Supplimental document

This document presents supplimental material used to test Q-learning algorithm for Udacity's self-driving cab project for Udacity's machine learning nano-degree (https://www.udacity.com/course/machine-learning-engineer-nanodegree--nd009). First I import required packages in python.

In [25]:
```
import random
from environment import Agent, Environment
from planner import RoutePlanner
from simulator import Simulator
from agent_Q import LearningAgent as Q_learner
from agent_Q_2states import LearningAgent as Q_learner_2s
import numpy as np

from agent_random import LearningAgent as Random_learner
import operator
import matplotlib.pyplot as plt

%pylab inline
## Makes sure code from scripts above are loaded.
%load_ext autoreload
%autoreload 2
```

```
Populating the interactive namespace from numpy and matplotlib
The autoreload extension is already loaded. To reload it, use:
  %reload_ext autoreload

WARNING: pylab import has clobbered these variables: ['random']
`%matplotlib` prevents importing * from pylab and numpy
```

Next I defined functions that take in different parameters and run simulations.

In [170]:
```
def simulate_env_Random(learner,Num_sim = 1000,num_dummies = 3,gamma = 0.
alpha = 0.1):
    e = Environment()
    a = e.create_agent(learner)
    e.num_dummies = num_dummies
    a.gamma = gamma
    a.alpha = alpha
    #a.Q_prev = []
    Q_all = []
    given_time_all = []
    steps_all = []
    for i in range(Num_sim):
        e.set_primary_agent(a, enforce_deadline=False)
        sim = Simulator(e, update_delay=-1, display=False)
        sim.run(n_trials=1)
        steps_all.append(e.steps_end)
        given_time_all.append(e.given_time)
    Q_agent = []
    return steps_all,given_time_all,Q_agent

def simulate_env_Q(learner,Num_sim = 1000,num_dummies = 3,gamma = 0.1,al
pha = 0.1):
    e = Environment()
    a = e.create_agent(learner)
    e.num_dummies = num_dummies
    a.gamma = gamma
    a.alpha = alpha
    #a.Q_prev = []
    Q_all = []
    given_time_all = []
    steps_all = []
    for i in range(Num_sim):
        e.set_primary_agent(a, enforce_deadline=False)
        sim = Simulator(e, update_delay=-1, display=False)
        sim.run(n_trials=1)
        steps_all.append(e.steps_end)
        given_time_all.append(e.given_time)
    Q_agent = a.Q_prev
    return steps_all,given_time_all,Q_agent

def get_failure_points(given_time_all,steps_all,threshold):
    ind_not_reached = [i for i in range(len(given_time_all)) \
                    if ((steps_all[i])<-threshold)]
    steps_not_reached = [steps_all[i] for i in
range(len(given_time_all)) \
                      if ((steps_all[i])<-threshold)]
    return ind_not_reached,steps_not_reached
```

Random agent

First I test a random agent. This agent takes random steps, and moves around the environment.

In [228]:
```
### Different learning results

steps_all_3_r,given_time_all_3_r,Q_agent_3_r = \
    simulate_env_Random(Random_learner,100,3,0.1,0.1)
```

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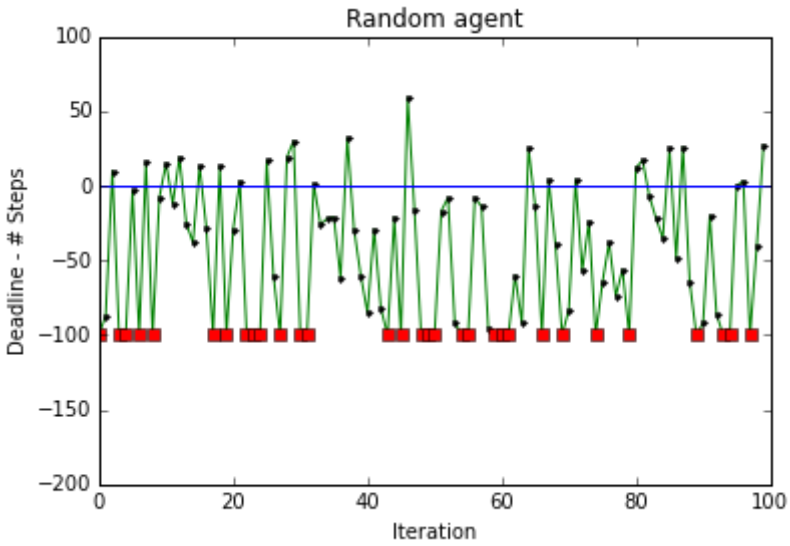
Random agent: Performance

Plot below shows the performance of a random agent. The random agent was able to reach the target within deadline for about 20% of the trials, but in almost 25% of the trials, could not find the target destination even after 100 steps past the deadline.

