWorkSharing(nAgents,constructor,teamDims,agentTeams,showViz=showViz,spe
      2 s0 = team0.getBestSolution()
      3 carDesign = asParameters(s0.r)


<ipython-input-144-54eb3105a7c1> in teamWorkSharing(teamSize, agentConstructor, teamSpe
     87     while i < steps:
     88 #                 pCi = pComm #*(i/steps) #we can make them wait until later to con
---> 89         squad.nMeetings += squad.step(pComm,showViz,soBias,groupConformityBias)
     90         score = squad.getBestScore()
     91         squad.scoreHistory.append(score)


<ipython-input-89-97d78a2f6313> in step(self, pComm, showViz, soBias, groupConformityBi
    142             else: #CHANGE: #CHRIS I'm going to make getSharedPosition look only at
    143                 teamPosition = self.getSubTeamPosition(a.team) if groupConformityBi
--> 144                 didMove = a.move(soBias=soBias,groupConformityBias = groupConformit
    145         if len(talkers)%2>0: #odd number, have last one explore instead of share
    146             a = talkers.pop()


<ipython-input-87-c8e6a043d1df> in move(self, soBias, groupConformityBias, teamPositio
     32 #         print('considering moving '+str(d) + ' from '+str(self.r))
     33         candidateSolution = asParameters((self.rNorm + d)*scalingVector)
---> 34         candidateSolution = constrain(candidateSolution,self.myDims)
     35
     36         acceptsNewSolution = self.evaluate(candidateSolution,soBias,groupConformity


<ipython-input-35-f18db74a4428> in constrain(p, dimsToConstrain)
      1 def constrain(p,dimsToConstrain=np.ones(len(paramsDF))):
      2 #     p_attribute = getAttr(p)
----> 3     paramIndices = [i for i in range(len(dimsToConstrain)) if dimsToConstrain[i] ==
      4     for i in paramIndices: #range(len(paramsDF)): # we need to do the equations bou
      5 #         if not dimsToConstrain[i]: #we don't need to check this dimension, it dic


TypeError: object of type 'numpy.int64' has no len()
```

```
In [98]: print("cabin len, m: " +str(carDesign.lc))
         print("front wing angle, deg: " +str(carDesign.afw*180/np.pi))
```

```
---------------------------------------------------------------------------

NameError                                 Traceback (most recent call last)

<ipython-input-98-997ebdf3b7b9> in <module>()
----> 1 print("cabin len, m: " +str(carDesign.lc))
      2 print("front wing angle, deg: " +str(carDesign.afw*180/np.pi))


NameError: name 'carDesign' is not defined
```

```
In [99]: p = startParams()
```

```
In [100]: print("random start point:")
          print("cabin len, m: " +str(p.lc))
          print("front wing angle, deg: " +str(p.afw*180/np.pi))
```

```
random start point:
cabin len, m: 1.525
front wing angle, deg: 22.96603615023486
```

5.1 Run SAE team

```
In [101]: resetDefaultParameters()
```

```
In [102]: # for k in range(reps):
          # #     if k%10 == 0:
          # #         startPositions = np.random.uniform(-1*startRange,startRange,[teamSize,nD
          #     for i in range(len(aiRanges)):
          #         aiRange = aiRanges[i]
          #         for j in range(len(aiScoresMeans)):
          #             aiScore = aiScoresMeans[j]
          #             team = teamWorkSpecialized(nAgents,constructor,teamDims,agentTeams,sho
          #             score = team.getBestScore()
          #             scores.append(score)
          #             aiScores = [a.kai.KAI for a in team.agents]
          #             aiTeamMeans.append(np.mean(aiScores))
          #             aiTeamRange.append(np.max(aiScores) - np.min(aiScores))
          #             nMeetings.append(team.nMeetings)
          #             teamMeetings.append(team.nTeamMeetings)
          #             scoreMatrix[i,j] += score
          #             plt.clf()
          #             plt.plot(range(len(team.scoreHistory)),team.scoreHistory)
          #             plt.ylim([-3,0])
          #             plt.xlim([0,100])
          #             plt.savefig("./figs/teamScores_mu:"+str(aiScore)+"_sd:"+str(aiRange)+"
```

```
            # #             print(team.nMeetings)
            # scoreMatrix = np.array(scoreMatrix) / reps #the average score
            # print("time to complete: "+str(timer.time() - t))
            # print("ai ranges: "+str(aiRanges))
            # print("ai means: "+str(aiScoresMeans))
            # print("reps:" +str(reps))
            # np.savetxt("./results/scoreMatrix_+"+str(timer.time())+".csv", scoreMatrix, delimi
```

5.2 Use MultiProcessing for parallel computing

In [176]:
```
curatedTeams = False
def teamWorkProcess(processID):
    np.random.seed()
    team = teamWorkSharing(nAgents,constructor,teamDimensions_CONST,agentTeams,showVi
    return team
```

In [104]:
```
# !jupyter nbconvert --to script Chicago.ipynb
```

6 Problem Solving Styles and paramter tuning

In [196]:
```
#first: how much is their style affecting their behavior?
resetDefaultParameters()
t0 = timer.time()
allTeamObjects = []

resetDefaultParameters()
reps = 1
nAgents = 33
agentTeams = saeTeams(nAgents)

