Deep Reinforcement Learning on Stock Data

Reinforcement Learning

Reinforcement Learning (RL) is a type of machine learning paradigm that involves an agent learning to make decisions by interacting with an environment.

The agent learns to achieve a goal or maximize a reward by taking suitable actions in different situations.

It's based on the idea of learning from feedback, wherein the agent receives rewards or penalties based on its actions.

Import Libraries

In [2]:
```
import time
import copy
import numpy as np
import pandas as pd
import chainer
import chainer.functions as F
import chainer.links as L
from plotly import tools
from plotly.graph_objs import *
from plotly.offline import init_notebook_mode, iplot, iplot_mpl
init_notebook_mode()
```

Read the data

In [3]:
```
data = pd.read_csv('../input/Data/Stocks/goog.us.txt')
data['Date'] = pd.to_datetime(data['Date'])
data = data.set_index('Date')
print(data.index.min(), data.index.max())
data.head()
```

```
2014-03-27 00:00:00 2017-11-10 00:00:00
```

Out[3]:

Date	Open	High	Low	Close	Volume	OpenInt
2014-03-27	568.00	568.00	552.92	558.46	13052	0
2014-03-28	561.20	566.43	558.67	559.99	41003	0
2014-03-31	566.89	567.00	556.93	556.97	10772	0
2014-04-01	558.71	568.45	558.71	567.16	7932	0
2014-04-02	599.99	604.83	562.19	567.00	146697	0

Train and Test Datasets

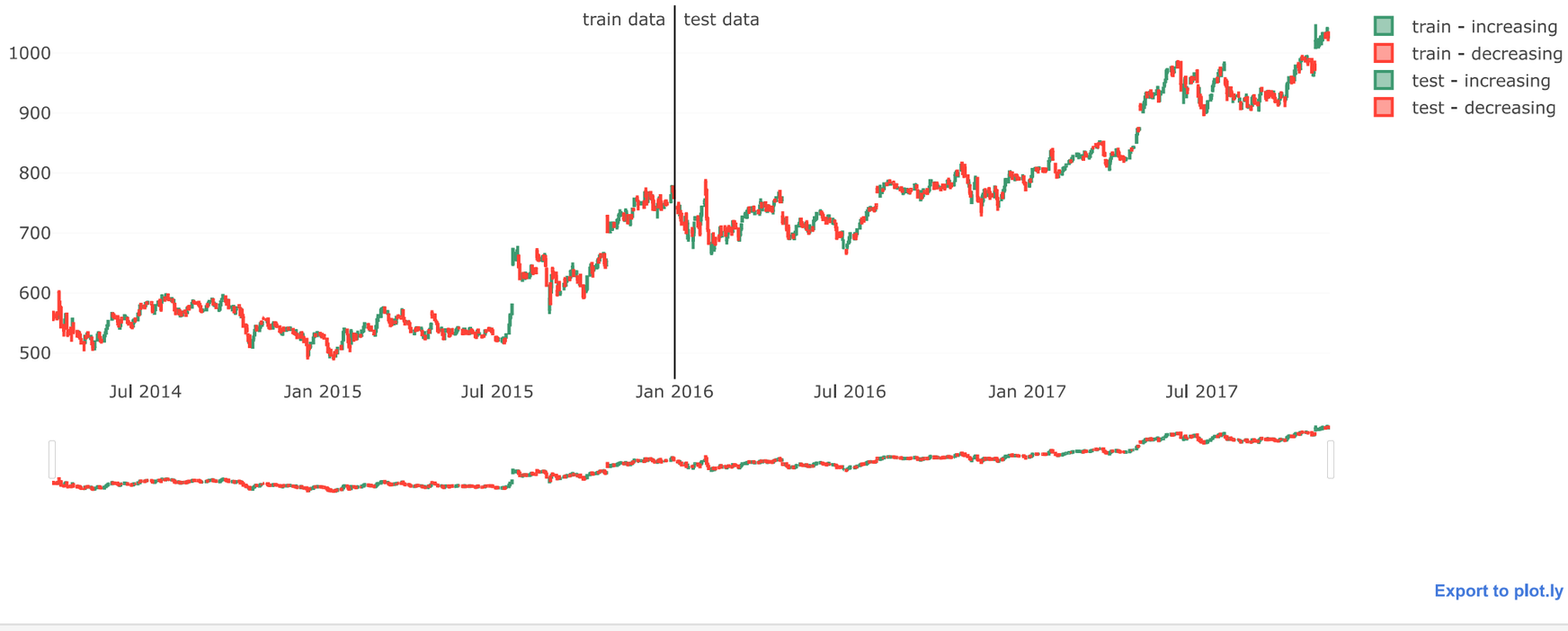
In [4]:
```
date_split = '2016-01-01'
train = data[:date_split]
test = data[date_split:]
len(train), len(test)
```

Out[4]:
```
(446, 470)
```

In [5]:
```
def plot_train_test(train, test, date_split):

    data = [
        Candlestick(x=train.index, open=train['Open'], high=train['High'], low=train['Low'], close=train['Close'], name='train'),
        Candlestick(x=test.index, open=test['Open'], high=test['High'], low=test['Low'], close=test['Close'], name='test')
    ]
    layout = {
         'shapes': [
             {'x0': date_split, 'x1': date_split, 'y0': 0, 'y1': 1, 'xref': 'x', 'yref': 'paper', 'line': {'color': 'rgb(0,0,0)', 'width': 1}}
         ],
        'annotations': [
            {'x': date_split, 'y': 1.0, 'xref': 'x', 'yref': 'paper', 'showarrow': False, 'xanchor': 'left', 'text': ' test data'},
            {'x': date_split, 'y': 1.0, 'xref': 'x', 'yref': 'paper', 'showarrow': False, 'xanchor': 'right', 'text': 'train data '}
        ]
    }
    figure = Figure(data=data, layout=layout)
    iplot(figure)
```

