In [27]:
```
import random
import sys
import numpy as np
import csv
import math
from collections import defaultdict
from collections import OrderedDict
import matplotlib.pyplot as plt
```

In [2]:
```
class game():
    def __init__(self, suits = 4):
        self.agentHand = defaultdict(int)
        self.compHand = defaultdict(int)
        self.book = defaultdict(int)
        self.count = 0
        for i in range(1,14):
            self.agentHand[i] = 0
            self.compHand[i] = 0
            self.book[i] = 0
        self.suits = suits
        self.deck = list(range(1,14)) * self.suits # cards as 1-13, a=1, j=11, et
        random.shuffle(self.deck)
        self.score = [0,0] #agent score, computer score
        self.stepCount = 0 # debug
        self.deal()
        #self.debug()
        return

    def emptyDeck(self):
        return len(self.deck) == 0

    def agentDraw(self):
        if self.emptyDeck():
            return
        card = self.deck.pop(0)
        self.agentHand[card] += 1
        return card

    def compDraw(self):
        if self.emptyDeck():
            return
        card = self.deck.pop(0)
        self.compHand[card] += 1
        return card

    def agentHas(self, card): # check if agent has card
        return self.agentHand[card] != 0

    def compHas(self, card): # check if agent has card
        return self.compHand[card] != 0

    def agentSteal(self, card): # agent take computer card
        #print("steal", self.compHand[card])
        self.agentHand[card] += self.compHand[card]
        self.compHand[card] = 0
        #print(self.agentHand[card],self.compHand[card])
        return

    def compSteal(self, card): # computer take agent card
        self.compHand[card] += self.agentHand[card]
        self.agentHand[card] = 0
        return

    def agentBook(self, card): # check if agent scores
        if self.agentHand[card] == 4:
```

```
            self.book[card] += 1
            self.agentHand[card] = 0
            self.score[0] += 1
            return True
        return False

    def compBook(self, card): # check if computer scores
        if self.compHand[card] == 4:
            self.book[card] += 1
            self.compHand[card] = 0
            self.score[1] += 1
            return True
        return False

    def agentEmpty(self):
        return sum(self.agentHand.values()) == 0

    def compEmpty(self):
        return sum(self.compHand.values()) == 0

    def gameOver(self):
        return sum(self.score) == 13

    def deal(self): # start of game each player gets 7 cards
        for i in range(7):
            self.agentDraw()
            self.compDraw()
        return

    def agentAct(self):
        return

    def compAct(self):
        options = [x for x in self.book if self.book[x] == 0]
        if options == []:
            options = [1]
        return random.choice(options)

    def step(self, action = None):
        # state / action
        # states are known info
        # agent cards, completed books, remaining deck, amount of
        # computer cards,
        self.count += 1
        if self.count >= 1000:
            self.reset()
        temp = 0
        #print("agentTurn") # debug
        while(True): # agent turn
            if self.agentEmpty():
                self.agentDraw()
            agentPick = random.choice(range(1,14))
            if action is not None:
                agentPick = action # agent action to select number
            #print(agentPick)
            if self.compHas(agentPick):
                temp += 1
```

```
                self.agentSteal(agentPick)
                self.agentBook(agentPick)
            else:
                if temp == 0:
                    self.agentBook(self.agentDraw())
                break
        temp = 0
        if self.gameOver():
            #self.debug()
            return
        #print("compTurn") # debug
        while(True): # computer turn
            if self.compEmpty():
                self.compDraw()
            compPick = self.compAct()
            #print(compPick)
            if self.agentHas(compPick):
                temp += 1
                self.compSteal(compPick)
                self.compBook(compPick)
            else:
                if temp == 0:
                    self.compBook(self.compDraw())
                break
        #self.debug()
        self.stepCount += 1
        return

    def reward(self):
        if not self.gameOver():
            return 0
        if self.score[0] > self.score[1]:
            return 1
        return -1

    def debug(self):
        print("step count", self.stepCount)
        print("aHand", self.agentHand)
        print("cHand", self.compHand)
        print("deck remaining", len(self.deck))
        print("book", self.book)
        print("score", self.score)

    def reset(self):
        self.agentHand = defaultdict(int)
        self.compHand = defaultdict(int)
        self.book = defaultdict(int)
        self.count = 0
        for i in range(1,14):
            self.agentHand[i] = 0
            self.compHand[i] = 0
            self.book[i] = 0
        self.deck = list(range(1,14)) * self.suits # cards as 1-13, a=1, j=11, et
        random.shuffle(self.deck)
        self.score = [0,0] #agent score, computer score
        self.stepCount = 0 # debug
        self.deal()
```

```
        #self.debug()
        return
```

