Accelerated Chi-Squared

May 3, 2019

0.1 Project Description

In this project, we aim to calculate the following equation on multiple GPUs using PyTorch and find its lowest value on a grid where i, j go up to 80, 60 respectively. Ultimately, we wish to compare SOM mapping time on a GPU and a CPU.

$$\chi^2_{i,j} = \sum_{k=1}^{11} (G^k - W^k_{i,j})$$

Therefore, for purposes of programming with PyTorch, W is a single tensor with depth, height, width of `11, 60, 80` and G's are a set of tensors with depth, height, width of `11, 1, 1`.

Author: Miladiouss (Milad Pourrahmani)
Email : mpourrah@uci.edu / miladiouss@gmail.com
Date : May 3, 2019

0.2 Imports and GPU Test

In [2]:
```
#----------------------------------------------------------
# IPython
from IPython.core.interactiveshell import InteractiveShell
InteractiveShell.ast_node_interactivity = "all"
from IPython import display
#----------------------------------------------------------
from time import time
import numpy as np
import math
from numba import vectorize, cuda
```

In [3]:
```
from datetime import datetime
timeFormat = '%a %b %d %Y at %H:%M:%S'
import socket
deviceName = socket.gethostname()
import getpass
userName = getpass.getuser()

t1 = datetime.now()
print(t1.strftime(timeFormat) + ' on ' + deviceName + ' by ' + userName)
```

```python
# GPU Detection Tests
from torch.cuda import device_count
import torch
import gpustat

if False:
    print("""
    If pytorch raises "RuntimeError: cuda runtime error (30)" after suspension,
    run the following commands in linux terminal:

    sudo rmmod nvidia_uvm
    sudo rmmod nvidia
    sudo modprobe nvidia
    sudo modprobe nvidia_uvm

    Then restart Jupyter kernel
    """)

print('gpustat output:\n')
gpustat.print_gpustat()
print('\n\n')

numGPUs = torch.cuda.device_count()
print('=== Name of {} GPUs by PyTorch ===\n'.format(numGPUs))
for i in range(numGPUs):
    print('[{}]: {}'.format(i, torch.cuda.get_device_name(i)))
print('=================================')

torch.cuda.empty_cache()
```

```
Fri May 03 2019 at 02:06:06 on neuron by miladiouss
gpustat output:

neuron  Fri May  3 02:06:06 2019
[0] GeForce 940MX    | 47'C,   0 % |     0 /  2004 MB |
[1] TITAN V          | 37'C,  10 % |     0 / 12036 MB |



=== Name of 2 GPUs by PyTorch ===

[0]: TITAN V
[1]: GeForce 940MX
=================================
```

