In [1]:
```
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]:
```
[4.081, 4.055, 4.027, 3.958, 3.993, 3.981, 3.958, 3.978, 4.011, 3.963]
```

In [4]:
```
def stateBinBook(game):
    return int("".join([str(n) for n in game.book.values()]),2) # book state as b
```

In [5]:
```
def update_Q_sarsa(alpha, gamma, Q, state, action, reward, next_state=None, next_
    # returns updated Q-value
    current = Q[state][action-1]  # access dictionary state as key, then index of
    # get value of state, action pair at next time step
    Qsa_next = Q[next_state][next_action-1] if next_state is not None else 0
    target = reward + (gamma * Qsa_next)               # construct TD target
    new_value = current + (alpha * (target - current)) # get updated value
    return new_value
```

In [6]:
```
def epsilon_greedy(Q, state, nA, epsilon):
    # epsilon-greedy action for supplied state.
    # Q (dict): action-value function
    # state (int): current state
    # nA (int): number actions in the environment (13)
    # eps (float): epsilon
    if random.random() > epsilon: # select greedy action with probability epsilon
        return np.argmax(Q[state])
    else:                      # otherwise, select an action randomly
        return random.choice(np.arange(1,14))
```

In [7]:
```
def sarsa(game, nIter, alpha, gamma=1.0, epsmin=0.01):
    nA = 13                # number of actions
    Q = defaultdict(lambda: np.zeros(nA))  # initialize empty dictionary of array
    scores = []

    for i in range(1, nIter+1):
        # monitor progress
        if i % 1000 == 0:
            print("\rEpisode {}/{}".format(i, nIter), end="")
            scores.append((i,game.score[0]))
            sys.stdout.flush()
        score = 0                                          # initialize score
        game.reset()
        state = stateBinBook(game) # start episode

        eps = max(1.0 / i, epsmin)                      # set value of epsilon
        action = epsilon_greedy(Q, state, nA, eps)            # epsilon-greedy ac

        while True:
            game.step(action) # take action A, observe R, S'
            next_state = stateBinBook(game)
            reward = game.reward()
            score += reward                                 # add reward to ag
            if not game.gameOver():
                next_action = epsilon_greedy(Q, next_state, nA, eps) # epsilon-gr
                Q[state][action-1] = update_Q_sarsa(alpha, gamma, Q, \
                                                    state, action, reward, next_sta

                state = next_state     # S <- S'
                action = next_action   # A <- A'
            if game.gameOver():
                Q[state][action-1] = update_Q_sarsa(alpha, gamma, Q, \
                                                    state, action, reward)
                break

    return Q, scores
```

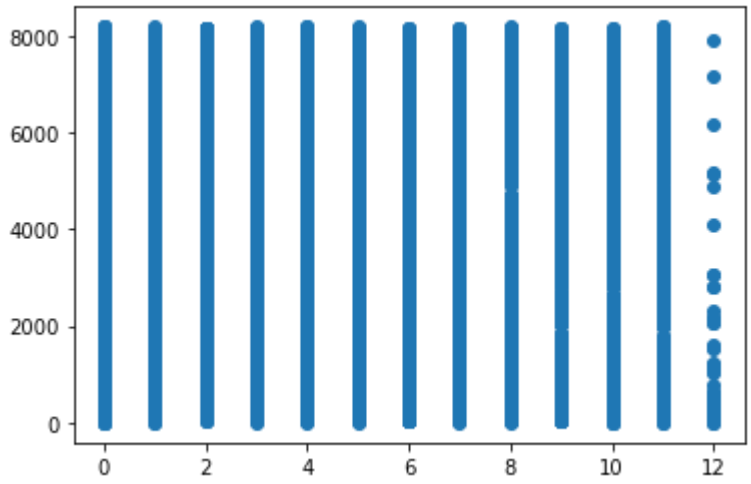
In [8]:
```
g = game()

Q_sarsa, scores = sarsa(g, 3000000, 0.009)