In [3]:
```
#test
scores = []
for j in range(10):
    ave = 0
    n = 1000
    for i in range(n):
        g = game()
        while not g.gameOver():
            g.step()
        ave += g.score[0]
    scores.append(ave/n)
scores
```

Out[3]:
```
[4.043, 4.105, 4.042, 4.077, 4.017, 3.921, 4.029, 3.994, 3.941, 3.984]
```

In [4]:
```
def getProbs(qState, epsilon, nA):
    # qState = array of action valule functions for states
    # epsilon = equiprobable random & 1-epsilon = greedy policy
    # nA = number of actions
    #init w/ prob for non greedy actions b
    probs = np.ones(nA) * epsilon/nA
    greedy_action = np.argmax(qState)
    if np.count_nonzero(qState == qState[greedy_action]) > 1:
        return np.ones(nA)/nA
    probs[greedy_action] = 1 - epsilon + epsilon/nA
    return probs
    #probs = np.zeros((2,13)) # 2 rows per whether card in book or not, and 13 pe
```

In [5]:
```
def stateBinBook(game):
    return int("".join([str(n) for n in game.book.values()]),2) # book state as b
```

In [6]:
```
def generateEpisode(game, Q, epsilon, nA):
    # game env, action value table, epsilon, num actions
    episode = []
    game.reset()
    state = stateBinBook(game)

    while True:
        if state in Q:
            action = np.random.choice(range(1,14), p = getProbs(Q[state], epsilor
        else:
            action = random.choice(range(1,14))
        g.step(action)
        nextState = stateBinBook(game)
        reward = game.reward()
        episode.append((state,action,reward))
        state = nextState

        if game.gameOver():
            break

    return episode
```

In [7]:
```
def updateQ(game,episode,Q,alpha,gamma):
    #
    states,actions,rewards = zip(*episode)
    discounts = [gamma**t for t in range(len(rewards)+1)]

    for t,state in enumerate(states):
        oldQs = Q[state][actions[t]-1]
        Gt = sum([x*y for x,y in zip(discounts[:-(t+1)],rewards[t:])])
        Q[state][actions[t]-1] = oldQs + alpha*(Gt - oldQs)

    return Q
```

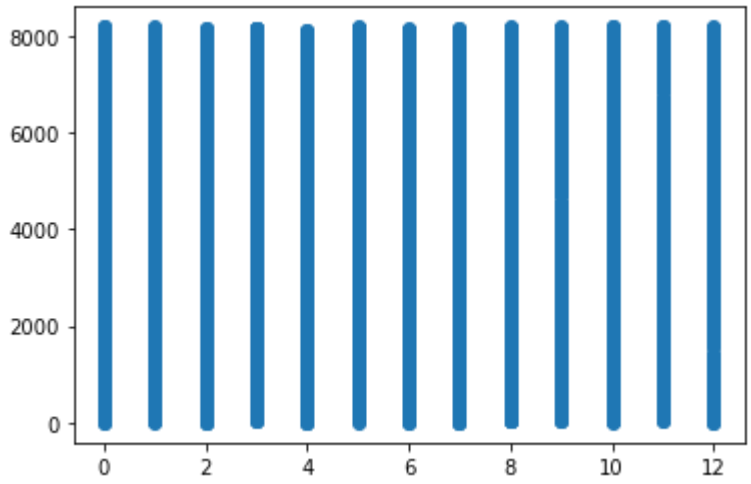
In [8]:
```
def control(game, nIter, alpha, Q = None, gamma = 1.0, eps_start = 1.0, eps_decay
    #
    nA = 13
    if Q is None:
        Q = defaultdict(lambda: np.zeros(nA))
    epsilon = eps_start

    scores = []

    for i in range(nIter):
        epsilon = max(epsilon*eps_decay, eps_min)
        episode = generateEpisode(game,Q,epsilon,nA)
        Q = updateQ(game,episode,Q,alpha,gamma)
        if i % 1000 == 0:
            scores.append((i,g.score[0]))
            print('\rEpisode {}/{}.'.format(i, nIter), end = "")
            sys.stdout.flush()

    policy = dict((state, np.argmax(action)) for state, action in Q.items())
    return policy, Q, scores
```