In [6]:
```
plot_train_test(train, test, date_split)
```



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In [7]:

```python
class Environment1:

    def __init__(self, data, history_t=90):
        self.data = data
        self.history_t = history_t
        self.reset()

    def reset(self):
        self.t = 0
        self.done = False
        self.profits = 0
        self.positions = []
        self.position_value = 0
        self.history = [0 for _ in range(self.history_t)]
        return [self.position_value] + self.history # obs

    def step(self, act):
        reward = 0

        # act = 0: stay, 1: buy, 2: sell
        if act == 1:
            self.positions.append(self.data.iloc[self.t, :]['Close'])
        elif act == 2: # sell
            if len(self.positions) == 0:
                reward = -1
            else:
                profits = 0
```

```
                for p in self.positions:
                    profits += (self.data.iloc[self.t, :]['Close'] - p)
                reward += profits
                self.profits += profits
                self.positions = []

        # set next time
        self.t += 1
        self.position_value = 0
        for p in self.positions:
            self.position_value += (self.data.iloc[self.t, :]['Close'] - p)
        self.history.pop(0)
        self.history.append(self.data.iloc[self.t, :]['Close'] - self.data.iloc[(self.t-1), :]['Close'])

        # clipping reward
        if reward > 0:
            reward = 1
        elif reward < 0:
            reward = -1

        return [self.position_value] + self.history, reward, self.done # obs, reward, done
```

In [8]:
```
env = Environment1(train)
print(env.reset())
for _ in range(3):
    pact = np.random.randint(3)
    print(env.step(pact))
```

```
[0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0,
0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0]
([1.5299999999999727, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0,
0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 1.5299999999999727], 0, False)
([0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0,
0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 1.5299999999999727, -3.0199999999999818], 1, False)
([0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0,
0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 1.5299999999999727, -3.0199999999999818, 10.189999999999941], -1, False)
```

In [9]:
```
# DQN

def train_dqn(env):

    class Q_Network(chainer.Chain):

        def __init__(self, input_size, hidden_size, output_size):
            super(Q_Network, self).__init__(
                fc1 = L.Linear(input_size, hidden_size),
                fc2 = L.Linear(hidden_size, hidden_size),
                fc3 = L.Linear(hidden_size, output_size)
            )

        def __call__(self, x):
            h = F.relu(self.fc1(x))
            h = F.relu(self.fc2(h))
            y = self.fc3(h)
            return y

        def reset(self):
            self.zerograds()

    Q = Q_Network(input_size=env.history_t+1, hidden_size=100, output_size=3)
```

```
    Q_ast = copy.deepcopy(Q)
    optimizer = chainer.optimizers.Adam()
    optimizer.setup(Q)

    epoch_num = 50
    step_max = len(env.data)-1
    memory_size = 200
    batch_size = 20
    epsilon = 1.0
    epsilon_decrease = 1e-3
    epsilon_min = 0.1
    start_reduce_epsilon = 200
    train_freq = 10
    update_q_freq = 20
    gamma = 0.97
    show_log_freq = 5

    memory = []
    total_step = 0
    total_rewards = []
    total_losses = []

    start = time.time()
    for epoch in range(epoch_num):

        pobs = env.reset()
        step = 0
        done = False
        total_reward = 0
        total_loss = 0

        while not done and step < step_max:

            # select act
            pact = np.random.randint(3)
            if np.random.rand() > epsilon:
                pact = Q(np.array(pobs, dtype=np.float32).reshape(1, -1))
                pact = np.argmax(pact.data)

            # act
            obs, reward, done = env.step(pact)

            # add memory
            memory.append((pobs, pact, reward, obs, done))
            if len(memory) > memory_size:
                memory.pop(0)

            # train or update q
            if len(memory) == memory_size:
                if total_step % train_freq == 0:
                    shuffled_memory = np.random.permutation(memory)
                    memory_idx = range(len(shuffled_memory))
                    for i in memory_idx[::batch_size]:
                        batch = np.array(shuffled_memory[i:i+batch_size])
                        b_pobs = np.array(batch[:, 0].tolist(), dtype=np.float32).reshape(batch_size, -1)
                        b_pact = np.array(batch[:, 1].tolist(), dtype=np.int32)
                        b_reward = np.array(batch[:, 2].tolist(), dtype=np.int32)
                        b_obs = np.array(batch[:, 3].tolist(), dtype=np.float32).reshape(batch_size, -1)
                        b_done = np.array(batch[:, 4].tolist(), dtype=np.bool)
```

```
                    q = Q(b_pobs)
                    maxq = np.max(Q_ast(b_obs).data, axis=1)
                    target = copy.deepcopy(q.data)
                    for j in range(batch_size):
                        target[j, b_pact[j]] = b_reward[j]+gamma*maxq[j]*(not b_done[j])
                    Q.reset()
                    loss = F.mean_squared_error(q, target)
                    total_loss += loss.data
                    loss.backward()
                    optimizer.update()

                if total_step % update_q_freq == 0:
                    Q_ast = copy.deepcopy(Q)

            # epsilon
            if epsilon > epsilon_min and total_step > start_reduce_epsilon:
                epsilon -= epsilon_decrease

            # next step
            total_reward += reward
            pobs = obs
            step += 1
            total_step += 1

        total_rewards.append(total_reward)
        total_losses.append(total_loss)

        if (epoch+1) % show_log_freq == 0:
            log_reward = sum(total_rewards[((epoch+1)-show_log_freq):])/show_log_freq
            log_loss = sum(total_losses[((epoch+1)-show_log_freq):])/show_log_freq
            elapsed_time = time.time()-start
            print('\t'.join(map(str, [epoch+1, epsilon, total_step, log_reward, log_loss, elapsed_time])))
            start = time.time()

    return Q, total_losses, total_rewards
```