steps = 50
aiScoresMeans = [100]
aiRanges = [90]
pComms = [0.2]
meetingTimes = 10 #team meating every how many steps?
for i in range(reps):
    for pComm in pComms:
        for aiScore in aiScoresMeans:
            for aiRange in aiRanges:
                team = teamWorkSharing(nAgents,constructor,teamDimensions_CONST,agent
                allTeamObjects.append(team)
print("time to complete: "+str(timer.time()-t0))
```

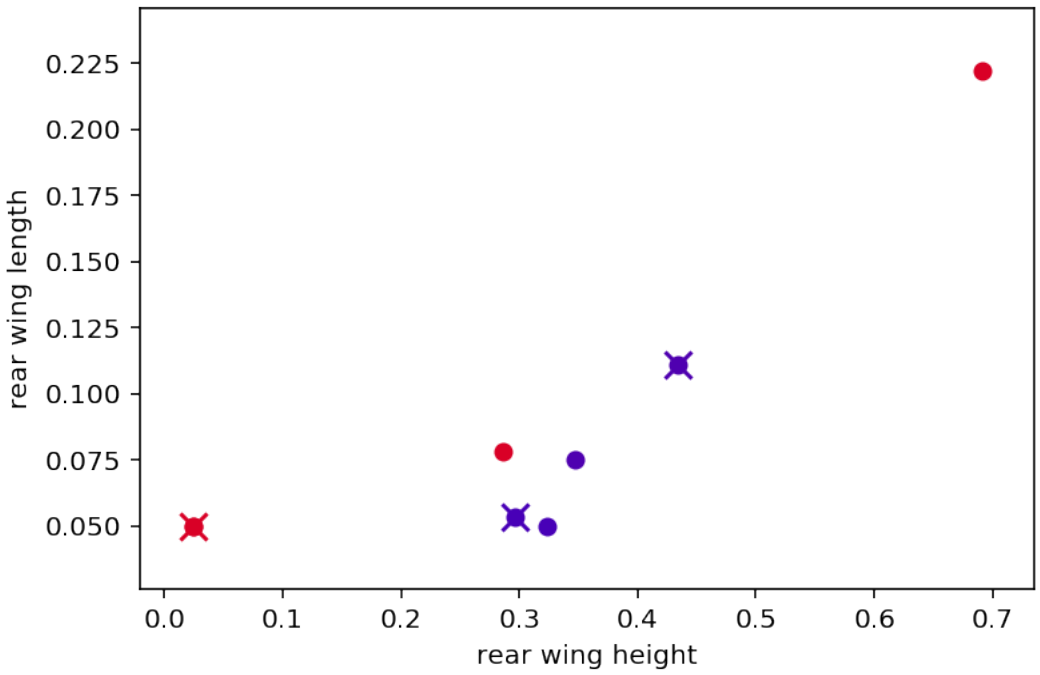
```
time to complete: 9.17118215560913
```

In [197]:
```
team0 = allTeamObjects[0]
team0.nTeamMeetings
```

```
Out[197]: 10
```

```
In [191]: team = allTeamObjects[0]
          t = 9
          a0 = team.agents[t]
          a1 = team.agents[t+11]
          a2 = team.agents[t+22]

          print("mixed team")
          showPath([a0,a1,a2])
```

```
mixed team
```




```
In [ ]: t0 = timer.time()
        resetDefaultParameters()

        pComm = 0.2
        pComms = [0.2]# np.linspace(0,.3,20)

        VERBOSE = False
        showViz = False

        reps = 4 # 10 #$40 #5
```

```
        aiScoresMeans = [100]#np.linspace(80,120,3)
        aiRanges = [0] # np.linspace(0,30,2)

        meetingTimes = steps #have one meeting at the end
        TEAM_MEETING_COST = 1


        scoreMatrix = np.zeros([len(aiRanges),len(aiScoresMeans)])

        exitFlag = 0

        allTeamObjects = []

        for pComm in pComms:
            if __name__ == '__main__':
                pool = multiprocessing.Pool(processes = 4)
                allTeams = pool.map(teamWorkProcess, range(reps))#[pool.apply_async(teamWorkPr
                print('moving on')
                for team in allTeams:
                    allTeamObjects.append(team)
        # allTeams = [t for tl in allTeamObjects for t in tl]
        print("time to complete: "+str(timer.time()-t0))
        allTeams = allTeamObjects
        chaching()

In [179]: t0 = timer.time()
          resetDefaultParameters()
          curatedTeams = True

          pComm = 0.2
          pComms = [0.2]# np.linspace(0,.3,20)

          steps = 50
          reps = 4 # 10 #$40 #5

          aiScoresMeans = [100]#np.linspace(80,120,3)
          aiRanges = [0] # np.linspace(0,30,2)

          meetingTimes = steps #have one meeting at the end

          allTeamObjects = []
          for pComm in pComms:
              if __name__ == '__main__':
                  pool = multiprocessing.Pool(processes = 4)
                  allTeams = pool.map(teamWorkProcess, range(reps))
                  print('moving on')
                  for team in allTeams:
                      allTeamObjects.append(team)
```

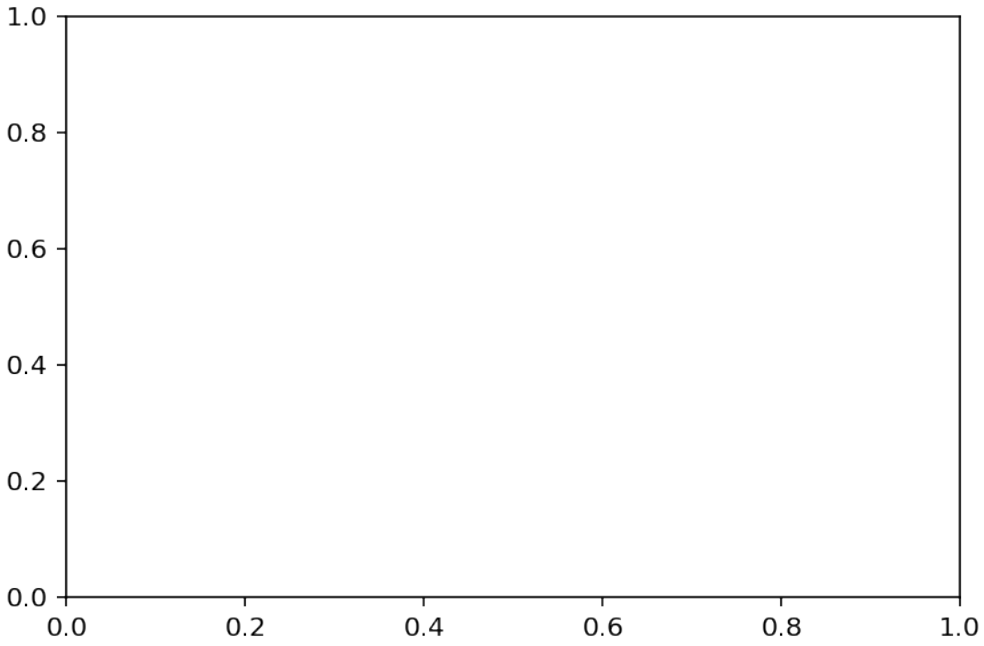
```
    # allTeams = [t for tl in allTeamObjects for t in tl]
    print("time to complete: "+str(timer.time()-t0))
    allTeams = allTeamObjects
    chaching()


