Deep Autoencoding Gaussian Mixture Model for Unsupervised Anomaly Detection

```
import numpy as np
import pandas as pd
import torch
from data_loader import *
from main import *
from tqdm import tqdm
```

KDD Cup 1999 Data (10% subset)

This is the data set used for The Third International Knowledge Discovery and Data Mining Tools Competition, which was held in conjunction with KDD-99 The Fifth International Conference on Knowledge Discovery and Data Mining. The competition task was to build a network intrusion detector, a predictive model capable of distinguishing between "bad" connections, called intrusions or attacks, and "good" normal connections. This database contains a standard set of data to be audited, which includes a wide variety of intrusions simulated in a military network environment.

```
#WIndows
#transaction_data = pd.read_csv("C:/Users/cncluser/Downloads/ieee-fraud-detection/t
#macOS
transaction_data = pd.read_csv("/Users/nami/Downloads/ieee-fraud-detection/train_tr

transaction_data
```

	TransactionID	isFraud	TransactionDT	TransactionAmt	Prod
0	2987000	0	86400	68.50	W
1	2987001	0	86401	29.00	W
2	2987002	0	86469	59.00	W
3	2987003	0	86499	50.00	W

4	2987004	0	86506	50.00	H
...	...	...	...	...	...
590535	3577535	0	15811047	49.00	W
590536	3577536	0	15811049	39.50	W
590537	3577537	0	15811079	30.95	W
590538	3577538	0	15811088	117.00	W
590539	3577539	0	15811131	279.95	W

590540 rows × 394 columns

```
#Windows
#identity_data = pd.read_csv("C:/Users/cncluser/Downloads/ieee-fraud-detection/trai
#macOS
identity_data = pd.read_csv("/Users/nami/Downloads/ieee-fraud-detection/train_ident

identity_data
```

	TransactionID	id_01	id_02	id_03	id_04	id_05
0	2987004	0.0	70787.0	NaN	NaN	NaN
1	2987008	-5.0	98945.0	NaN	NaN	0.0
2	2987010	-5.0	191631.0	0.0	0.0	0.0
3	2987011	-5.0	221832.0	NaN	NaN	0.0
4	2987016	0.0	7460.0	0.0	0.0	1.0

...	...	...	...	...	...	...
144228	3577521	-15.0	145955.0	0.0	0.0	0.0
144229	3577526	-5.0	172059.0	NaN	NaN	1.0
144230	3577529	-20.0	632381.0	NaN	NaN	-1.0
144231	3577531	-5.0	55528.0	0.0	0.0	0.0
144232	3577534	-45.0	339406.0	NaN	NaN	-10.0

144233 rows × 41 columns

```
data = transaction_data.set_index('TransactionID').join(identity_data.set_index('Tr
data
```

	isFraud	TransactionDT	TransactionAmt	ProductCD
TransactionID				
2987000	0	86400	68.50	W
2987001	0	86401	29.00	W
2987002	0	86469	59.00	W
2987003	0	86499	50.00	W
2987004	0	86506	50.00	H

...	...	...	...	...	.
3577535	0	15811047	49.00	W	6
3577536	0	15811049	39.50	W	1
3577537	0	15811079	30.95	W	1
3577538	0	15811088	117.00	W	7
3577539	0	15811131	279.95	W	1

590540 rows × 433 columns

Pre-processing

"isFraud" = 0 -> normal, "isFraud" = 1 -> anomaly.