0.3 PyTorch Implementation and Timing

```
In [90]: for N in (10, 100, 1000, 10000, 100000, 1000000):
             _   = torch.manual_seed(42)
             vs = 11
         #     N  = 100 # Suggestion for CPU/GPU: 1e4/1e6
             bs = 1000 # Suggestion for GPU: 1000
             printMod = ['t_tot', 'all'][1]
             #====================================================

             # Imports
             from time import time

             import torch
             import torch.nn as nn
             import torch.nn.functional as F
             from torch.utils.data import Dataset, DataLoader

             # Device managements
             deviceID = 0
             device = torch.device('cuda:{}'.format(deviceID) if torch.cuda.is_available() else
             if False:
                 device = 'cpu'
                 torch.set_num_threads = 1
             else:
                 if printMod == 'all':
                     print('device name         :  {}'.format(torch.cuda.get_device_name(device
             if printMod == 'all':
                 print('device              :  {}'.format(device))

             # Dataset
             class RandomDataset(Dataset):

                 def __init__(self, size):
                     self.len = size

                 def __getitem__(self, index):
                     return torch.randn((vs, 1, 1))

                 def __len__(self):
                     return self.len

             valset    = RandomDataset(N)
             valLoader = DataLoader(valset, batch_size=bs, pin_memory=False)

             # Main model
             class Model(nn.Module):
                 def __init__(self, W_depth = vs, W_height = 80, W_width = 60, feed = None, bs
```

```python
        super(Model, self).__init__()
        self.W = torch.rand((W_depth, W_height, W_width))
        if feed is not None:
            self.W = feed
        self.W        = self.W.to(device)
        self.localGs  = torch.randn((bs, vs, 1, 1))
        self.localGs  = self.localGs.to(device)


    def chiFunc(self, Gs):
        '''Works on batches'''
        output = torch.add(self.W, -Gs)**2
        output = output.sum(1)
        output = torch.min(output.flatten(1), 1)
        # Returns lowest values and corresponding locations
        return output


    def forward(self, Gs, local = False):
        if Gs is None:
            Gs = self.localGs
        return self.chiFunc(Gs)

# Place model on device
model = Model()
if True and device != 'cpu':
    model = torch.nn.DataParallel(model, device_ids=[deviceID])
else:
    model = model.to(device)

# Timing setup
t_calc  = 0
t_trans = 0
t_tot   = 0

t1_tot = time()

# Main calculations

# Mock data is created on GPU
if True:
    if printMod == 'all':
        print("Data Management    :  Generated  on device")
    for i in range(N//bs):
        t1_calc = time()
        output = model(None)
        t2_calc = time()
        t_calc += t2_calc - t1_calc
```

```python
            # Mock data is transfered to GPU
            else:
                if printMod == 'all':
                    print("Data Management    :  Transfered to device")
                for i, Gbatch in enumerate(valLoader):
                    t1_trans = time()
                    Gbatch = Gbatch.to(device)
                    t2_trans = time()
                    t_trans += t2_trans - t1_trans

                    t1_calc = time()
                    output = model(Gbatch)
                    t2_calc = time()
                    t_calc += t2_calc - t1_calc

            t2_tot = time()
            t_tot = t2_tot - t1_tot

            # Reports
            if printMod == 'all':
                print('Load Time          : {: e} s per {:.0e}'.format(t_tot - t_trans - t_cal
                print('Transfer Time      : {: e} s per {:.0e}'.format(t_trans, N))
                print('Calculation Time   : {: e} s per {:.0e}'.format(t_calc, N))
                print('Total      Time    : {: e} s per {:.0e}'.format(t_tot, N))
                print("===================================================================
            if printMod == 't_tot':
                print(t_tot, end=', ')
```

```
device name        :  TITAN V
device             :  cuda:0
Data Management    :  Generated  on device
Load Time          :  5.674362e-05 s per 1e+01
Transfer Time      :  0.000000e+00 s per 1e+01
Calculation Time   :  0.000000e+00 s per 1e+01
Total      Time    :  5.674362e-05 s per 1e+01
Shooby's CPU Time  :  9.000000e+00 s per 1e+04
=====================================================================================
device name        :  TITAN V
device             :  cuda:0
Data Management    :  Generated  on device
Load Time          :  6.365776e-05 s per 1e+02
Transfer Time      :  0.000000e+00 s per 1e+02
Calculation Time   :  0.000000e+00 s per 1e+02
Total      Time    :  6.365776e-05 s per 1e+02
Shooby's CPU Time  :  9.000000e+00 s per 1e+04
=====================================================================================
device name        :  TITAN V
```

```
device             :  cuda:0
Data Management    :  Generated  on device
Load Time          :  9.822845e-05 s per 1e+03
Transfer Time      :  0.000000e+00 s per 1e+03
Calculation Time   :  4.632473e-04 s per 1e+03
Total       Time   :  5.614758e-04 s per 1e+03
Shooby's CPU Time  :  9.000000e+00 s per 1e+04
=====================================================================================
device name        :  TITAN V
device             :  cuda:0
Data Management    :  Generated  on device
Load Time          :  7.224083e-05 s per 1e+04
Transfer Time      :  0.000000e+00 s per 1e+04
Calculation Time   :  1.677513e-03 s per 1e+04
Total       Time   :  1.749754e-03 s per 1e+04
Shooby's CPU Time  :  9.000000e+00 s per 1e+04
=====================================================================================
device name        :  TITAN V
device             :  cuda:0
Data Management    :  Generated  on device
Load Time          :  2.365112e-04 s per 1e+05
Transfer Time      :  0.000000e+00 s per 1e+05
Calculation Time   :  1.928306e-02 s per 1e+05
Total       Time   :  1.951957e-02 s per 1e+05
Shooby's CPU Time  :  9.000000e+00 s per 1e+04
=====================================================================================
device name        :  TITAN V
device             :  cuda:0
Data Management    :  Generated  on device
Load Time          :  3.108501e-03 s per 1e+06
Transfer Time      :  0.000000e+00 s per 1e+06
Calculation Time   :  1.292557e+00 s per 1e+06
Total       Time   :  1.295666e+00 s per 1e+06
Shooby's CPU Time  :  9.000000e+00 s per 1e+04
=====================================================================================
```