---------------------------------------------------------------------------

RemoteTraceback                           Traceback (most recent call last)

RemoteTraceback:
"""
Traceback (most recent call last):
  File "/anaconda3/lib/python3.6/multiprocessing/pool.py", line 119, in worker
    result = (True, func(*args, **kwds))
  File "/anaconda3/lib/python3.6/multiprocessing/pool.py", line 44, in mapstar
    return list(map(*args))
  File "<ipython-input-176-fe14314c6318>", line 4, in teamWorkProcess
    team = teamWorkSharing(nAgents,constructor,teamDimensions_CONST,agentTeams,showViz=sho
  File "<ipython-input-144-54eb3105a7c1>", line 82, in teamWorkSharing
    myKai = aiScore - aiRange/2.0 + aiRange*(float(i)/(len(teamAgents)-1))
TypeError: unsupported operand type(s) for /: 'NoneType' and 'float'
"""


The above exception was the direct cause of the following exception:


TypeError                                 Traceback (most recent call last)

<ipython-input-179-9fdbf164033c> in <module>()
     18     if __name__ == '__main__':
     19         pool = multiprocessing.Pool(processes = 4)
---> 20         allTeams = pool.map(teamWorkProcess, range(reps))
     21         print('moving on')
     22         for team in allTeams:


/anaconda3/lib/python3.6/multiprocessing/pool.py in map(self, func, iterable, chunksiz
264         in a list that is returned.
265         '''
--> 266         return self._map_async(func, iterable, mapstar, chunksize).get()
267
268     def starmap(self, func, iterable, chunksize=None):


/anaconda3/lib/python3.6/multiprocessing/pool.py in get(self, timeout)
642             return self._value
```

```
    643         else:
--> 644             raise self._value
    645
    646     def _set(self, i, obj):


    TypeError: unsupported operand type(s) for /: 'NoneType' and 'float'
```

```
In [ ]: allScores = [t.getBestScore() for t in allTeamObjects]
        nShares = [t.nMeetings/nAgents for t in allTeamObjects]
        plt.scatter(nShares,allScores)
```

```
In [150]: allScores = [t.getBestScore() for t in allTeamObjects]
          scoresForPComm = []
          for i in range(int(len(allScores)/4)):
              theseScores = allScores[0+i*4:4+i*4]
              scoresForPComm.append(np.mean(theseScores))
          plt.scatter(pComms,scoresForPComm)
          plt.title("avg score vs pComm")
          plt.savefig("./figs/avgScore_Vs_pComm.pdf")


          ---------------------------------------------------------------------------

          ValueError                                Traceback (most recent call last)

          <ipython-input-150-68f874ca81d1> in <module>()
            5     theseScores = allScores[0+i*4:4+i*4]
            6     scoresForPComm.append(np.mean(theseScores))
          ----> 7 plt.scatter(pComms,scoresForPComm)
            8 plt.title("avg score vs pComm")
            9 plt.savefig("./figs/avgScore_Vs_pComm.pdf")


          /anaconda3/lib/python3.6/site-packages/matplotlib/pyplot.py in scatter(x, y, s, c, mar
          3468                          vmin=vmin, vmax=vmax, alpha=alpha,
          3469                          linewidths=linewidths, verts=verts,
          -> 3470                       edgecolors=edgecolors, data=data, **kwargs)
          3471     finally:
          3472         ax._hold = washold


          /anaconda3/lib/python3.6/site-packages/matplotlib/__init__.py in inner(ax, *args, **kw
          1853                         "the Matplotlib list!)" % (label_namer, func.__name__),
          1854                         RuntimeWarning, stacklevel=2)
          -> 1855             return func(ax, *args, **kwargs)
          1856
```

```
    1857         inner.__doc__ = _add_data_doc(inner.__doc__,


/anaconda3/lib/python3.6/site-packages/matplotlib/axes/_axes.py in scatter(self, x, y,
    4241         y = np.ma.ravel(y)
    4242         if x.size != y.size:
-> 4243             raise ValueError("x and y must be the same size")
    4244
    4245         if s is None:


ValueError: x and y must be the same size
```

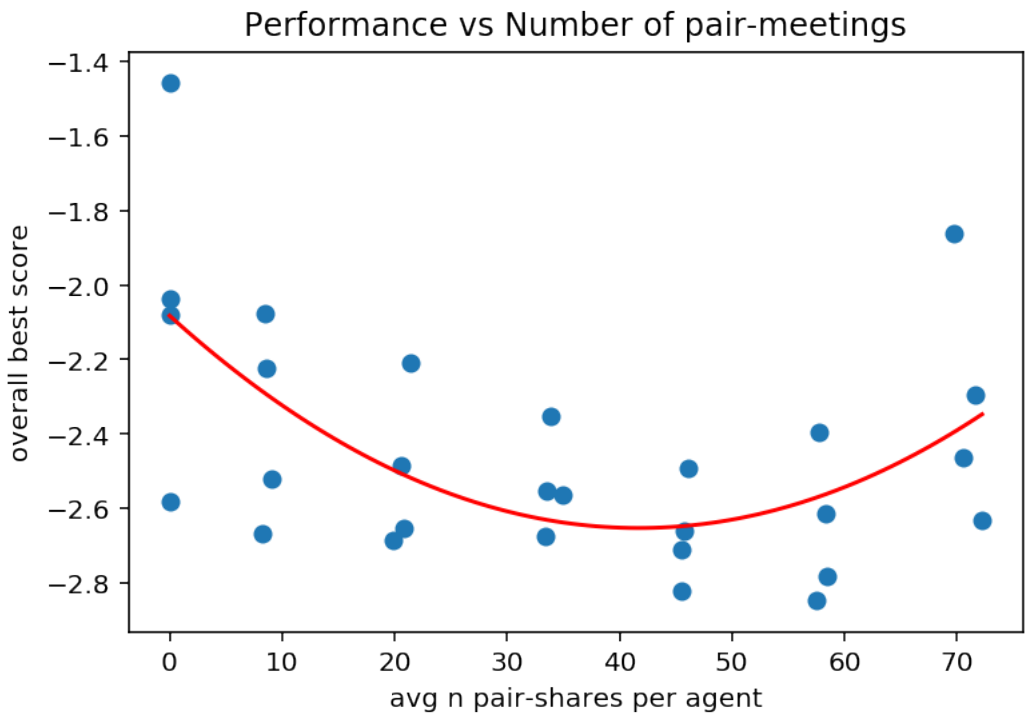