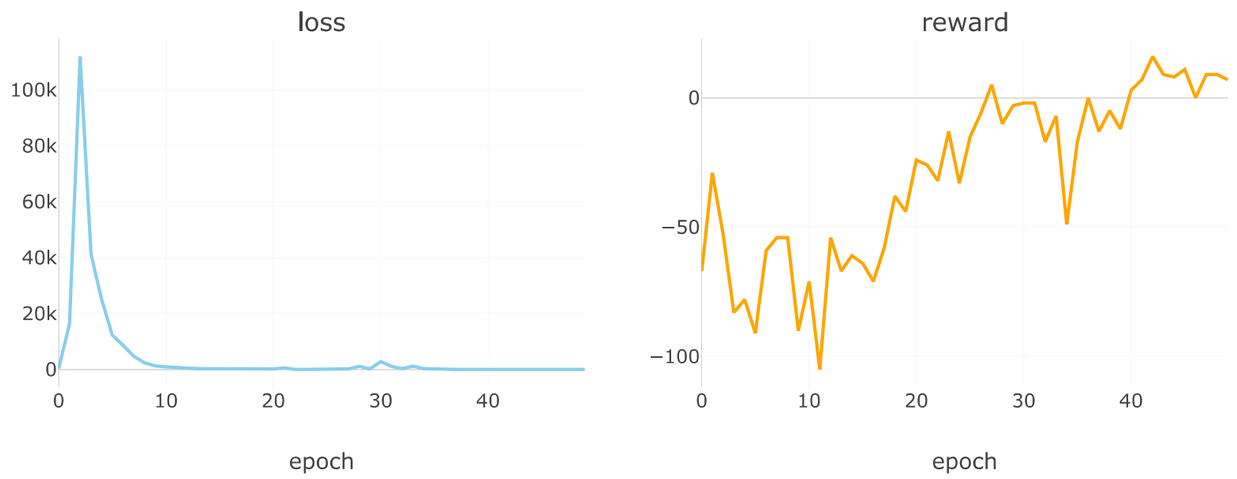
In [10]:
```
Q, total_losses, total_rewards = train_dqn(Environment1(train))
```

```
5       0.0999999999999992      2225    -62.0   38994.727623    9.185798168182373
10      0.0999999999999992      4450    -69.6   5872.36153181   10.086313247680664
15      0.0999999999999992      6675    -71.6   490.885859407   9.929555654525757
20      0.0999999999999992      8900    -55.0   228.797397427   9.453218221664429
25      0.0999999999999992      11125   -25.6   182.087579884   9.757601499557495
30      0.0999999999999992      13350   -5.8    337.967664644   10.504354476928711
35      0.0999999999999992      15575   -15.4   1159.82199649   12.502948999404907
40      0.0999999999999992      17800   -9.4    57.2816223043   10.434857845306396
45      0.0999999999999992      20025   8.6     28.5512007653   10.884730577468872
50      0.0999999999999992      22250   7.2     22.5572660003   10.777376413345337
```

In [11]:
```
def plot_loss_reward(total_losses, total_rewards):

    figure = tools.make_subplots(rows=1, cols=2, subplot_titles=('loss', 'reward'), print_grid=False)
    figure.append_trace(Scatter(y=total_losses, mode='lines', line=dict(color='skyblue')), 1, 1)
    figure.append_trace(Scatter(y=total_rewards, mode='lines', line=dict(color='orange')), 1, 2)
    figure['layout']['xaxis1'].update(title='epoch')
    figure['layout']['xaxis2'].update(title='epoch')
    figure['layout'].update(height=400, width=900, showlegend=False)
    iplot(figure)
```