In [171]:
```
plt.plot(steps_all_3_r,'g',steps_all_3_r,'k.')

threshold = 99;
ind_not_reached,steps_not_reached = get_failure_points(given_time_all_3_
r,
                                                       steps_all_3_r,thr
eshold)
plt.plot(ind_not_reached,steps_not_reached,'rs')
plt.plot([0,100],[0,0])
plt.ylim(-200,100)
plt.title('Random agent')
plt.xlabel('Iteration')
plt.ylabel('Deadline - # Steps')
```

Out[171]:
```
<matplotlib.text.Text at 0x128172d10>
```



In [231]:
```
# Training different learners
steps_all_2s_3,given_time_all_2s_3,Q_agent_2s_3 = \
    simulate_env_Q(Q_learner_2s,100,3,0.1,1)
steps_all_3,given_time_all_3,Q_agent_3 = \
    simulate_env_Q(Q_learner,100,3,0.1,1)

steps_all_2s_20,given_time_all_2s_20,Q_agent_2s_20 = \
    simulate_env_Q(Q_learner_2s,100,20,0.1,1)
steps_all_20,given_time_all_20,Q_agent_20 = \
    simulate_env_Q(Q_learner,100,20,0.1,1)


steps_all_2s_40,given_time_all_2s_40,Q_agent_2s_40 = \
    simulate_env_Q(Q_learner_2s,100,40,0.1,1)
steps_all_40,given_time_all_40,Q_agent_40 = \
    simulate_env_Q(Q_learner,100,40,0.1,1)
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Q-learning agent: Performance, 5 states (traffic light, 3 X oncoming traffic, way-point)

Plots below shows the performance of a Q-learning agent for $\alpha = 1$ and $\gamma = 0.1$ with information of 5 states (traffic light, 3 X oncoming traffic, way-point), for 3, 20 and 40 other agents in the environment. The Q-learning agent performed much better than the random agent for all the cases, and was able to reach the destination within deadline.

In [225]:
```
plt.figure(figsize=(12,12));
plt.subplot(2,2,1)
plt.plot(steps_all_3_r,'g',steps_all_3_r,'k.')
plt.ylim(-120,100)
plt.title('Random agent')
plt.xlabel('Iteration')
plt.ylabel('Deadline - # Steps')
ind_not_reached,steps_not_reached = get_failure_points(given_time_all_3_
r,
                                                       steps_all_3_r,thr
eshold)
plt.plot(ind_not_reached,steps_not_reached,'rs')
plt.plot([0,100],[0,0])