```
In [270]: scoresForPComm

Out[270]: [-2.039567859600141,
           -2.3723489379415725,
           -2.5074387728312346,
           -2.5356173009237106,
           -2.6708729308720294,
           -2.6598657473999867,
           -2.3124368793668864]

In [233]: # bigTeamSet= bigTeamSet[0:20]
          # for t in allTeamObjects:
```

```
#     bigTeamSet.append(t)
# len(bigTeamSet)
# bigTeamSet = [i for l in bigTeamSet for i in l]
```

Out[233]: 28

In [236]:
```
x = np.array([t.nMeetings / 33 for t in bigTeamSet])
yr = np.array([t.getBestScore() for t in bigTeamSet])
# xcat = [round(i*2,-1)/2 for i in x]
plt.scatter(x,yr)
p = np.polyfit(x,yr,2)
z = np.poly1d(p)
x1 = np.linspace(0,max(x),100)
plt.plot(x1,z(x1),color='red')
plt.title('Performance vs Number of pair-meetings')
plt.xlabel("avg n pair-shares per agent")
plt.ylabel("overall best score")
t = str(timer.time())
np.savetxt("./savedParams/"+t+".txt",[makeParamString()], fmt='%s')
plt.savefig("./figs/pairwiseSharing_noReset_"+t+".pdf")
```



In [393]:
```
#bootstrapping for mean and sd of minimum point
bestNshares = []
```

```
            allInd = range(len(bigTeamSet))
            for i in range(1000):
                ind = np.random.choice(allInd,14)
                teams = [bigTeamSet[j] for j in ind]
                x = [t.nMeetings/33 for t in teams]
                y = [t.getBestScore() for t in teams]
                x1 = np.linspace(min(x),max(x),300)
                p = np.polyfit(x,y,2)
                z = np.poly1d(p)
                predicted = z(x1)
                bestNshares.append(x1[np.argmin(predicted)])

            print("best n shares per agent:")
            print("mean:" +str(np.mean(bestNshares)))
            print("std: "+str(np.std(bestNshares)))
```

```
best n shares per agent:
mean:43.4431558731124
std: 9.50356733199722
```

6.1 Organic Team Composition

```
In [116]: t0 = timer.time()
          resetDefaultParameters()
          reps = 16 # 10 #$40 #5

          aiScoresMeans = [None]#np.linspace(80,120,3)
          aiRanges = [None] # np.linspace(0,30,2)

          meetingTimes = steps #have one meeting at the end

          allTeamObjects = []

          for aiScore in aiScoresMeans:
              for aiRange in aiRanges:
                  if __name__ == '__main__':
                      pool = multiprocessing.Pool(processes = 4)
                      allTeams = pool.map(teamWorkProcess, range(reps))#[pool.apply_async(team
                      print('moving on')
                      for team in allTeams:
                          allTeamObjects.append(team)
          print("time to complete: "+str(timer.time()-t0))
          allTeams = allTeamObjects
          chaching()
```

```
Process ForkPoolWorker-10:
Process ForkPoolWorker-11:
```

```
Process ForkPoolWorker-9:
Process ForkPoolWorker-12:
Traceback (most recent call last):
Traceback (most recent call last):
Traceback (most recent call last):
Traceback (most recent call last):
  File "/anaconda3/lib/python3.6/multiprocessing/process.py", line 258, in _bootstrap
    self.run()
  File "/anaconda3/lib/python3.6/multiprocessing/process.py", line 258, in _bootstrap
    self.run()
  File "/anaconda3/lib/python3.6/multiprocessing/process.py", line 258, in _bootstrap
    self.run()



        ---------------------------------------------------------------------------

        KeyboardInterrupt                         Traceback (most recent call last)

        <ipython-input-116-c753e2caad78> in <module>()
         14         if __name__ == '__main__':
         15             pool = multiprocessing.Pool(processes = 4)
    ---> 16             allTeams = pool.map(teamWorkProcess, range(reps))#[pool.apply_async(tea
         17             print('moving on')
         18             for team in allTeams:


        /anaconda3/lib/python3.6/multiprocessing/pool.py in map(self, func, iterable, chunksize
        264         in a list that is returned.
        265         '''
    --> 266         return self._map_async(func, iterable, mapstar, chunksize).get()
        267
        268     def starmap(self, func, iterable, chunksize=None):


        /anaconda3/lib/python3.6/multiprocessing/pool.py in get(self, timeout)
        636
        637     def get(self, timeout=None):
    --> 638         self.wait(timeout)
        639         if not self.ready():
        640             raise TimeoutError


        /anaconda3/lib/python3.6/multiprocessing/pool.py in wait(self, timeout)
        633
        634     def wait(self, timeout=None):
    --> 635         self._event.wait(timeout)
        636
```

```
    637     def get(self, timeout=None):


    /anaconda3/lib/python3.6/threading.py in wait(self, timeout)
    549             signaled = self._flag
    550             if not signaled:
--> 551                 signaled = self._cond.wait(timeout)
    552             return signaled
    553