In [12]:
```
plot_loss_reward(total_losses, total_rewards)
```



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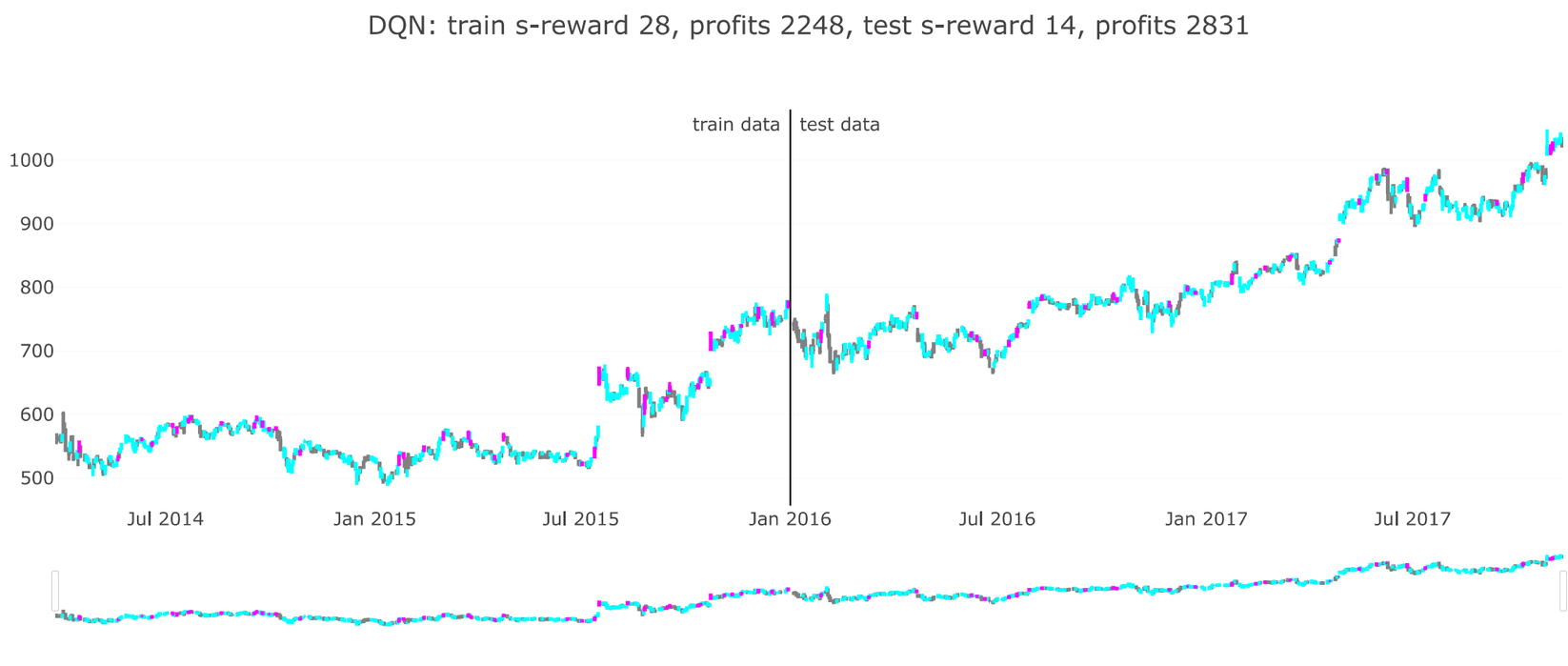
In [13]:
```
def plot_train_test_by_q(train_env, test_env, Q, algorithm_name):

    # train
    pobs = train_env.reset()
    train_acts = []
    train_rewards = []

    for _ in range(len(train_env.data)-1):

        pact = Q(np.array(pobs, dtype=np.float32).reshape(1, -1))
        pact = np.argmax(pact.data)
        train_acts.append(pact)

        obs, reward, done = train_env.step(pact)
        train_rewards.append(reward)

        pobs = obs

    train_profits = train_env.profits

    # test
    pobs = test_env.reset()
    test_acts = []
    test_rewards = []

    for _ in range(len(test_env.data)-1):

        pact = Q(np.array(pobs, dtype=np.float32).reshape(1, -1))
        pact = np.argmax(pact.data)
        test_acts.append(pact)
```

```
        obs, reward, done = test_env.step(pact)
        test_rewards.append(reward)

        pobs = obs

    test_profits = test_env.profits

    # plot
    train_copy = train_env.data.copy()
    test_copy = test_env.data.copy()
    train_copy['act'] = train_acts + [np.nan]
    train_copy['reward'] = train_rewards + [np.nan]
    test_copy['act'] = test_acts + [np.nan]
    test_copy['reward'] = test_rewards + [np.nan]
    train0 = train_copy[train_copy['act'] == 0]
    train1 = train_copy[train_copy['act'] == 1]
    train2 = train_copy[train_copy['act'] == 2]
    test0 = test_copy[test_copy['act'] == 0]
    test1 = test_copy[test_copy['act'] == 1]
    test2 = test_copy[test_copy['act'] == 2]
    act_color0, act_color1, act_color2 = 'gray', 'cyan', 'magenta'

    data = [
        Candlestick(x=train0.index, open=train0['Open'], high=train0['High'], low=train0['Low'], close=train0['Close'], increasing=dict(line=dict(color=act_color0)), decreasing=dict(line=dict(color=ac
        Candlestick(x=train1.index, open=train1['Open'], high=train1['High'], low=train1['Low'], close=train1['Close'], increasing=dict(line=dict(color=act_color1)), decreasing=dict(line=dict(color=ac
        Candlestick(x=train2.index, open=train2['Open'], high=train2['High'], low=train2['Low'], close=train2['Close'], increasing=dict(line=dict(color=act_color2)), decreasing=dict(line=dict(color=ac
        Candlestick(x=test0.index, open=test0['Open'], high=test0['High'], low=test0['Low'], close=test0['Close'], increasing=dict(line=dict(color=act_color0)), decreasing=dict(line=dict(color=act_col
        Candlestick(x=test1.index, open=test1['Open'], high=test1['High'], low=test1['Low'], close=test1['Close'], increasing=dict(line=dict(color=act_color1)), decreasing=dict(line=dict(color=act_col
        Candlestick(x=test2.index, open=test2['Open'], high=test2['High'], low=test2['Low'], close=test2['Close'], increasing=dict(line=dict(color=act_color2)), decreasing=dict(line=dict(color=act_col
    ]
    title = '{}: train s-reward {}, profits {}, test s-reward {}, profits {}'.format(
        algorithm_name,
        int(sum(train_rewards)),
        int(train_profits),
        int(sum(test_rewards)),
        int(test_profits)
    )
    layout = {
        'title': title,
        'showlegend': False,
         'shapes': [
             {'x0': date_split, 'x1': date_split, 'y0': 0, 'y1': 1, 'xref': 'x', 'yref': 'paper', 'line': {'color': 'rgb(0,0,0)', 'width': 1}}
         ],
        'annotations': [
            {'x': date_split, 'y': 1.0, 'xref': 'x', 'yref': 'paper', 'showarrow': False, 'xanchor': 'left', 'text': ' test data'},
            {'x': date_split, 'y': 1.0, 'xref': 'x', 'yref': 'paper', 'showarrow': False, 'xanchor': 'right', 'text': 'train data '}
        ]
    }
    figure = Figure(data=data, layout=layout)
    iplot(figure)
```