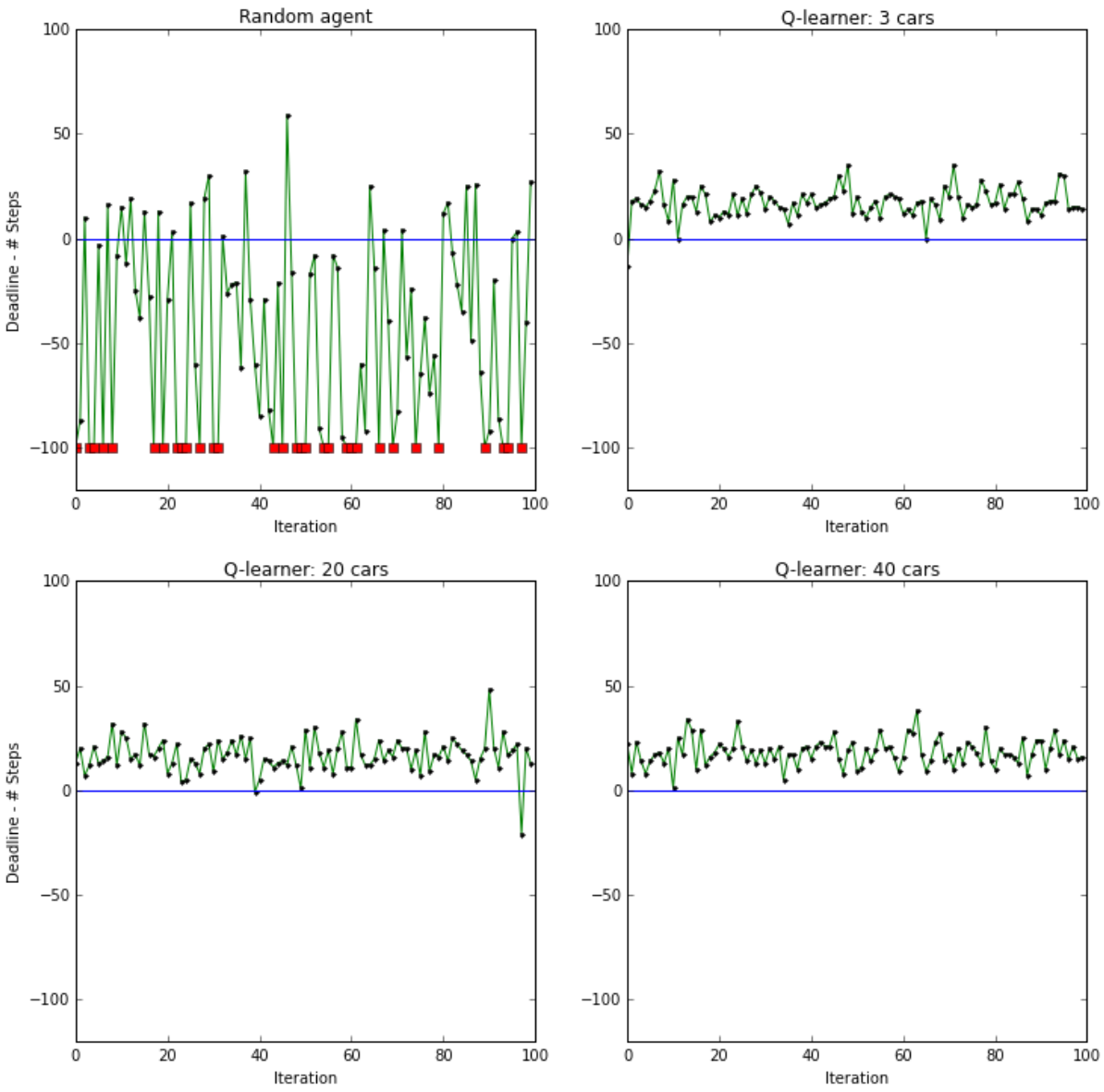

plt.subplot(2,2,2)
plt.plot(steps_all_3,'g',steps_all_3,'k.')
plt.title('Q-learner: 3 cars')
plt.xlabel('Iteration')
ind_not_reached,steps_not_reached = get_failure_points(given_time_all_3,
                                                       steps_all_3,thres
hold)
plt.plot(ind_not_reached,steps_not_reached,'rs')
plt.ylim(-120,100)
plt.plot([0,100],[0,0])

plt.subplot(2,2,3)
plt.plot(steps_all_20,'g',steps_all_20,'k.')
plt.title('Q-learner: 20 cars')
plt.xlabel('Iteration')
plt.ylabel('Deadline - # Steps')

ind_not_reached,steps_not_reached =
get_failure_points(given_time_all_20,
                                                       steps_all_20,thre
shold)
plt.plot(ind_not_reached,steps_not_reached,'rs')
plt.ylim(-120,100)
plt.plot([0,100],[0,0])


plt.subplot(2,2,4)
plt.plot(steps_all_40,'g',steps_all_40,'k.')
plt.title('Q-learner: 40 cars')
plt.xlabel('Iteration')
ind_not_reached,steps_not_reached =
get_failure_points(given_time_all_40,
                                                       steps_all_40,thre
shold)
plt.plot(ind_not_reached,steps_not_reached,'rs')
plt.ylim(-120,100)
plt.plot([0,100],[0,0])
```

```
Out[225]: [<matplotlib.lines.Line2D at 0x134b1fe10>]
```



In [226]:
```
plt.figure(figsize=(15,4));