In [ ]:

1. GPU Time Records (Without Data Transfer)

```
=====================================================================================
device name        :  TITAN V
device             :  cuda:0
Data Management    :  Generated  on device
Load Time          :  1.814365e-03 s per 1e+01
Transfer Time      :  0.000000e+00 s per 1e+01
Calculation Time   :  0.000000e+00 s per 1e+01
```

```
Total       Time   :  1.814365e-03 s per 1e+01
==================================================================================
device name        :  TITAN V
device             :  cuda:0
Data Management    :  Generated  on device
Load Time          :  4.076958e-05 s per 1e+02
Transfer Time      :  0.000000e+00 s per 1e+02
Calculation Time   :  0.000000e+00 s per 1e+02
Total       Time   :  4.076958e-05 s per 1e+02
==================================================================================
device name        :  TITAN V
device             :  cuda:0
Data Management    :  Generated  on device
Load Time          :  5.221367e-05 s per 1e+03
Transfer Time      :  0.000000e+00 s per 1e+03
Calculation Time   :  4.060268e-04 s per 1e+03
Total       Time   :  4.582405e-04 s per 1e+03
==================================================================================
device name        :  TITAN V
device             :  cuda:0
Data Management    :  Generated  on device
Load Time          :  5.388260e-05 s per 1e+04
Transfer Time      :  0.000000e+00 s per 1e+04
Calculation Time   :  1.125097e-03 s per 1e+04
Total       Time   :  1.178980e-03 s per 1e+04
==================================================================================
device name        :  TITAN V
device             :  cuda:0
Data Management    :  Generated  on device
Load Time          :  1.611710e-04 s per 1e+05
Transfer Time      :  0.000000e+00 s per 1e+05
Calculation Time   :  1.376677e-02 s per 1e+05
Total       Time   :  1.392794e-02 s per 1e+05
==================================================================================
device name        :  TITAN V
device             :  cuda:0
Data Management    :  Generated  on device
Load Time          :  3.225565e-03 s per 1e+06
Transfer Time      :  0.000000e+00 s per 1e+06
Calculation Time   :  1.292620e+00 s per 1e+06
Total       Time   :  1.295846e+00 s per 1e+06
==================================================================================
```

```
In [4]: run1 = 3.5762786865234375e-06, 4.291534423828125e-06, 0.00026679039001464844, 0.0015590
        run2 = 2.86102294921875e-06, 2.6226043701171875e-06, 0.00026988983154296875, 0.0016419
        run3 = 3.0994415283203125e-06, 3.5762786865234375e-06, 0.00048613548278808594, 0.00197
        Ns   = np.array([10, 100, 1000, 10000, 100000, 1000000, 10000000])
```

```
run1 = np.array(run1)
run2 = np.array(run2)
run3 = np.array(run3)

run123I = np.mean((run1, run2, run3), 0)
```