In [14]:
```
plot_train_test_by_q(Environment1(train), Environment1(test), Q, 'DQN')
```



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In [15]:

```python
# Double DQN

def train_ddqn(env):

    class Q_Network(chainer.Chain):

        def __init__(self, input_size, hidden_size, output_size):
            super(Q_Network, self).__init__(
                fc1 = L.Linear(input_size, hidden_size),
                fc2 = L.Linear(hidden_size, hidden_size),
                fc3 = L.Linear(hidden_size, output_size)
            )

        def __call__(self, x):
            h = F.relu(self.fc1(x))
            h = F.relu(self.fc2(h))
            y = self.fc3(h)
            return y

        def reset(self):
            self.zerograds()

    Q = Q_Network(input_size=env.history_t+1, hidden_size=100, output_size=3)
    Q_ast = copy.deepcopy(Q)
    optimizer = chainer.optimizers.Adam()
    optimizer.setup(Q)
```

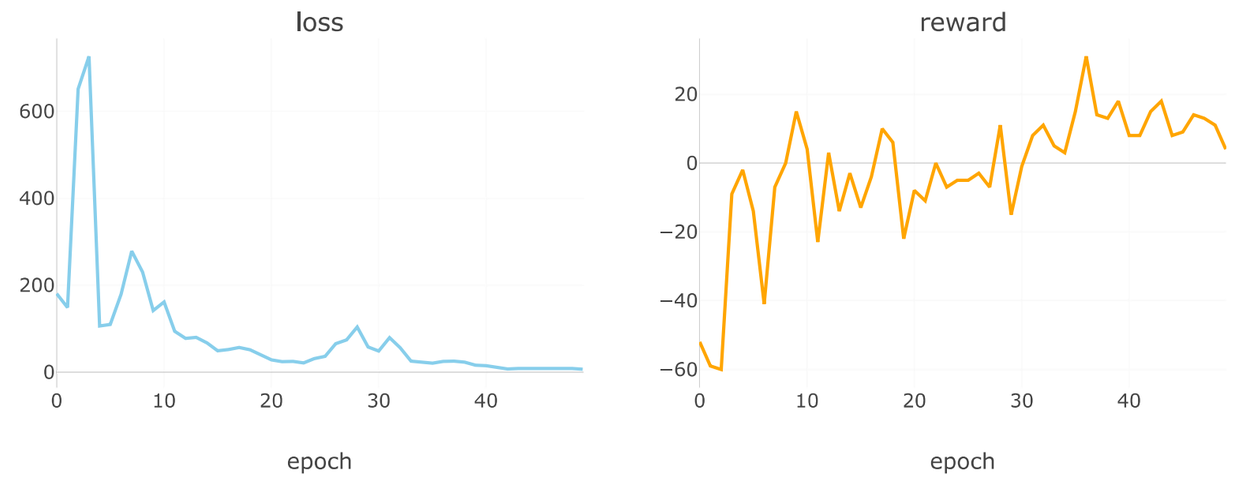
```
epoch_num = 50
step_max = len(env.data)-1
memory_size = 200
batch_size = 50
epsilon = 1.0
epsilon_decrease = 1e-3
epsilon_min = 0.1
start_reduce_epsilon = 200
train_freq = 10
update_q_freq = 20
gamma = 0.97
show_log_freq = 5

memory = []
total_step = 0
total_rewards = []
total_losses = []

start = time.time()
for epoch in range(epoch_num):

    pobs = env.reset()
    step = 0
    done = False
    total_reward = 0
    total_loss = 0

    while not done and step < step_max:

        # select act
        pact = np.random.randint(3)
        if np.random.rand() > epsilon:
            pact = Q(np.array(pobs, dtype=np.float32).reshape(1, -1))
            pact = np.argmax(pact.data)

        # act
        obs, reward, done = env.step(pact)

        # add memory
        memory.append((pobs, pact, reward, obs, done))
        if len(memory) > memory_size:
            memory.pop(0)

        # train or update q
        if len(memory) == memory_size:
            if total_step % train_freq == 0:
                shuffled_memory = np.random.permutation(memory)
                memory_idx = range(len(shuffled_memory))
                for i in memory_idx[::batch_size]:
                    batch = np.array(shuffled_memory[i:i+batch_size])
                    b_pobs = np.array(batch[:, 0].tolist(), dtype=np.float32).reshape(batch_size, -1)
                    b_pact = np.array(batch[:, 1].tolist(), dtype=np.int32)
                    b_reward = np.array(batch[:, 2].tolist(), dtype=np.int32)
                    b_obs = np.array(batch[:, 3].tolist(), dtype=np.float32).reshape(batch_size, -1)
                    b_done = np.array(batch[:, 4].tolist(), dtype=np.bool)

                    q = Q(b_pobs)
                    """ <<< DQN -> Double DQN
                    maxq = np.max(Q_ast(b_obs).data, axis=1)
                    === """
```

```
                    indices = np.argmax(q.data, axis=1)
                    maxqs = Q_ast(b_obs).data
                    """ >>> """
                    target = copy.deepcopy(q.data)
                    for j in range(batch_size):
                        """ <<< DQN -> Double DQN
                        target[j, b_pact[j]] = b_reward[j]+gamma*maxq[j]*(not b_done[j])
                        === """
                        target[j, b_pact[j]] = b_reward[j]+gamma*maxqs[j, indices[j]]*(not b_done[j])
                        """ >>> """
                    Q.reset()
                    loss = F.mean_squared_error(q, target)
                    total_loss += loss.data
                    loss.backward()
                    optimizer.update()

                if total_step % update_q_freq == 0:
                    Q_ast = copy.deepcopy(Q)

            # epsilon
            if epsilon > epsilon_min and total_step > start_reduce_epsilon:
                epsilon -= epsilon_decrease

            # next step
            total_reward += reward
            pobs = obs
            step += 1
            total_step += 1

        total_rewards.append(total_reward)
        total_losses.append(total_loss)

        if (epoch+1) % show_log_freq == 0:
            log_reward = sum(total_rewards[((epoch+1)-show_log_freq):])/show_log_freq
            log_loss = sum(total_losses[((epoch+1)-show_log_freq):])/show_log_freq
            elapsed_time = time.time()-start
            print('\t'.join(map(str, [epoch+1, epsilon, total_step, log_reward, log_loss, elapsed_time])))
            start = time.time()

    return Q, total_losses, total_rewards
```