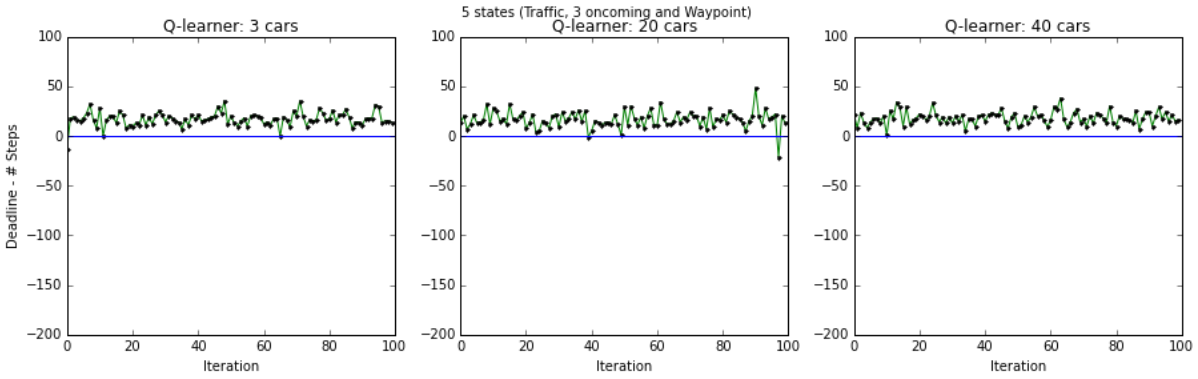
plt.subplot(1,3,1)
plt.plot(steps_all_3,'g',steps_all_3,'k.')
plt.title('Q-learner: 3 cars')
plt.ylabel('Deadline - # Steps')

plt.xlabel('Iteration')
plt.ylim(-200,100)
plt.plot([0,100],[0,0])

plt.subplot(1,3,2)
plt.plot(steps_all_20,'g',steps_all_20,'k.')
plt.title('Q-learner: 20 cars')
plt.xlabel('Iteration')
ind_not_reached,steps_not_reached =
get_failure_points(given_time_all_20,
                                                    steps_all_20,thre
shold)
plt.plot(ind_not_reached,steps_not_reached,'rs')
plt.ylim(-200,100)
plt.plot([0,100],[0,0])

plt.subplot(1,3,3)
plt.plot(steps_all_40,'g',steps_all_40,'k.')
plt.title('Q-learner: 40 cars')
plt.xlabel('Iteration')
ind_not_reached,steps_not_reached =
get_failure_points(given_time_all_40,
                                                    steps_all_40,thre
shold)
plt.plot(ind_not_reached,steps_not_reached,'rs')
plt.ylim(-200,100)
plt.plot([0,100],[0,0])
plt.suptitle('5 states (Traffic, 3 oncoming and Waypoint)')
```

Out[226]: <matplotlib.text.Text at 0x135287210>



In [198]:
```
Q_agent_40_srt = sorted(Q_agent_40.items(),key=operator.itemgetter(1),re
verse=True)
Q_agent_20_srt = sorted(Q_agent_20.items(),key=operator.itemgetter(1),re
verse=True)
Q_agent_3_srt = sorted(Q_agent_3.items(),key=operator.itemgetter(1),reve
rse=True)
```

In [211]:
```
import pandas as pd
Q_agent_40_srt = sorted(Q_agent_40.items(),key=operator.itemgetter(1),re
verse=True)
Q_agent_20_srt = sorted(Q_agent_20.items(),key=operator.itemgetter(1),re
verse=True)
Q_agent_3_srt = sorted(Q_agent_3.items(),key=operator.itemgetter(1),reve
rse=True)
df = {'Q-3 (light,oncoming,left,right,way-point,action)': pd.Series(Q_ag
ent_3_srt[0:10]),
     'Q-20 (light,oncoming,left,right,way-point,action)': pd.Series(Q_ag
ent_20_srt[0:10]),
     'Q-40 (light,oncoming,left,right,way-point,action)': pd.Series(Q_ag
ent_40_srt[0:10])}
pd.DataFrame(data = df)
```

Out[211]:

	Q-20 (light,oncoming,left,right,way-point,action)	Q-3 (light,oncoming,left,right,way-point,action)	Q-4 poi
0	(green,None,None,None,forward,forward, 8.21193...	(green,None,None,None,forward,forward, 6.19096...	(gre 4.2
1	(green,None,None,None,right,right, 64941.1002869)	(green,None,None,None,left,left, 22129.5384059)	(gre 596
2	(green,None,None,None,left,left, 24285.9658697)	(red,None,None,None,right,right, 10691.9014387)	(gre 360
3	(red,None,None,None,right,right, 22004.8156005)	(green,None,None,None,right,right, 9590.26253166)	(red 270
4	(green,None,None,right,forward,forward, 16.62)	(green,left,None,None,forward,forward, 28.74122)	(gre 14.3
5	(green,left,None,None,forward,forward, 15.2)	(green,None,None,forward,forward,forward, 19.282)	(gre 14.3
6	(green,None,None,left,forward,forward, 14.2)	(green,None,None,left,left,left, 4.2)	(gre
7	(green,None,None,forward,forward,forward, 12.0)	(green,None,None,right,forward,forward, 4.2)	(gre 12.(
8	(green,None,left,None,forward,forward, 9.282)	(green,None,left,None,right,right, 4.2)	(gre 6.62
9	(green,None,forward,None,right,right, 4.2)	(green,None,None,left,forward,forward, 4.2)	(gre 4.2)

Q-learning agent: Performance, 2 states (traffic light, way-point)

Plots below shows the performance of a Q-learning agent for $\alpha = 1$ and $\gamma = 0.1$ with information of 2 states (traffic light, way-point), for 3, 20 and 40 other agents in the environment. The Q-learning agent performed much better than the random agent when there were only 3 agents in the environment. For more agents, the Q-learning algorithm could not find the target, especially when the number of agents increased from 20 to 40.

In [232]:
```
plt.figure(figsize=(15,4));