Next, the categorical variables are converted to a one hot encoding representation. My implementation is a bit different from the original paper in this aspect. Since I am only using the 10% subset to generate the columns, I get 118 features instead of 120 as reported in the paper.

```
one_hot_ProductCD = pd.get_dummies(data["ProductCD"])
one_hot_card4 = pd.get_dummies(data["card4"])
one_hot_card6 = pd.get_dummies(data["card6"])
one_hot_Pemaildomain = pd.get_dummies(data["P_emaildomain"])
one_hot_Remaildomain = pd.get_dummies(data["R_emaildomain"])
one_hot_M1 = pd.get_dummies(data["M1"])
one_hot_M2 = pd.get_dummies(data["M2"])
one_hot_M3 = pd.get_dummies(data["M3"])
one_hot_M4 = pd.get_dummies(data["M4"])
one_hot_M5 = pd.get_dummies(data["M5"])
one_hot_M6 = pd.get_dummies(data["M6"])
one_hot_M7 = pd.get_dummies(data["M7"])
one_hot_M8 = pd.get_dummies(data["M8"])
one_hot_M9 = pd.get_dummies(data["M9"])
one_hot_id12 = pd.get_dummies(data["id_12"])
one_hot_id15 = pd.get_dummies(data["id_15"])
one_hot_id16 = pd.get_dummies(data["id_16"])
one_hot_id23 = pd.get_dummies(data["id_23"])
one_hot_id27 = pd.get_dummies(data["id_27"])
one_hot_id28 = pd.get_dummies(data["id_28"])
one_hot_id29 = pd.get_dummies(data["id_29"])
one_hot_id30 = pd.get_dummies(data["id_30"])
one_hot_id31 = pd.get_dummies(data["id_31"])
```

```
one_hot_id33 = pd.get_dummies(data["id_33"])
one_hot_id34 = pd.get_dummies(data["id_34"])
one_hot_id35 = pd.get_dummies(data["id_35"])
one_hot_id36 = pd.get_dummies(data["id_36"])
one_hot_id37 = pd.get_dummies(data["id_37"])
one_hot_id38 = pd.get_dummies(data["id_38"])
one_hot_DeviceType = pd.get_dummies(data["DeviceType"])
one_hot_DeviceInfo = pd.get_dummies(data["DeviceInfo"])
```

```
data = data.drop("ProductCD",axis=1)
data = data.drop("card4",axis=1)
data = data.drop("card6",axis=1)
data = data.drop("P_emaildomain",axis=1)
data = data.drop("R_emaildomain",axis=1)
data = data.drop("M1",axis=1)
data = data.drop("M2",axis=1)
data = data.drop("M3",axis=1)
data = data.drop("M4",axis=1)
data = data.drop("M5",axis=1)
data = data.drop("M6",axis=1)
data = data.drop("M7",axis=1)
data = data.drop("M8",axis=1)
data = data.drop("M9",axis=1)
data = data.drop("id_12",axis=1)
data = data.drop("id_15",axis=1)
data = data.drop("id_16",axis=1)
data = data.drop("id_23",axis=1)
data = data.drop("id_27",axis=1)
data = data.drop("id_28",axis=1)
data = data.drop("id_29",axis=1)
data = data.drop("id_30",axis=1)
data = data.drop("id_31",axis=1)
data = data.drop("id_33",axis=1)
data = data.drop("id_34",axis=1)
data = data.drop("id_35",axis=1)
data = data.drop("id_36",axis=1)
data = data.drop("id_37",axis=1)
data = data.drop("id_38",axis=1)
data = data.drop("DeviceType",axis=1)
data = data.drop("DeviceInfo",axis=1)
```

```
data_header = data.columns
data_header = data_header.drop("isFraud")
#data_header
```

```
data = pd.concat([one_hot_ProductCD, one_hot_card4, one_hot_card6,
                  one_hot_Pemaildomain, one_hot_Remaildomain, one_hot_M1,
```

```
                        one_hot_M2, one_hot_M3, one_hot_M4,
                        one_hot_M5, one_hot_M6, one_hot_M7,
                        one_hot_M8, one_hot_M9, one_hot_id12,
                        one_hot_id15, one_hot_id16, one_hot_id23,
                        one_hot_id27, one_hot_id28, one_hot_id29,
                        one_hot_id30, one_hot_id31, one_hot_id33,
                        one_hot_id34, one_hot_id35, one_hot_id36,
                        one_hot_id37, one_hot_id38, one_hot_DeviceType,
                        one_hot_DeviceInfo, data],axis=1)
data.head()
```

	C	H	R	S	W	american express	discover	master
TransactionID								
2987000	0	0	0	0	1	0	1	0
2987001	0	0	0	0	1	0	0	1
2987002	0	0	0	0	1	0	0	0
2987003	0	0	0	0	1	0	0	1
2987004	0	1	0	0	0	0	0	1

5 rows × 2834 columns

```
#data.loc[:,"SAMSUNG SM-G892A Build/NRD90M"]
```

```
proportions = data["isFraud"].value_counts()
print(proportions)
print("Anomaly Percentage",proportions[1] / proportions.sum())
```

```
0    569877
1     20663
Name: isFraud, dtype: int64
Anomaly Percentage 0.03499000914417313
```

```
#proportions_alfa = data["isFraud"].value_counts(normalize=True)
#print(proportions_alfa)
```