In [16]:
```
Q, total_losses, total_rewards = train_ddqn(Environment1(train))
```

```
5       0.0999999999999992      2225    -36.4   362.532034132   5.976006746292114
10      0.0999999999999992      4450    -9.4    188.051366159   7.1547322273254395
15      0.0999999999999992      6675    -6.6    96.137116237    6.8685243129730225
20      0.0999999999999992      8900    -4.6    50.2297730058   6.529151439666748
25      0.0999999999999992      11125   -6.2    25.7622961797   6.623997926712036
30      0.0999999999999992      13350   -3.8    67.7237939358   7.270005941390991
35      0.0999999999999992      15575   5.2     46.4835077588   7.701663970947266
40      0.0999999999999992      17800   18.2    21.8936307523   7.602718114852905
45      0.0999999999999992      20025   11.4    9.97410044037   7.157979726791382
50      0.0999999999999992      22250   10.2    7.85483987899   7.09658408164978
```

In [17]:
```
plot_loss_reward(total_losses, total_rewards)
```



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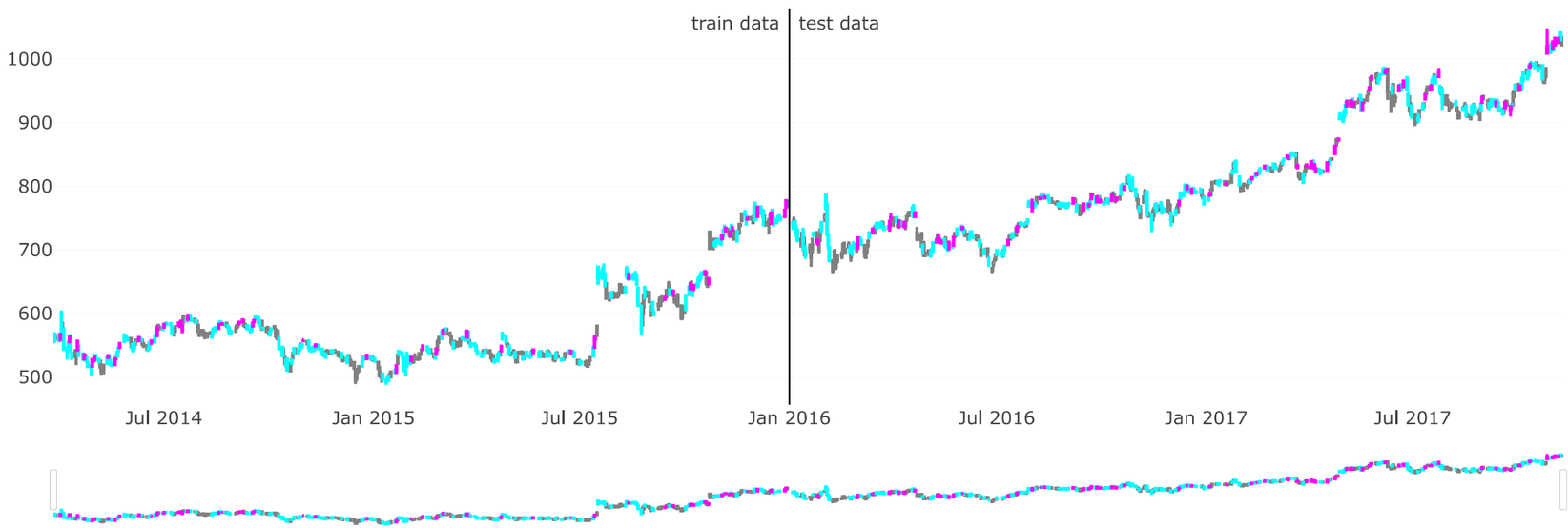
In [18]:
```
plot_train_test_by_q(Environment1(train), Environment1(test), Q, 'Double DQN')
```