    /anaconda3/lib/python3.6/threading.py in wait(self, timeout)
    293         try:    # restore state no matter what (e.g., KeyboardInterrupt)
    294             if timeout is None:
--> 295                 waiter.acquire()
    296                 gotit = True
    297             else:


    KeyboardInterrupt:


File "/anaconda3/lib/python3.6/multiprocessing/process.py", line 258, in _bootstrap
  self.run()
File "/anaconda3/lib/python3.6/multiprocessing/process.py", line 93, in run
  self._target(*self._args, **self._kwargs)
File "/anaconda3/lib/python3.6/multiprocessing/process.py", line 93, in run
  self._target(*self._args, **self._kwargs)
File "/anaconda3/lib/python3.6/multiprocessing/process.py", line 93, in run
  self._target(*self._args, **self._kwargs)
File "/anaconda3/lib/python3.6/multiprocessing/process.py", line 93, in run
  self._target(*self._args, **self._kwargs)
File "/anaconda3/lib/python3.6/multiprocessing/pool.py", line 119, in worker
  result = (True, func(*args, **kwds))
File "/anaconda3/lib/python3.6/multiprocessing/pool.py", line 119, in worker
  result = (True, func(*args, **kwds))
File "/anaconda3/lib/python3.6/multiprocessing/pool.py", line 119, in worker
  result = (True, func(*args, **kwds))
File "/anaconda3/lib/python3.6/multiprocessing/pool.py", line 119, in worker
  result = (True, func(*args, **kwds))
File "/anaconda3/lib/python3.6/multiprocessing/pool.py", line 44, in mapstar
  return list(map(*args))
File "/anaconda3/lib/python3.6/multiprocessing/pool.py", line 44, in mapstar
  return list(map(*args))
File "/anaconda3/lib/python3.6/multiprocessing/pool.py", line 44, in mapstar
  return list(map(*args))
File "/anaconda3/lib/python3.6/multiprocessing/pool.py", line 44, in mapstar
  return list(map(*args))
```

```
File "<ipython-input-103-8407a5242295>", line 3, in teamWorkProcess
  team = teamWorkSharing(nAgents,constructor,teamDimensions_CONST,agentTeams,showViz=showViz
File "<ipython-input-103-8407a5242295>", line 3, in teamWorkProcess
  team = teamWorkSharing(nAgents,constructor,teamDimensions_CONST,agentTeams,showViz=showViz
File "<ipython-input-103-8407a5242295>", line 3, in teamWorkProcess
  team = teamWorkSharing(nAgents,constructor,teamDimensions_CONST,agentTeams,showViz=showViz
File "<ipython-input-93-dc99972b5787>", line 81, in teamWorkSharing
  squad.nMeetings += squad.step(pComm,showViz,soBias,groupConformityBias)
File "<ipython-input-103-8407a5242295>", line 3, in teamWorkProcess
  team = teamWorkSharing(nAgents,constructor,teamDimensions_CONST,agentTeams,showViz=showViz
File "<ipython-input-93-dc99972b5787>", line 81, in teamWorkSharing
  squad.nMeetings += squad.step(pComm,showViz,soBias,groupConformityBias)
File "<ipython-input-93-dc99972b5787>", line 81, in teamWorkSharing
  squad.nMeetings += squad.step(pComm,showViz,soBias,groupConformityBias)
File "<ipython-input-93-dc99972b5787>", line 81, in teamWorkSharing
  squad.nMeetings += squad.step(pComm,showViz,soBias,groupConformityBias)
File "<ipython-input-89-97d78a2f6313>", line 144, in step
  didMove = a.move(soBias=soBias,groupConformityBias = groupConformityBias, teamPosition=tea
File "<ipython-input-89-97d78a2f6313>", line 144, in step
  didMove = a.move(soBias=soBias,groupConformityBias = groupConformityBias, teamPosition=tea
File "<ipython-input-89-97d78a2f6313>", line 144, in step
  didMove = a.move(soBias=soBias,groupConformityBias = groupConformityBias, teamPosition=tea
File "<ipython-input-89-97d78a2f6313>", line 144, in step
  didMove = a.move(soBias=soBias,groupConformityBias = groupConformityBias, teamPosition=tea
File "<ipython-input-87-c8e6a043d1df>", line 34, in move
  candidateSolution = constrain(candidateSolution,self.myDims)
File "<ipython-input-87-c8e6a043d1df>", line 34, in move
  candidateSolution = constrain(candidateSolution,self.myDims)
File "<ipython-input-87-c8e6a043d1df>", line 36, in move
  acceptsNewSolution = self.evaluate(candidateSolution,soBias,groupConformityBias,teamPositi
File "<ipython-input-35-f18db74a4428>", line 20, in constrain
  for i, otherParam in paramsDF[paramsDF.team == variable].iterrows():#dimension is driven b
File "<ipython-input-87-c8e6a043d1df>", line 33, in move
  candidateSolution = asParameters((self.rNorm + d)*scalingVector)
File "<ipython-input-35-f18db74a4428>", line 7, in constrain
  param = paramsDF.loc[i]
File "/anaconda3/lib/python3.6/site-packages/pandas/core/frame.py", line 2679, in __getitem_
  return self._getitem_array(key)
File "<ipython-input-16-44b66c927d5f>", line 7, in asParameters
  setattr(p,pNames[i],pList[i])
File "<ipython-input-87-c8e6a043d1df>", line 116, in evaluate
  gcB = self.groupConformityBias(teamPosition,self.rNorm,candidateSolutionNorm)
File "/anaconda3/lib/python3.6/site-packages/pandas/core/frame.py", line 2721, in _getitem_a
  return self._take(indexer, axis=0)
File "/anaconda3/lib/python3.6/site-packages/pandas/core/indexing.py", line 1478, in __getit
  return self._getitem_axis(maybe_callable, axis=axis)
File "/anaconda3/lib/python3.6/site-packages/pandas/core/series.py", line 766, in __getitem_
  result = self.index.get_value(self, key)
```