In [9]:
```
num_episodes = 3000000
alpha = 0.05
g = game()
policy, Q, scores = control(g, num_episodes, alpha)
```

```
Episode 2999000/3000000.
```

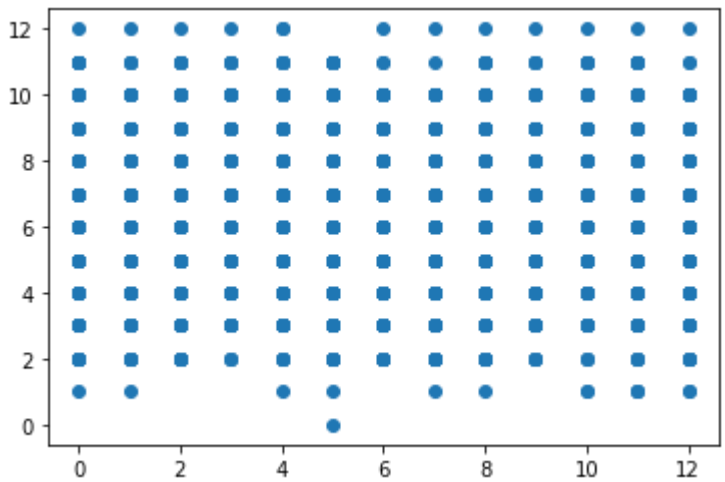
In [10]:
```
xpol = []
ypol = []
for key, value in policy.items():
    xpol += [value]
    ypol += [key]
plt.scatter(xpol,ypol)
```

Out[10]:
```
<matplotlib.collections.PathCollection at 0x29d2c2e4c48>
```



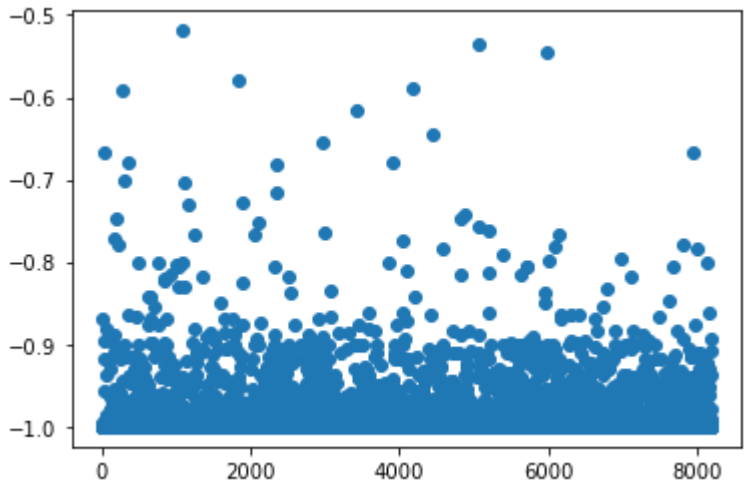
In [11]:
```
xpol = []
ypol = []
for key, value in policy.items():
    xpol += [value]
    ypol += ["{0:b}".format(key).count("1")]
plt.scatter(xpol,ypol)
```

Out[11]:
```
<matplotlib.collections.PathCollection at 0x29d2bc2f4c8>
```



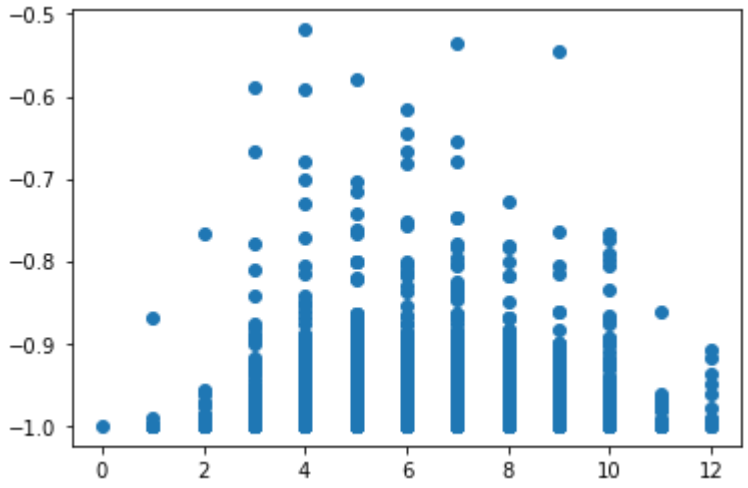
In [12]:
```
xQ = []
yQ = []
for key, value in Q.items():
    xQ += [key]
    yQ += [max(value)]
plt.scatter(xQ,yQ)
```