2. GPU Time Records (With Data Transfer)

```
=====================================================================================
device name        :  TITAN V
device             :  cuda:0
Data Management    :  Transfered to device
Load Time          :  3.957748e-04 s per 1e+01
Transfer Time      :  6.866455e-05 s per 1e+01
Calculation Time   :  4.634857e-04 s per 1e+01
Total       Time   :  9.279251e-04 s per 1e+01
=====================================================================================
device name        :  TITAN V
device             :  cuda:0
Data Management    :  Transfered to device
Load Time          :  7.259846e-04 s per 1e+02
Transfer Time      :  4.839897e-05 s per 1e+02
Calculation Time   :  1.916885e-04 s per 1e+02
Total       Time   :  9.660721e-04 s per 1e+02
=====================================================================================
device name        :  TITAN V
device             :  cuda:0
Data Management    :  Transfered to device
Load Time          :  5.710125e-03 s per 1e+03
Transfer Time      :  2.176762e-04 s per 1e+03
Calculation Time   :  4.482269e-04 s per 1e+03
Total       Time   :  6.376028e-03 s per 1e+03
=====================================================================================
device name        :  TITAN V
device             :  cuda:0
Data Management    :  Transfered to device
Load Time          :  4.211116e-02 s per 1e+04
Transfer Time      :  1.444340e-03 s per 1e+04
Calculation Time   :  4.163265e-03 s per 1e+04
Total       Time   :  4.771876e-02 s per 1e+04
=====================================================================================
device name        :  TITAN V
device             :  cuda:0
Data Management    :  Transfered to device
Load Time          :  3.824205e-01 s per 1e+05
Transfer Time      :  1.075053e-02 s per 1e+05
Calculation Time   :  2.390003e-02 s per 1e+05
Total       Time   :  4.170711e-01 s per 1e+05
```

```
================================================================================
device name         :  TITAN V
device              :  cuda:0
Data Management     :  Transfered to device
Load Time           :  5.193329e+00 s per 1e+06
Transfer Time       :  1.403193e-01 s per 1e+06
Calculation Time    :  3.657453e-01 s per 1e+06
Total       Time    :  5.699394e+00 s per 1e+06
================================================================================
```

```
In [5]: run1 = 0.00046634674072265625, 0.0010683536529541016, 0.0068149566650390625, 0.0564520
        run2 = 0.0008776187896728516, 0.0008144378662109375, 0.006388425827026367, 0.052498102
        run3 = 0.0010247230529785156, 0.0011801719665527344, 0.012906789779663086, 0.044039964

        run1 = np.array(run1)
        run2 = np.array(run2)
        run3 = np.array(run3)

        run123II = np.mean((run1, run2, run3), 0)
```

3. CPU Time Records ```==```

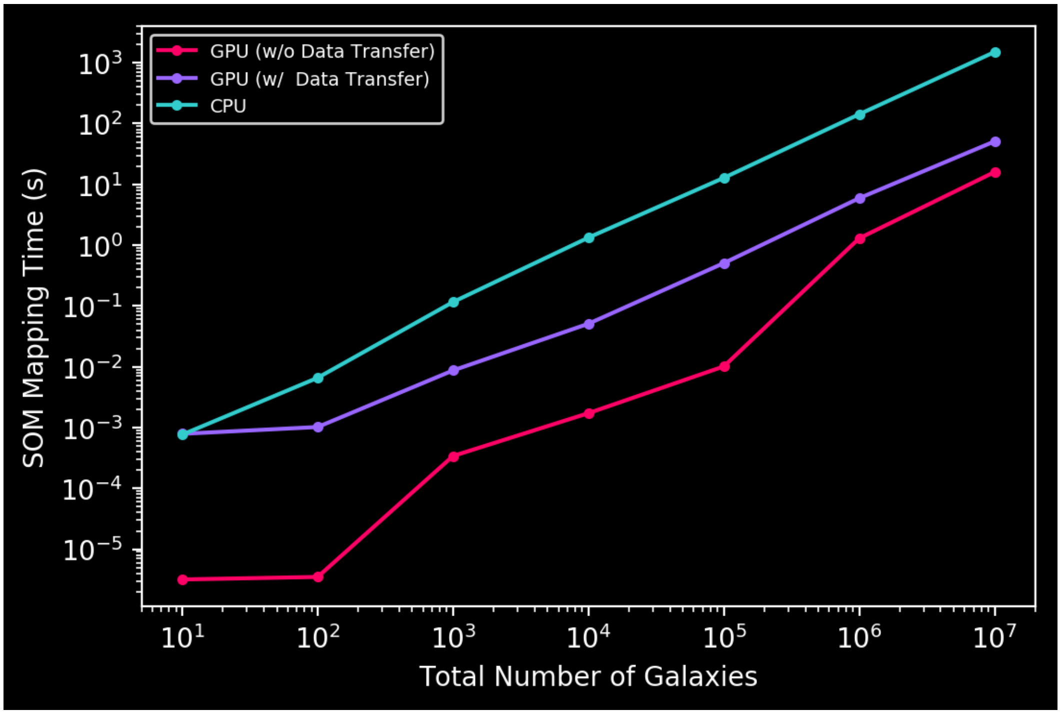
```
device              :  cpu Data Management    :  Transfered to
device Load Time          :  4.427433e-04 s per 1e+01 Transfer
Time      :  5.245209e-06 s per 1e+01 Calculation Time   :  1.560926e-03
s per 1e+01 Total       Time   :  2.008915e-03 s per 1e+01
================================================================================
device              :  cpu Data Management    :  Transfered to
device Load Time          :  8.444786e-04 s per 1e+02 Transfer
Time      :  9.059906e-06 s per 1e+02 Calculation Time   :  1.104832e-02
s per 1e+02 Total       Time   :  1.190186e-02 s per 1e+02
================================================================================
device              :  cpu Data Management    :  Transfered to
device Load Time          :  6.634235e-03 s per 1e+03 Transfer
Time      :  2.670288e-05 s per 1e+03 Calculation Time   :  9.969068e-02
s per 1e+03 Total       Time   :  1.063516e-01 s per 1e+03
================================================================================
device              :  cpu Data Management    :  Transfered to
device Load Time          :  6.788874e-02 s per 1e+04 Transfer
Time      :  2.219677e-04 s per 1e+04 Calculation Time   :  1.463918e+00
s per 1e+04 Total       Time   :  1.532029e+00 s per 1e+04
================================================================================
device              :  cpu Data Management    :  Transfered to
device Load Time          :  5.639410e-01 s per 1e+05 Transfer
Time      :  1.487732e-03 s per 1e+05 Calculation Time   :  1.349072e+01
s per 1e+05 Total       Time   :  1.405615e+01 s per 1e+05
================================================================================
device              :  cpu Data Management    :  Transfered to
device Load Time          :  5.423350e+00 s per 1e+06 Transfer
```

```
Time      :  1.540160e-02 s per 1e+06 Calculation Time   :  1.374256e+02
s per 1e+06 Total       Time   :  1.428644e+02 s per 1e+06
========================================================================================
```

```
In [6]: run1 = 0.0007658004760742188, 0.006584882736206055, 0.11615705490112305, 1.330733299925
        run2 = run1
        run3 = run1
        Ns   = np.array([10, 100, 1000, 10000, 100000, 1000000, 10000000])

        run1 = np.array(run1)
        run2 = np.array(run2)
        run3 = np.array(run3)

        run123III = np.mean((run1, run2, run3), 0)
```