plt.subplot(1,3,1)
plt.plot(steps_all_2s_3,'g',steps_all_2s_3,'k.')
plt.title('Q-learner: 3 cars')
plt.ylabel('Deadline - # Steps')

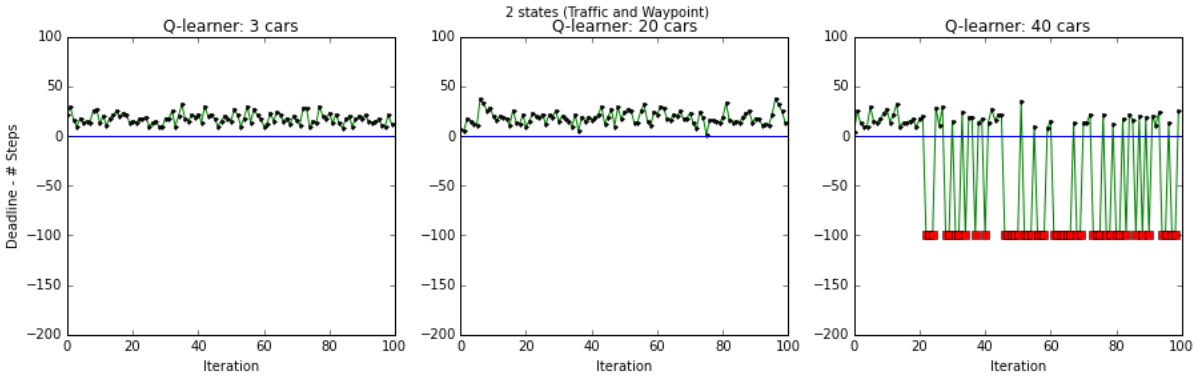
plt.xlabel('Iteration')
plt.ylim(-200,100)
plt.plot([0,100],[0,0])

plt.subplot(1,3,2)
plt.plot(steps_all_2s_20,'g',steps_all_2s_20,'k.')
plt.title('Q-learner: 20 cars')
plt.xlabel('Iteration')
ind_not_reached,steps_not_reached = get_failure_points(given_time_all_2s
_20,
                                                       steps_all_2s_20,t
hreshold)
plt.plot(ind_not_reached,steps_not_reached,'rs')
plt.ylim(-200,100)
plt.plot([0,100],[0,0])

plt.subplot(1,3,3)
plt.plot(steps_all_2s_40,'g',steps_all_2s_40,'k.')
plt.title('Q-learner: 40 cars')
plt.xlabel('Iteration')
ind_not_reached,steps_not_reached = get_failure_points(given_time_all_2s
_40,
                                                       steps_all_2s_40,t
hreshold)
plt.plot(ind_not_reached,steps_not_reached,'rs')
plt.ylim(-200,100)
plt.plot([0,100],[0,0])