# obtain the corresponding state-value function
#V = dict((k,np.max(v)) for k, v in Q_sarsa.items())
```

```
Episode 3000000/3000000
```

In [9]:
```
policy = dict((state, np.argmax(action)) for state, action in Q_sarsa.items())
```

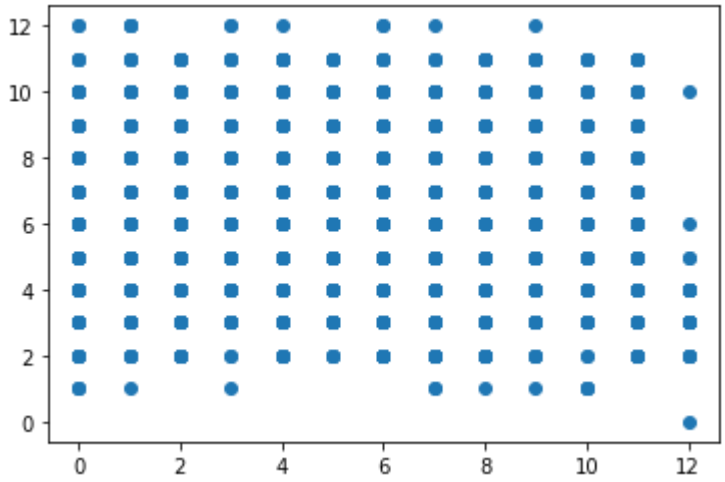
In [10]:
```
xpol = []
ypol = []
for key, value in policy.items():
    xpol += [value]
    ypol += [key]
plt.scatter(xpol,ypol)
```

Out[10]: <matplotlib.collections.PathCollection at 0x19df221f648>



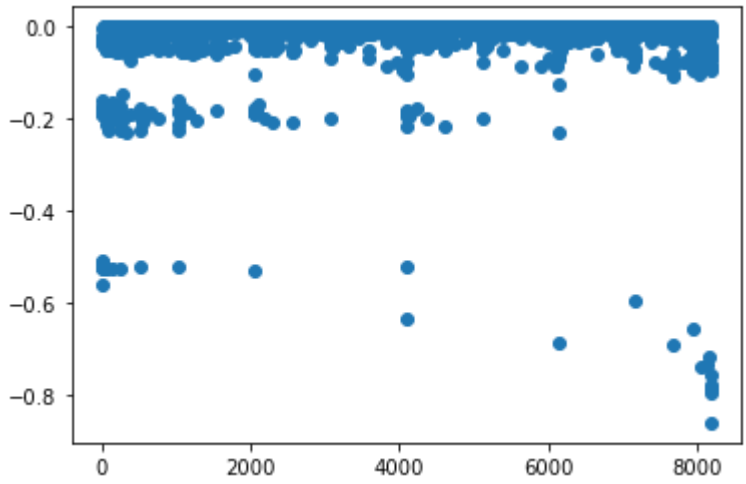
In [11]:
```
xpol = []
ypol = []
for key, value in policy.items():
    xpol += [value]
    ypol += ["{0:b}".format(key).count("1")]
plt.scatter(xpol,ypol)
```

Out[11]: <matplotlib.collections.PathCollection at 0x19df2945748>



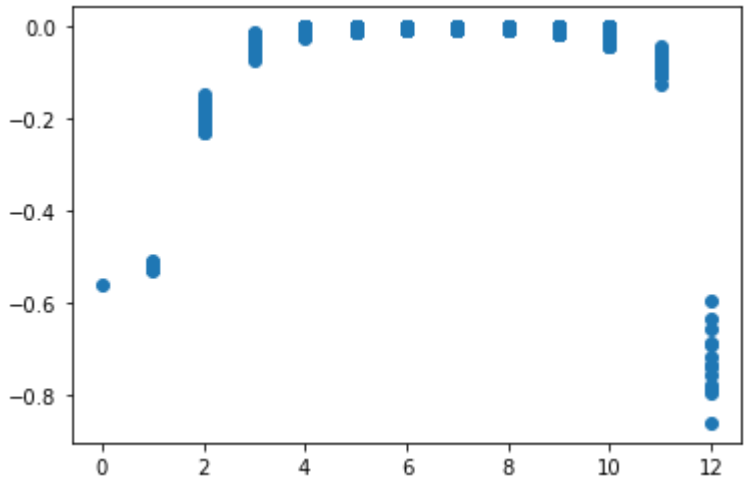
In [12]:
```
xQ = []
yQ = []
for key, value in Q_sarsa.items():
    xQ += [key]
    yQ += [max(value)]
plt.scatter(xQ,yQ)
```

Out[12]: <matplotlib.collections.PathCollection at 0x19df2a0bf88>



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

Out[13]: <matplotlib.collections.PathCollection at 0x19df2ab6c88>



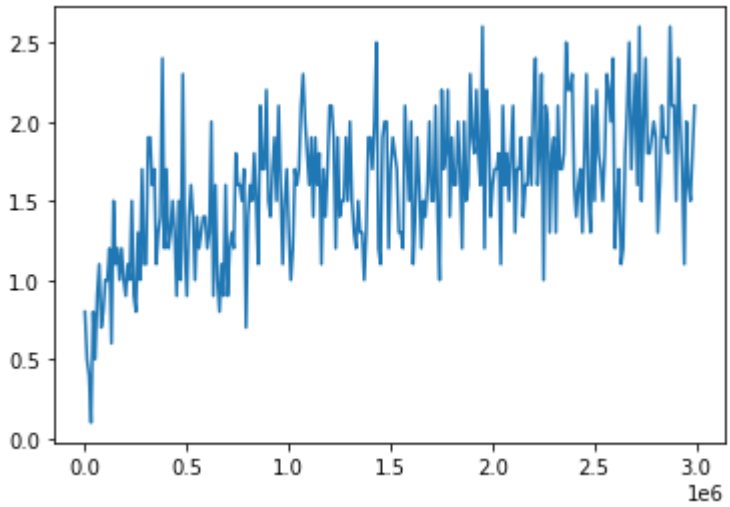
In [14]:
```
# example of step action log, reward for all steps are 0 except for the end, of w
g = game()
g.reset()
while not g.gameOver():
    g.step()
    g.debug()
    print("")
```