Normalize all the numeric variables.

```
cols_to_norm = data_header
print(cols_to_norm)

#data.loc[:, cols_to_norm] = (data[cols_to_norm] - data[cols_to_norm].mean()) / dat
min_cols = data.loc[data["isFraud"]==0 , cols_to_norm].min()
max_cols = data.loc[data["isFraud"]==0 , cols_to_norm].max()

data.loc[:, cols_to_norm] = (data[cols_to_norm] - min_cols) / (max_cols - min_cols)
```

```
Index(['TransactionDT', 'TransactionAmt', 'card1', 'card2', 'card3', 'card5',
       'addr1', 'addr2', 'dist1', 'dist2',
       ...
       'id_17', 'id_18', 'id_19', 'id_20', 'id_21', 'id_22', 'id_24', 'id_25',
       'id_26', 'id_32'],
      dtype='object', length=401)
```

```
print(min_cols)
print(max_cols)
data.head()
```

```
TransactionDT     86400.000
TransactionAmt        0.251
card1              1000.000
card2               100.000
card3               100.000
                     ...
id_22                10.000
id_24                11.000
id_25               100.000
id_26               100.000
id_32                 0.000
Length: 401, dtype: float64
TransactionDT     1.581113e+07
TransactionAmt    3.193739e+04
card1             1.839600e+04
card2             6.000000e+02
card3             2.310000e+02
```

```
                    ...
id_22              4.400000e+01
id_24              2.600000e+01
id_25              5.480000e+02
id_26              2.160000e+02
id_32              3.200000e+01
Length: 401, dtype: float64
```

	C	H	R	S	W	american express	discover	master
TransactionID								
2987000	0	0	0	0	1	0	1	0
2987001	0	0	0	0	1	0	0	1
2987002	0	0	0	0	1	0	0	0
2987003	0	0	0	0	1	0	0	1
2987004	0	1	0	0	0	0	0	1

5 rows × 2834 columns

I saved the preprocessed data into a numpy file format and load it using the pytorch data loader.

```
np.savez_compressed("ieee_fraud",ieee=data.as_matrix())
```

```
/usr/local/var/pyenv/versions/anaconda3-2019.10/envs/ana3env/lib/python3.7/site-pac
  """Entry point for launching an IPython kernel.
```