Out[12]: <matplotlib.collections.PathCollection at 0x29d2cd65108>



In [13]:
```
xQ = []
yQ = []
for key, value in Q.items():
    xQ += ["{0:b}".format(key).count("1")]
    yQ += [max(value)]
plt.scatter(xQ,yQ)
```

Out[13]: <matplotlib.collections.PathCollection at 0x29d2cebad48>



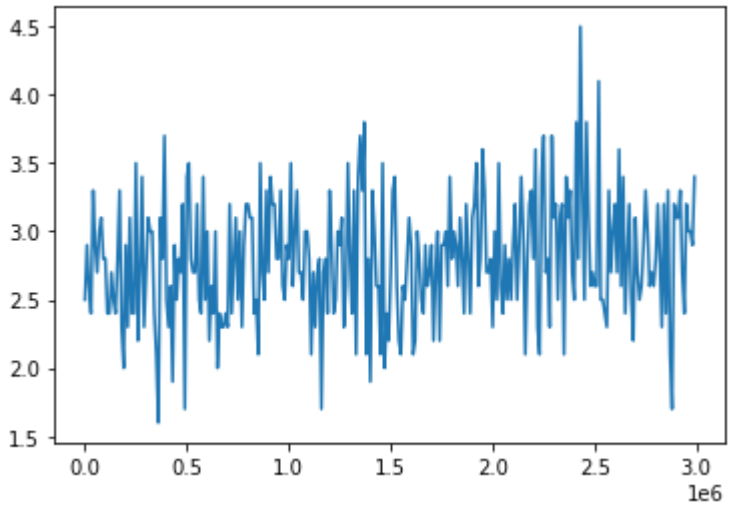
In [14]:
```
# example of step action log, reward for all steps are 0 except for the end, of w
g = game()
g.reset()
while not g.gameOver():
    g.step()
    g.debug()
    print("")
```

```
0, 9: 1, 10: 0, 11: 0, 12: 0, 13: 1})
score [1, 1]

step count 20
aHand defaultdict(<class 'int'>, {1: 3, 2: 2, 3: 2, 4: 0, 5: 0, 6: 0, 7: 0,
8: 0, 9: 0, 10: 1, 11: 0, 12: 3, 13: 0})
cHand defaultdict(<class 'int'>, {1: 1, 2: 0, 3: 0, 4: 1, 5: 3, 6: 3, 7: 3,
8: 2, 9: 0, 10: 3, 11: 3, 12: 0, 13: 0})
deck remaining 14
book defaultdict(<class 'int'>, {1: 0, 2: 0, 3: 0, 4: 0, 5: 0, 6: 0, 7: 0, 8:
0, 9: 1, 10: 0, 11: 0, 12: 0, 13: 1})
score [1, 1]

step count 21
aHand defaultdict(<class 'int'>, {1: 3, 2: 2, 3: 2, 4: 0, 5: 0, 6: 0, 7: 0,
8: 0, 9: 0, 10: 1, 11: 0, 12: 0, 13: 0})
cHand defaultdict(<class 'int'>, {1: 1, 2: 0, 3: 0, 4: 1, 5: 3, 6: 3, 7: 0,
8: 2, 9: 0, 10: 3, 11: 3, 12: 3, 13: 0})
deck remaining 13
book defaultdict(<class 'int'>, {1: 0, 2: 0, 3: 0, 4: 0, 5: 0, 6: 0, 7: 1, 8:
```

In [41]:
```
def compress(list): # takes the average of every group of 10 elements in a list
    c = []
    for i in range(0,len(list),10):
        c += [np.average(list[i:i+10])]
    return c
```

In [45]:
```
xscore = [i for i,j in scores[1::10]]
yscore = [j for i,j in scores]
plt.plot(xscore,compress(yscore))
#plt.xscale('log',basex=10)
```

Out[45]:
```
[<matplotlib.lines.Line2D at 0x29d31c0f2c8>]
```



In [15]:
```
w = csv.writer(open("policyC.csv", "w"))
for key, val in policy.items():
    w.writerow([key, val])
```

In [16]:
```
w = csv.writer(open("QC.csv", "w"))
for key, val in Q.items():
    w.writerow([key, val])
```

In [17]:
```
w = csv.writer(open("scoreC.csv", "w"))
for x in scores:
    w.writerow([x[0], x[1]])
```