```
  File "<ipython-input-87-c8e6a043d1df>", line 98, in groupConformityBias
    rgNorm = normalizedRG(self.kai.RG) #normalized score for Rule/Group Conformity
  File "/anaconda3/lib/python3.6/site-packages/pandas/core/generic.py", line 2791, in _take
    if not result._get_axis(axis).equals(self._get_axis(axis)):
  File "/anaconda3/lib/python3.6/site-packages/pandas/core/indexing.py", line 1912, in _getite
    return self._get_label(key, axis=axis)
  File "/anaconda3/lib/python3.6/site-packages/pandas/core/indexes/base.py", line 3103, in get_
    tz=getattr(series.dtype, 'tz', None))
  File "<ipython-input-79-89c2adce5a5d>", line 4, in normalizedRG
    return (rg - kaiDF_DATASET.mean().RG)/kaiDF_DATASET.std().RG
  File "/anaconda3/lib/python3.6/site-packages/pandas/core/indexing.py", line 140, in _get_labe
    return self.obj._xs(label, axis=axis)
  File "/anaconda3/lib/python3.6/site-packages/pandas/core/indexes/base.py", line 2434, in equa
    if self.is_(other):
  File "/anaconda3/lib/python3.6/site-packages/pandas/core/generic.py", line 9589, in stat_func
    numeric_only=numeric_only)
KeyboardInterrupt
  File "/anaconda3/lib/python3.6/site-packages/pandas/core/generic.py", line 2997, in xs
    new_values = self._data.fast_xs(loc)
  File "/anaconda3/lib/python3.6/site-packages/pandas/core/frame.py", line 6851, in _reduce
    result = f(values)
  File "/anaconda3/lib/python3.6/site-packages/pandas/core/indexes/base.py", line 618, in is_
    return self._id is getattr(
  File "/anaconda3/lib/python3.6/site-packages/pandas/core/internals.py", line 4074, in fast_xs
    dtype = _interleaved_dtype(self.blocks)
  File "/anaconda3/lib/python3.6/site-packages/pandas/core/frame.py", line 6840, in f
    return op(x, axis=axis, skipna=skipna, **kwds)
KeyboardInterrupt
  File "/anaconda3/lib/python3.6/site-packages/pandas/core/internals.py", line 5048, in _interl
    dtype = find_common_type([b.dtype for b in blocks])
  File "/anaconda3/lib/python3.6/site-packages/pandas/core/nanops.py", line 77, in _f
    return f(*args, **kwargs)
  File "/anaconda3/lib/python3.6/site-packages/pandas/core/nanops.py", line 125, in f
    if _has_infs(result):
  File "/anaconda3/lib/python3.6/site-packages/pandas/core/internals.py", line 5048, in <listco
    dtype = find_common_type([b.dtype for b in blocks])
  File "/anaconda3/lib/python3.6/site-packages/pandas/core/internals.py", line 354, in dtype
    return self.values.dtype
  File "/anaconda3/lib/python3.6/site-packages/pandas/core/nanops.py", line 169, in _has_infs
    return lib.has_infs_f8(result.ravel())
KeyboardInterrupt
KeyboardInterrupt
```

In [ ]:
```
tMeans = []
tSds = []
tScores = []
tRanges = []
```

```
        tMeetings = []
        for t in allTeamObjects:
            kais = [a.kai.KAI for a in t.agents]
            tMeans.append(np.mean(kais))
            tRanges.append(np.max(kais)-np.min(kais))
            tSds.append(np.std(kais))
            tScores.append(t.getBestScore())
            tMeetings.append(t.nMeetings)
```

```
In [ ]: plt.scatter(tMeans,tScores)
        p=np.polyfit(tMeans,tScores,1)
        print("scores vs means")
        print(p)
        f = np.poly1d(p)
        x = np.linspace(min(tMeans),max(tMeans),100)
        plt.plot(x,f(x))
```

```
In [ ]: plt.scatter(tSds,tScores)
        p=np.polyfit(tSds,tScores,1)
        print("scores vs stdevs")
        print(p)
        f = np.poly1d(p)
        x = np.linspace(min(tSds),max(tSds),100)
        plt.plot(x,f(x))
```

6.2 Specific Make-up Teams

```
In [348]: t0 = timer.time()
          resetDefaultParameters()

          reps = 4
          aiScoresMeans = [100]#np.linspace(80,120,3)
          aiRanges = np.linspace(0,100,8)

          allTeamObjects = []
          for aiScore in aiScoresMeans:
              for aiRange in aiRanges:
                  if __name__ == '__main__':
                      pool = multiprocessing.Pool(processes = 4)
                      allTeams = pool.map(teamWorkProcess, range(reps))#[pool.apply_async(team
                      print('moving on')
                      for team in allTeams:
                          allTeamObjects.append(team)
          print("time to complete: "+str(timer.time()-t0))
          chaching()
```