0.3.1 Plotting

```
In [11]: import matplotlib.pyplot as plt
         %matplotlib inline
         if True:
             _ = plt.style.use('dark_background')
         fig, axs = plt.subplots(1, 1)
         ax11 = axs

         _ = ax11.loglog(Ns, run123I, label = "GPU (w/o Data Transfer)", marker = '.', color =
         _ = ax11.loglog(Ns, run123II, label = "GPU (w/  Data Transfer)", marker = '.', color =
         _ = ax11.loglog(Ns, run123III, label = "CPU", marker = '.', color = '#33cccc')

         _ = fig.set_dpi(200)
         _ = ax11.set_xlabel('Total Number of Galaxies')
         _ = ax11.set_ylabel('SOM Mapping Time (s)')
         legend = ax11.legend(loc='upper left', shadow=True, fontsize='x-small')
```



0.4 Proof of Concept

This section was developed before creating a PyTorch model, even though it is placed last.

0.4.1 Data Initialization

In [7]:
```
quickTestDict = {'Number of Samples' : 2, 'Vector Size' : 3, 'Grid Height' : 2, 'Grid
longTestDict  = {'Number of Samples' : 10, 'Vector Size' : 11, 'Grid Height' : 100, 'G
paramDict = [quickTestDict, longTestDict][0]

N       = paramDict['Number of Samples']
W_shape = (paramDict['Vector Size'], paramDict['Grid Height'], paramDict['Grid Width']]
G_shape = (paramDict['Vector Size'], 1, 1)
dtype   = np.float32
rs      = np.random.RandomState(seed=42)
W       = rs.randint(0, 10, W_shape).astype(dtype)
Gs      = rs.randint(0, 10, (N, *G_shape)).astype(dtype)

# Convert to torch tensor
W       = torch.Tensor(W)
Gs      = torch.Tensor(Gs)
print('W  Shape: {}'.format(W.shape))
print('Gs Shape: {}'.format(Gs.shape))
```

```
W  Shape: torch.Size([3, 2, 2])
Gs Shape: torch.Size([2, 3, 1, 1])
```