plt.suptitle('2 states (Traffic and Waypoint)')
```

Out[232]: <matplotlib.text.Text at 0x135f36790>



Q-learning agent: Performance tuning, 5 states (traffic light, 3X oncoming traffic, way-point)

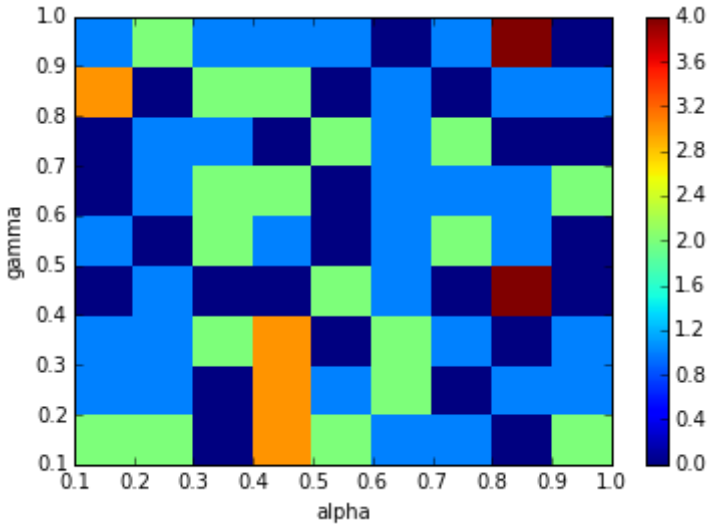
I next varied α and γ between 0 and 1 in steps of 0.1, and calculated number of times the smartcab misses the destination in 100 trials. Results indicate that the Q-learning algorith is robust to changes in α and γ, and in all cases the number of times destination was missed was less than 2. Based on this, I chose $\alpha = 0.3$ and $\gamma = 0.5$.

In [133]:
```
alpha_all = np.arange(0.1,1.1,0.1)
gamma_all = np.arange(0.1,1.1,0.1)
Num_fail_all = []
alpha_all,gamma_all = np.meshgrid(alpha_all,gamma_all)

Z_all = np.zeros((len(alpha_all),len(gamma_all)))
for i_alpha in range(len(alpha_all)):
    for i_gamma in range(len(gamma_all)):
        steps_all_3,given_time_all_3,Q_agent_3 = \
            simulate_env_Q(Q_learner,100,3,
                           gamma_all[i_alpha]
[i_gamma],alpha_all[i_alpha][i_gamma])
        num_fail = [i for i in steps_all_3 if i<0]
        Z_all[i_alpha][i_gamma] = len(num_fail)
```

In [213]:
```
fig, ax = plt.subplots()
heatmap = ax.pcolor(alpha_all,gamma_all,Z_all)
plt.colorbar(heatmap)
plt.xlabel('alpha')
plt.ylabel('gamma')
```

Out[213]: <matplotlib.text.Text at 0x131b70590>



Q-learning agent: Optimal performance

Optimal performance was obtained for $\alpha = 0.3$ and $\gamma = 0.5$. Simulation results indicate that of 100 trials, the smartcab missed destination in only 1 tiral, when the number of agents in environment was 40.

In [155]:
```
steps_all_3,given_time_all_3,Q_agent_3 = \
            simulate_env_Q(Q_learner,100,3,
                           .5,.3)
steps_all_20,given_time_all_20,Q_agent_20 = \
            simulate_env_Q(Q_learner,100,20,
                           .5,.3)
steps_all_40,given_time_all_40,Q_agent_40 = \
            simulate_env_Q(Q_learner,100,40,
                           .5,.3)
```

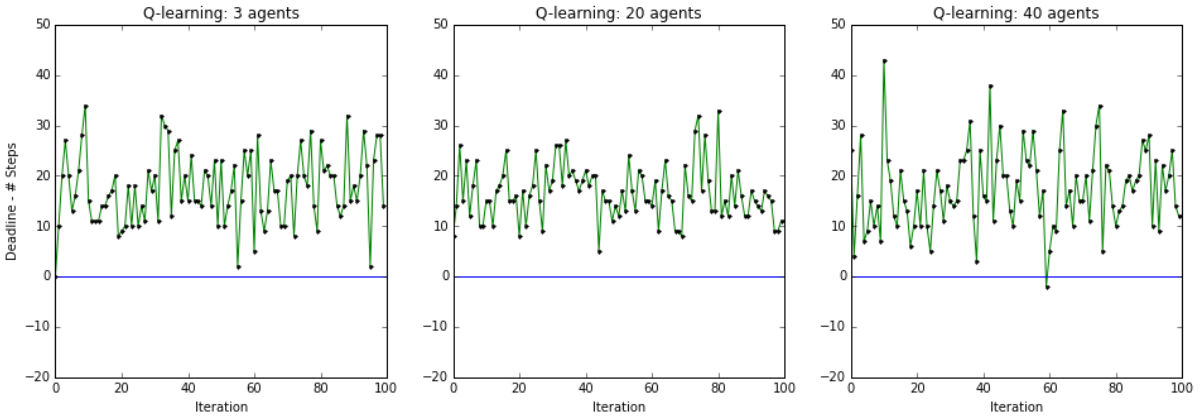
In [156]:
```
threshold = 99;
ind_not_reached,steps_not_reached = get_failure_points(given_time_all_3,
                                                       steps_all_3,threshold)