Double DQN: train s-reward 24, profits 1084, test s-reward 12, profits 1297



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In [19]:

```
# Dueling Double DQN

def train_dddqn(env):

    """ <<< Double DQN -> Dueling Double DQN
    class Q_Network(chainer.Chain):

        def __init__(self, input_size, hidden_size, output_size):
            super(Q_Network, self).__init__(
                fc1 = L.Linear(input_size, hidden_size),
                fc2 = L.Linear(hidden_size, hidden_size),
                fc3 = L.Linear(hidden_size, output_size)
            )

        def __call__(self, x):
            h = F.relu(self.fc1(x))
            h = F.relu(self.fc2(h))
            y = self.fc3(h)
            return y

        def reset(self):
            self.zerograds()
    === """
    class Q_Network(chainer.Chain):

        def __init__(self, input_size, hidden_size, output_size):
            super(Q_Network, self).__init__(
                fc1 = L.Linear(input_size, hidden_size),
                fc2 = L.Linear(hidden_size, hidden_size),
                fc3 = L.Linear(hidden_size, hidden_size//2),
                fc4 = L.Linear(hidden_size, hidden_size//2),
                state_value = L.Linear(hidden_size//2, 1),
                advantage_value = L.Linear(hidden_size//2, output_size)
            )
            self.input_size = input_size
            self.hidden_size = hidden_size
            self.output_size = output_size

        def __call__(self, x):
            h = F.relu(self.fc1(x))
            h = F.relu(self.fc2(h))
            hs = F.relu(self.fc3(h))
            ha = F.relu(self.fc4(h))
            state_value = self.state_value(hs)
            advantage_value = self.advantage_value(ha)
            advantage_mean = (F.sum(advantage_value, axis=1)/float(self.output_size)).reshape(-1, 1)
            q_value = F.concat([state_value for _ in range(self.output_size)], axis=1) + (advantage_value - F.concat([advantage_mean for _ in range(self.output_size)], axis=1))
            return q_value

        def reset(self):
            self.zerograds()
    """ >>> """

    Q = Q_Network(input_size=env.history_t+1, hidden_size=100, output_size=3)
    Q_ast = copy.deepcopy(Q)
    optimizer = chainer.optimizers.Adam()
    optimizer.setup(Q)

    epoch_num = 50
```

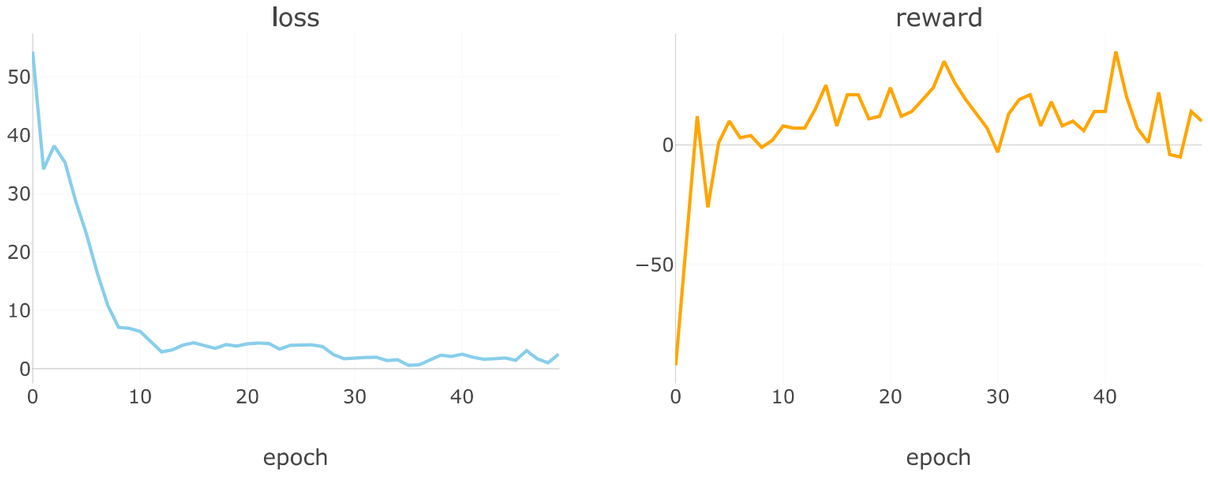
```
    step_max = len(env.data)-1
    memory_size = 200
    batch_size = 50
    epsilon = 1.0
    epsilon_decrease = 1e-3
    epsilon_min = 0.1
    start_reduce_epsilon = 200
    train_freq = 10
    update_q_freq = 20
    gamma = 0.97
    show_log_freq = 5

    memory = []
    total_step = 0
    total_rewards = []
    total_losses = []

    start = time.time()
    for epoch in range(epoch_num):

        pobs = env.reset()
        step = 0
        done = False
        total_reward = 0
        total_loss = 0

        while not done and step < step_max:

            # select act
            pact = np.random.randint(3)
            if np.random.rand() > epsilon:
                pact = Q(np.array(pobs, dtype=np.float32).reshape(1, -1))
                pact = np.argmax(pact.data)

            # act
            obs, reward, done = env.step(pact)

            # add memory
            memory.append((pobs, pact, reward, obs, done))
            if len(memory) > memory_size:
                memory.pop(0)

            # train or update q
            if len(memory) == memory_size:
                if total_step % train_freq == 0:
                    shuffled_memory = np.random.permutation(memory)
                    memory_idx = range(len(shuffled_memory))
                    for i in memory_idx[::batch_size]:
                        batch = np.array(shuffled_memory[i:i+batch_size])
                        b_pobs = np.array(batch[:, 0].tolist(), dtype=np.float32).reshape(batch_size, -1)
                        b_pact = np.array(batch[:, 1].tolist(), dtype=np.int32)
                        b_reward = np.array(batch[:, 2].tolist(), dtype=np.int32)
                        b_obs = np.array(batch[:, 3].tolist(), dtype=np.float32).reshape(batch_size, -1)
                        b_done = np.array(batch[:, 4].tolist(), dtype=np.bool)

                        q = Q(b_pobs)
                        """ <<< DQN -> Double DQN
                        maxq = np.max(Q_ast(b_obs).data, axis=1)
                        === """
                        indices = np.argmax(q.data, axis=1)
```

```
                    maxqs = Q_ast(b_obs).data
                    """ >>> """
                    target = copy.deepcopy(q.data)
                    for j in range(batch_size):
                        """ <<< DQN -> Double DQN
                        target[j, b_pact[j]] = b_reward[j]+gamma*maxq[j]*(not b_done[j])
                        === """
                        target[j, b_pact[j]] = b_reward[j]+gamma*maxqs[j, indices[j]]*(not b_done[j])
                        """ >>> """
                    Q.reset()
                    loss = F.mean_squared_error(q, target)
                    total_loss += loss.data
                    loss.backward()
                    optimizer.update()

            if total_step % update_q_freq == 0:
                Q_ast = copy.deepcopy(Q)

        # epsilon
        if epsilon > epsilon_min and total_step > start_reduce_epsilon:
            epsilon -= epsilon_decrease

        # next step
        total_reward += reward
        pobs = obs
        step += 1
        total_step += 1

    total_rewards.append(total_reward)
    total_losses.append(total_loss)

    if (epoch+1) % show_log_freq == 0:
        log_reward = sum(total_rewards[((epoch+1)-show_log_freq):])/show_log_freq
        log_loss = sum(total_losses[((epoch+1)-show_log_freq):])/show_log_freq
        elapsed_time = time.time()-start
        print('\t'.join(map(str, [epoch+1, epsilon, total_step, log_reward, log_loss, elapsed_time])))
        start = time.time()

return Q, total_losses, total_rewards
```