```
deck remaining 16
book defaultdict(<class 'int'>, {1: 0, 2: 0, 3: 1, 4: 1, 5: 0, 6: 0, 7: 0, 8:
0, 9: 0, 10: 0, 11: 0, 12: 0, 13: 0})
score [0, 2]


step count 23
aHand defaultdict(<class 'int'>, {1: 0, 2: 0, 3: 0, 4: 0, 5: 1, 6: 3, 7: 0,
8: 0, 9: 0, 10: 0, 11: 3, 12: 0, 13: 2})
cHand defaultdict(<class 'int'>, {1: 3, 2: 3, 3: 0, 4: 0, 5: 2, 6: 0, 7: 3,
8: 3, 9: 0, 10: 3, 11: 0, 12: 3, 13: 0})
deck remaining 15
book defaultdict(<class 'int'>, {1: 0, 2: 0, 3: 1, 4: 1, 5: 0, 6: 0, 7: 0, 8:
0, 9: 0, 10: 0, 11: 0, 12: 0, 13: 0})
score [0, 2]

step count 24
aHand defaultdict(<class 'int'>, {1: 0, 2: 0, 3: 0, 4: 0, 5: 0, 6: 3, 7: 0,
8: 0, 9: 0, 10: 3, 11: 3, 12: 3, 13: 0})
cHand defaultdict(<class 'int'>, {1: 3, 2: 3, 3: 0, 4: 0, 5: 3, 6: 0, 7: 3,
```

In [15]:
```
def compress(list):
    c = []
    for i in range(0,len(list),10):
        c += [np.average(list[i:i+10])]
    return c
```

In [16]:
```
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[16]:
```
[<matplotlib.lines.Line2D at 0x19df2b4afc8>]
```



In [24]:
```
f = open("policyTD.csv", "w")
w = csv.writer(f)
for key, val in policy.items():
    w.writerow([key, val])
f.close()
```

In [25]:
```
f = open("QTD.csv", "w")
w = csv.writer(f)
for key, val in Q_sarsa.items():
    w.writerow([key, val])
f.close()
```

In [26]:
```
f = open("scoreTD.csv", "w")
w = csv.writer(f)
for x in scores:
    w.writerow([x[0], x[1]])
f.close()
```

In [ ]:
```

```