plt.figure(figsize=(16,5))
plt.subplot(1,3,1)
plt.plot(steps_all_3,'g',steps_all_3,'k.')
plt.plot(ind_not_reached,steps_not_reached,'rs')
plt.plot([0,100],[0,0])
plt.ylim(-20,50)
plt.title('Q-learning: 3 agents')
plt.xlabel('Iteration')
plt.ylabel('Deadline - # Steps')

plt.subplot(1,3,2)
plt.plot(steps_all_20,'g',steps_all_20,'k.')
plt.plot(ind_not_reached,steps_not_reached,'rs')
plt.plot([0,100],[0,0])
plt.ylim(-20,50)
plt.title('Q-learning: 20 agents')
plt.xlabel('Iteration')

plt.subplot(1,3,3)
plt.plot(steps_all_40,'g',steps_all_40,'k.')
plt.plot(ind_not_reached,steps_not_reached,'rs')
plt.plot([0,100],[0,0])
plt.ylim(-20,50)
plt.title('Q-learning: 40 agents')
plt.xlabel('Iteration')
```

Out[156]: <matplotlib.text.Text at 0x123553b10>



In [214]:
```
import pandas as pd
Q_agent_40_srt = sorted(Q_agent_40.items(),key=operator.itemgetter(1),re
verse=True)
Q_agent_20_srt = sorted(Q_agent_20.items(),key=operator.itemgetter(1),re
verse=True)
Q_agent_3_srt = sorted(Q_agent_3.items(),key=operator.itemgetter(1),reve
rse=True)
df = {'Q-3 (light,oncoming,left,right,way-point,action)': pd.Series(Q_ag
ent_3_srt[0:10]),
     'Q-20 (light,oncoming,left,right,way-point,action)': pd.Series(Q_ag
ent_20_srt[0:10]),
     'Q-40 (light,oncoming,left,right,way-point,action)': pd.Series(Q_ag
ent_40_srt[0:10])}
pd.DataFrame(data = df)
```

Out[214]:

	Q-20 (light,oncoming,left,right,way-point,action)	Q-3 (light,oncoming,left,right,way-point,action)	Q-4 poi
0	(green,None,None,None,forward,forward, 8.21193...	(green,None,None,None,forward,forward, 6.19096...	(gre 4.2
1	(green,None,None,None,right,right, 64941.1002869)	(green,None,None,None,left,left, 22129.5384059)	(gre 596
2	(green,None,None,None,left,left, 24285.9658697)	(red,None,None,None,right,right, 10691.9014387)	(gre 360
3	(red,None,None,None,right,right, 22004.8156005)	(green,None,None,None,right,right, 9590.26253166)	(rec 270
4	(green,None,None,right,forward,forward, 16.62)	(green,left,None,None,forward,forward, 28.74122)	(gre 14.3
5	(green,left,None,None,forward,forward, 15.2)	(green,None,None,forward,forward,forward, 19.282)	(gre 14.3
6	(green,None,None,left,forward,forward, 14.2)	(green,None,None,left,left,left, 4.2)	(gre
7	(green,None,None,forward,forward,forward, 12.0)	(green,None,None,right,forward,forward, 4.2)	(gre 12.(
8	(green,None,left,None,forward,forward, 9.282)	(green,None,left,None,right,right, 4.2)	(gre 6.62
9	(green,None,forward,None,right,right, 4.2)	(green,None,None,left,forward,forward, 4.2)	(gre 4.2)