In [20]:
```
Q, total_losses, total_rewards = train_dddqn(Environment1(train))
```

```
5       0.0999999999999992      2225    -29.4   38.1641087133   9.779456615447998
10      0.0999999999999992      4450    3.6     12.950515821    10.579248428344727
15      0.0999999999999992      6675    12.4    4.27871555081   10.769827604293823
20      0.0999999999999992      8900    14.6    4.02654048405   11.711466312408447
25      0.0999999999999992      11125   18.6    4.1195472979    10.950128078460693
30      0.0999999999999992      13350   20.0    3.25838643042   11.056329011917114
35      0.0999999999999992      15575   11.6    1.76036339309   10.970870733261108
40      0.0999999999999992      17800   11.2    1.46561827543   10.56775975227356
45      0.0999999999999992      20025   16.2    1.97831109846   11.008494853973389
50      0.0999999999999992      22250   7.4     1.99162399785   10.179644584655762
```

In [21]:
```
plot_loss_reward(total_losses, total_rewards)
```



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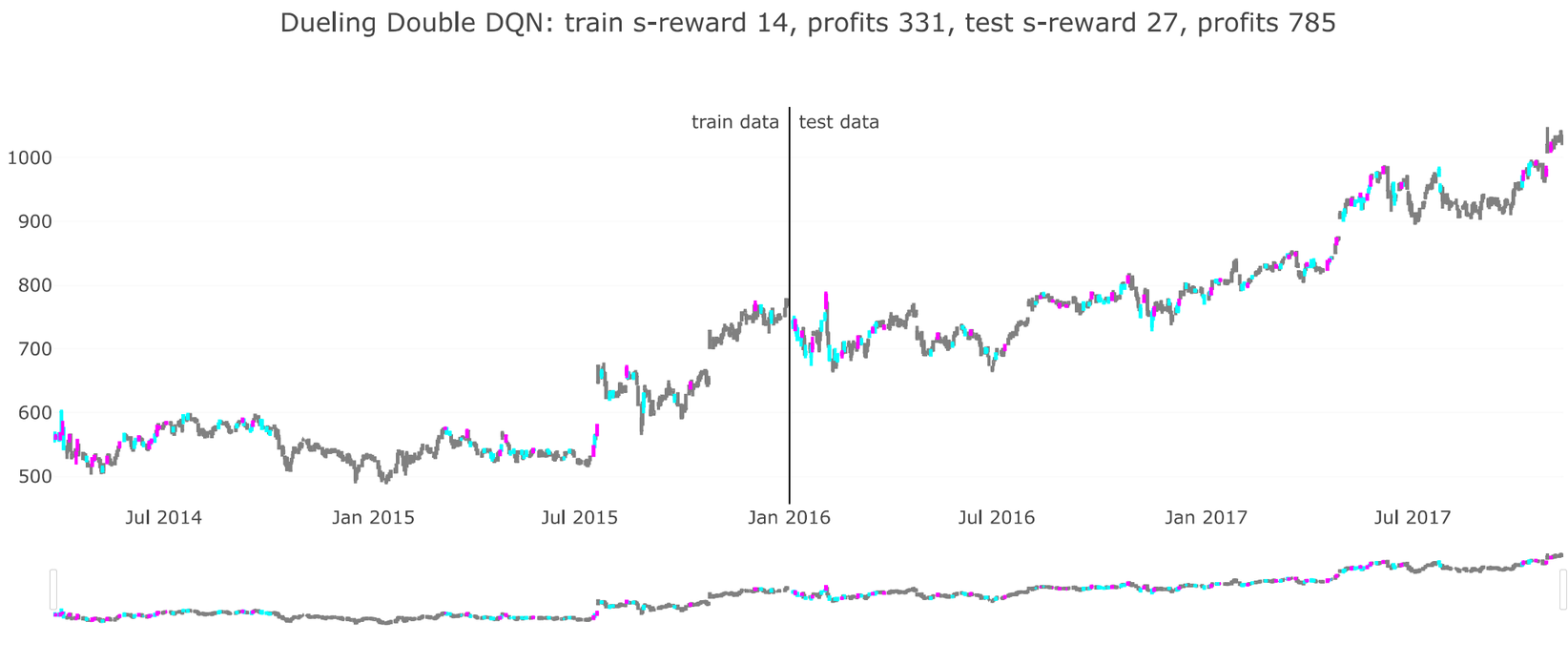
In [22]:
```
plot_train_test_by_q(Environment1(train), Environment1(test), Q, 'Dueling Double DQN')
```



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