```
moving on
moving on
moving on
```

```
moving on
moving on
moving on
moving on
moving on
time to complete: 907.2802548408508
```

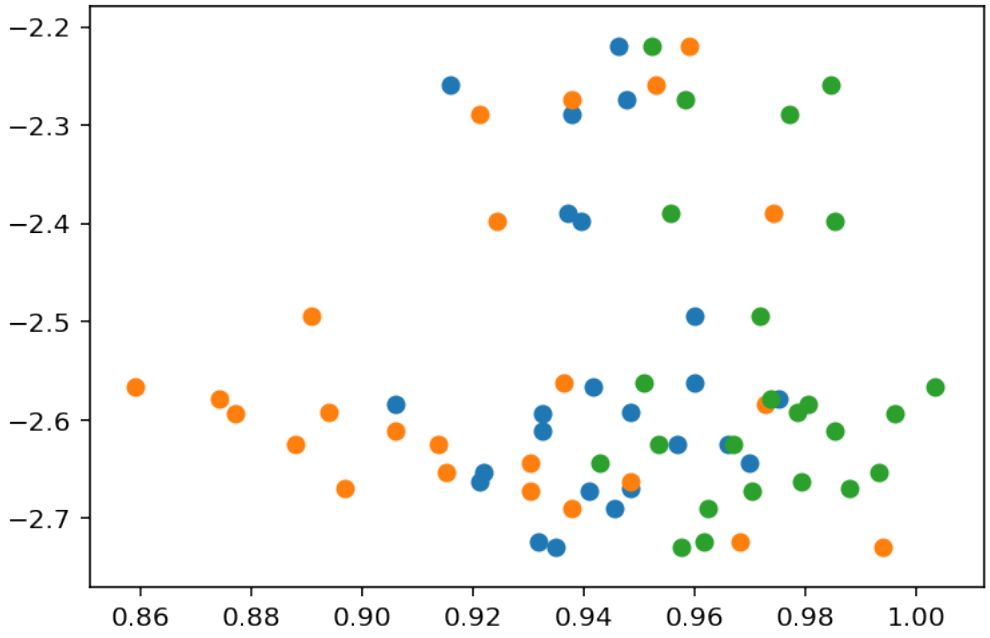
```
In [349]: def getBestScoreAtTime(team,t):
              # t is fraction of time in simulation. this is approximate
              scores = []
              for a in team.agents:
                  ml = len(a.memory)
                  memorySubset = a.memory[0:int(ml*t)]
                  scores.append(np.min([m.score for m in memorySubset]))
              return min(scores)
```

```
In [350]: # allTeamObjects1 = allTeamObjects
          # for t in allTeamObjects:
          #     allTeamObjects1.append(t)
```

```
In [394]: tMeans = []
          tSds = []
          tScores = []
          tRanges = []
          tMeetings = []
          bestScoresAtFraction = []
          so = []
          rg = []
          e = []
          for t in allTeamObjects:
              if t.getBestScore()>-2: continue
              kais = [a.kai.KAI for a in t.agents]
              tMeans.append(np.mean(kais))
              tRanges.append(np.max(kais)-np.min(kais))

              tSds.append(np.std(kais))
              tScores.append(t.getBestScore())
              tMeetings.append(t.nMeetings)
              bestScoresAtFraction.append(getBestScoreAtTime(t,.25))

              sos = [a.kai.SO for a in t.agents]
              so.append(np.mean(sos))

              es = [a.kai.E for a in t.agents]
              e.append(np.mean(es))

              rgs = [a.kai.RG for a in t.agents]
              rg.append(np.mean(rgs))
```

In [405]:
```
# any trends for subscores? not really
plt.scatter(np.array(rg)/40,tScores)
plt.scatter(np.array(e)/20,tScores)
plt.scatter(np.array(so)/45,tScores)
```

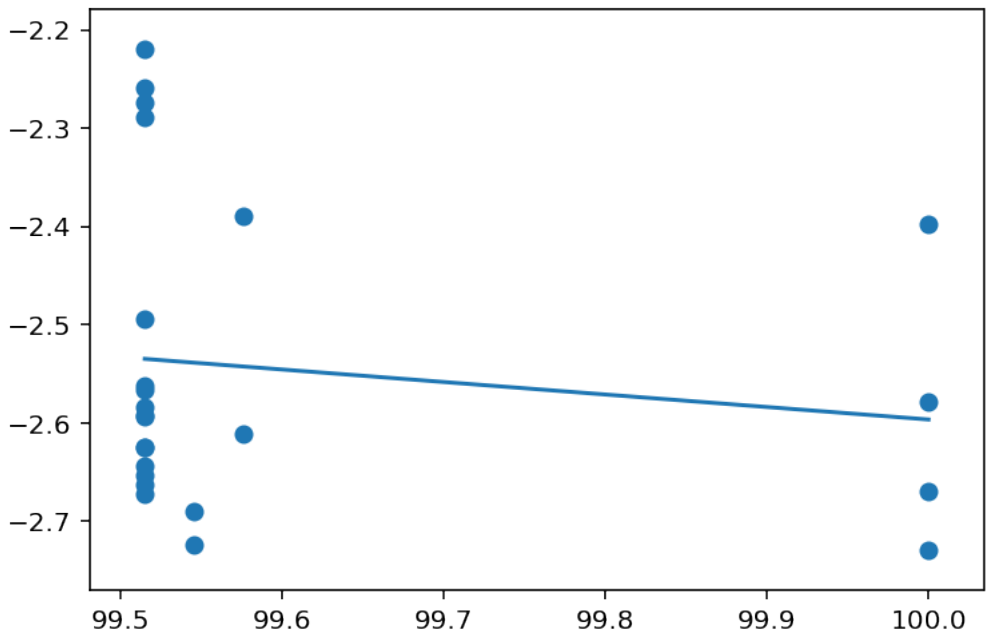
Out[405]: <matplotlib.collections.PathCollection at 0x1a366e6358>



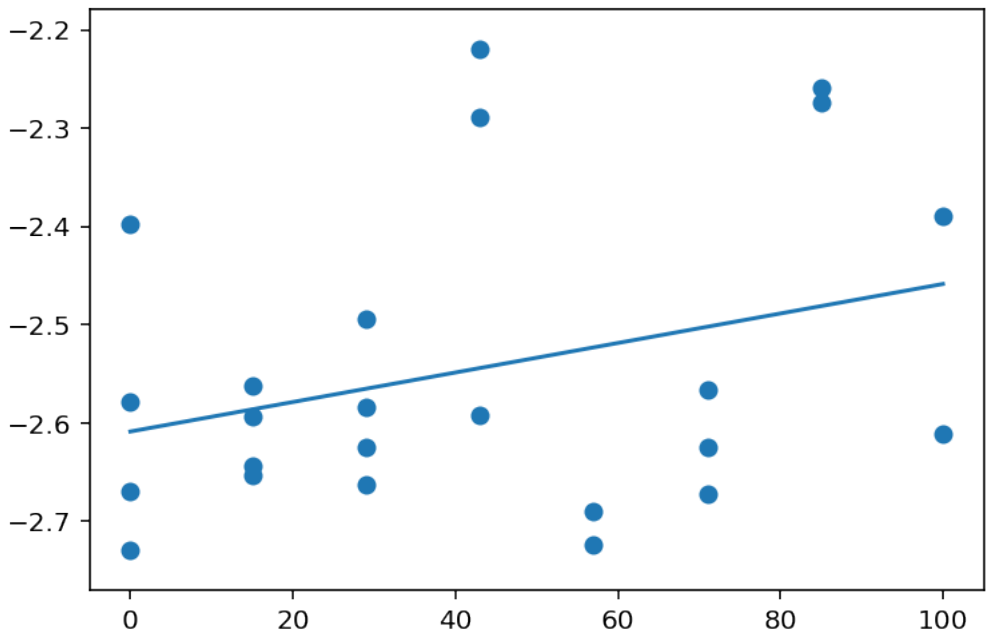
In [357]:
```
plt.scatter(tMeans,tScores)
p=np.polyfit(tMeans,tScores,1)
print("scores vs means")
print(p)
f = np.poly1d(p)
x = np.linspace(min(tMeans),max(tMeans),100)
plt.plot(x,f(x))
```