0.4.2 Method I

```
In [8]: if paramDict['dictName'] == 'quickTest':
            for i, G in enumerate(Gs):
                G_grid   = torch.ones_like(W)
                G_grid   = torch.mul(G, G_grid)
                chi_grid = torch.sum((W - G_grid)**2, 0)
                chi_min  = torch.min(chi_grid)
                print("Least Chi-Squared for G[{}]: {:.1e}".format(i, chi_min))
```

```
Least Chi-Squared for G[0]: 4.0e+00
Least Chi-Squared for G[1]: 2.5e+01
```

0.4.3 Method II (Using PyTorch Model)

```
In [11]: print("Model output (min chi for each batch and the corresponding location):")
         model = Model(feed=W)
         model(Gs.to(device))
```

```
Model output (min chi for each batch and the corresponding location):
```

```
Out[11]: (tensor([ 4., 25.], device='cuda:0'), tensor([2, 3], device='cuda:0'))
```

0.4.4 Method III

Compare the output of the following with the Method II output.

```
In [12]: if paramDict['dictName'] == 'quickTest':
             print('\nW = ')
             print(W)
             print('\nGs = ')
             print(Gs)

             print("\n(W - G)**2 for each G:")
             output = torch.add(W, -Gs)**2
             output

             print("\nSum of (W - G)**2 for each G:")
             output.sum(1)
```

```
W =
tensor([[[6., 3.],
```

```
         [7., 4.]],

        [[6., 9.],
         [2., 6.]],

        [[7., 4.],
         [3., 7.]]])

Gs =
tensor([[[[7.]],

         [[2.]],

         [[5.]]],


        [[[4.]],

         [[1.]],

         [[7.]]]])

(W - G)**2 for each G:
```

```
Out[12]: tensor([[[[ 1., 16.],
                   [ 0.,  9.]],

                  [[16., 49.],
                   [ 0., 16.]],

                  [[ 4.,  1.],
                   [ 4.,  4.]]],


                 [[[ 4.,  1.],
                   [ 9.,  0.]],

                  [[25., 64.],
                   [ 1., 25.]],

                  [[ 0.,  9.],
                   [16.,  0.]]]])
```

```
Sum of (W - G)**2 for each G:
```

```
Out[12]: tensor([[[21., 66.],
```

```
         [ 4., 29.]],

        [[29., 74.],
         [26., 25.]]]])
```

```
In [13]: # add works on batches too
         if False:
             torch.add(W, -Gs)
             torch.cat([torch.add(W, -Gs[0]), torch.add(W, -Gs[1])])
```

0.5 Recycle

```
In [ ]: # Recycled code from torch Model class

        # self.G_grid   = torch.ones_like(self.W)

        #     def ChiFunc1(self, G):
        #         G_grid   = self.G_grid
        #         G_grid   = torch.mul(G, self.G_grid)
        #         Chi_grid = torch.sum((self.W - G_grid)**2, 0)
        #         Chi_min  = torch.min(Chi_grid)
        #         return Chi_min

        #     def ChiFunc2(self, G):
        #         output = torch.add(self.W, -G)**2
        #         output = torch.sum(output, 0)
        #         output = torch.min(output)
        #         return output


        # Recycled code from Proof of Work

        # if True:
        #     print('\nW = ')
        #     print(W)
        #     print('\nG = ')
        #     print(G)
        #     print('\nW[:, 0, 0] = ', W[:, 0, 0].numpy())
        #     print('\nG[:, 0, 0] = ', G[:, 0, 0].numpy())
        #     print('\n(G00 - W00)**2 = ', (W[:, 0, 0] - G[:, 0, 0])**2)
        #     print('\nsum00 = ', torch.sum((W[:, 0, 0] - G[:, 0, 0])**2))
        #     print('\n(G00 - W01)**2 = ', (W[:, 0, 1] - G[:, 0, 0])**2)
        #     print('\nsum01 = ', torch.sum((W[:, 0, 1] - G[:, 0, 0])**2))
        #     print('\n(G00 - W10)**2 = ', (W[:, 1, 0] - G[:, 0, 0])**2)
        #     print('\nsum10 = ', torch.sum((W[:, 1, 0] - G[:, 0, 0])**2))
        #     print('\n(G00 - W11)**2 = ', (W[:, 1, 1] - G[:, 0, 0])**2)
        #     print('\nsum11 = ', torch.sum((W[:, 1, 1] - G[:, 0, 0])**2))
```