```
scores vs means
[-0.12731133 10.13473877]
```

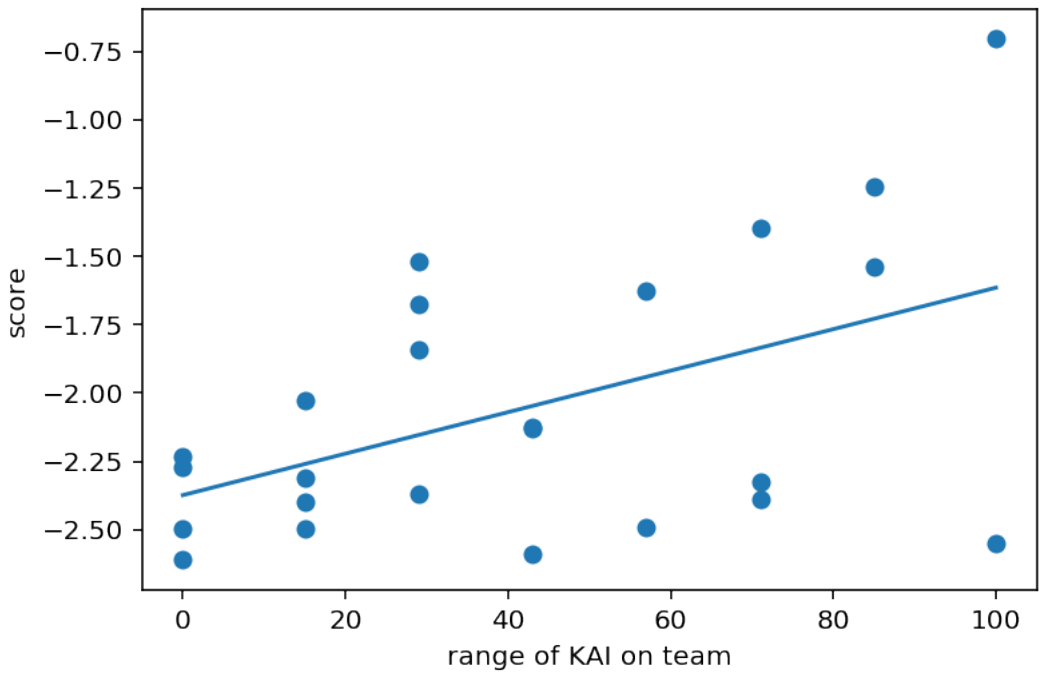
Out[357]: [<matplotlib.lines.Line2D at 0x1a36805f98>]




```
In [358]: plt.scatter(tRanges,tScores)
          p=np.polyfit(tRanges,tScores,1)
          print("scores vs stdevs")
          print(p)
          f = np.poly1d(p)
          x = np.linspace(min(tRanges),max(tRanges),100)
          plt.plot(x,f(x))

scores vs stdevs
[ 1.50189989e-03 -2.60862366e+00]


Out[358]: [<matplotlib.lines.Line2D at 0x1a367c9eb8>]
```




```
In [360]: plt.scatter(tRanges,bestScoresAtFraction)
          p=np.polyfit(tRanges,bestScoresAtFraction,1)
          print("scores vs stdevs")
          print(p)
          f = np.poly1d(p)
          x = np.linspace(min(tRanges),max(tRanges),100)
          plt.plot(x,f(x))
          plt.ylabel("score")
          plt.xlabel("range of KAI on team")

scores vs stdevs
[ 0.00758675 -2.37335727]


Out[360]: Text(0.5,0,'range of KAI on team')
```




```
In [ ]: diverseTeams= [ t for t in allTeamObjects if t.dAI > 0]
        uniformTeams = [ t for t in allTeamObjects if t.dAI == 0]
        colors = ['red' if t.dAI > 0 else 'blue' for t in allTeamObjects ]
        isDiverse = [True if t.dAI > 0 else False for t in allTeamObjects ]

In [ ]: avgDiverseScore = np.mean([t.getBestScore() for t in diverseTeams])
        avgUniformScore = np.mean([t.getBestScore() for t in uniformTeams])
        std1 = np.std([t.getBestScore() for t in diverseTeams])
        std2 = np.std([t.getBestScore() for t in uniformTeams])
        print("diverse score avg:" + str(avgDiverseScore))
        print("uniform score avg: " + str(avgUniformScore))
        print("stds:" + str(std1) + " and "+str(std2))

In [ ]: diverseScores = [t.getBestScore() for t in diverseTeams]
        avgDiverseScore = np.mean(diverseScores)
        uniformScores = [t.getBestScore() for t in uniformTeams]
        avgUniformScore = np.mean(uniformScores)
        std1 = np.std([t.getBestScore() for t in diverseTeams])
        std2 = np.std([t.getBestScore() for t in uniformTeams])
        print("diverse score avg:" + str(avgDiverseScore))
        print("uniform score avg: " + str(avgUniformScore))
        print("stds:" + str(std1) + " and "+str(std2))
        stat, p = scipy.stats.ttest_ind(diverseScores,uniformScores)
        print("significance: p= "+str(p))
```