I initially implemented this to be ran in the command line and use argparse to get the hyperparameters. To make it runnable in a jupyter notebook, I had to create a dummy class for the hyperparameters.

```
class hyperparams():
    def __init__(self, config):
```

```
        self.__dict__.update(**config)
defaults = {
    'lr' : 1e-4,
    'num_epochs' : 200,
    'batch_size' : 1024,
    'gmm_k' : 4,
    'lambda_energy' : 0.1,
    'lambda_cov_diag' : 0.005,
    'pretrained_model' : None,
    'mode' : 'train',
    'use_tensorboard' : False,
    'data_path' : 'ieee_fraud.npz',

    'log_path' : './dagmm/ieee_logs',
    'model_save_path' : './dagmm/ieee_models',
    'sample_path' : './dagmm/ieee_samples',
    'test_sample_path' : './dagmm/ieee_test_samples',
    'result_path' : './dagmm/ieee_results',

    'log_step' : 194//4,
    'sample_step' : 194,
    'model_save_step' : 194,
}
```

```
solver = main(hyperparams(defaults))
accuracy, precision, recall, f_score = solver.test()
```

```
590540
2833


  0%|          | 0/1 [00:00<?, ?it/s]

DaGMM
DaGMM(
  (encoder): Sequential(
    (0): Linear(in_features=118, out_features=60, bias=True)
    (1): Tanh()
    (2): Linear(in_features=60, out_features=30, bias=True)
    (3): Tanh()
    (4): Linear(in_features=30, out_features=10, bias=True)
    (5): Tanh()
    (6): Linear(in_features=10, out_features=1, bias=True)
  )
  (decoder): Sequential(
    (0): Linear(in_features=1, out_features=10, bias=True)
    (1): Tanh()
    (2): Linear(in_features=10, out_features=30, bias=True)
    (3): Tanh()
    (4): Linear(in_features=30, out_features=60, bias=True)
```

```
    (5): Tanh()
    (6): Linear(in_features=60, out_features=118, bias=True)
  )
  (estimation): Sequential(
    (0): Linear(in_features=3, out_features=10, bias=True)
    (1): Tanh()
    (2): Dropout(p=0.5, inplace=False)
    (3): Linear(in_features=10, out_features=4, bias=True)
    (4): Softmax(dim=1)
  )
)
The number of parameters: 18783







---------------------------------------------------------------------------


RuntimeError                              Traceback (most recent call last)

<ipython-input-16-db7e643ba5ba> in <module>
----> 1 solver = main(hyperparams(defaults))
      2 accuracy, precision, recall, f_score = solver.test()


~/notebook/anaconda_env/dagmm/main.py in main(config)
     23 
     24     if config.mode == 'train':
---> 25         solver.train()
     26     elif config.mode == 'test':
     27         solver.test()


~/notebook/anaconda_env/dagmm/solver.py in train(self)
     95                 input_data = self.to_var(input_data)
     96 
---> 97                 total_loss,sample_energy, recon_error, cov_diag = self.dagm
     98                 # Logging
     99                 loss = {}


~/notebook/anaconda_env/dagmm/solver.py in dagmm_step(self, input_data)
    160     def dagmm_step(self, input_data):
    161         self.dagmm.train()
--> 162         enc, dec, z, gamma = self.dagmm(input_data)
    163 
    164         total_loss, sample_energy, recon_error, cov_diag = self.dagmm.loss_


/usr/local/var/pyenv/versions/anaconda3-2019.10/envs/ana3env/lib/python3.7/site-pac
    539             result = self._slow_forward(*input, **kwargs)
    540         else:
--> 541             result = self.forward(*input, **kwargs)
    542         for hook in self._forward_hooks.values():
```

```
    543             hook_result = hook(self, input, result)


~/notebook/anaconda_env/dagmm/model.py in forward(self, x)
     68     def forward(self, x):
     69 
---> 70         enc = self.encoder(x)
     71 
     72         dec = self.decoder(enc)


/usr/local/var/pyenv/versions/anaconda3-2019.10/envs/ana3env/lib/python3.7/site-pac
    539             result = self._slow_forward(*input, **kwargs)
    540         else:
--> 541             result = self.forward(*input, **kwargs)
    542         for hook in self._forward_hooks.values():
    543             hook_result = hook(self, input, result)


/usr/local/var/pyenv/versions/anaconda3-2019.10/envs/ana3env/lib/python3.7/site-pac
     90     def forward(self, input):
     91         for module in self._modules.values():
---> 92             input = module(input)
     93         return input
     94 


/usr/local/var/pyenv/versions/anaconda3-2019.10/envs/ana3env/lib/python3.7/site-pac
    539             result = self._slow_forward(*input, **kwargs)
    540         else:
--> 541             result = self.forward(*input, **kwargs)
    542         for hook in self._forward_hooks.values():
    543             hook_result = hook(self, input, result)


/usr/local/var/pyenv/versions/anaconda3-2019.10/envs/ana3env/lib/python3.7/site-pac
     85 
     86     def forward(self, input):
---> 87         return F.linear(input, self.weight, self.bias)
     88 
     89     def extra_repr(self):


/usr/local/var/pyenv/versions/anaconda3-2019.10/envs/ana3env/lib/python3.7/site-pac
   1368     if input.dim() == 2 and bias is not None:
   1369         # fused op is marginally faster
-> 1370         ret = torch.addmm(bias, input, weight.t())
   1371     else:
   1372         output = input.matmul(weight.t())


RuntimeError: size mismatch, m1: [3 x 2833], m2: [118 x 60] at /Users/distiller/pro
```

I copy pasted the testing code here in the notebook so we could play around the results.

Incrementally compute for the GMM parameters across all training data for a better estimate

```
solver.data_loader.dataset.mode="train"
solver.dagmm.eval()
N = 0
mu_sum = 0
cov_sum = 0
gamma_sum = 0

for it, (input_data, labels) in enumerate(solver.data_loader):
    input_data = solver.to_var(input_data)
    enc, dec, z, gamma = solver.dagmm(input_data)
    phi, mu, cov = solver.dagmm.compute_gmm_params(z, gamma)

    batch_gamma_sum = torch.sum(gamma, dim=0)

    gamma_sum += batch_gamma_sum
    mu_sum += mu * batch_gamma_sum.unsqueeze(-1) # keep sums of the numerator only
    cov_sum += cov * batch_gamma_sum.unsqueeze(-1).unsqueeze(-1) # keep sums of the

    N += input_data.size(0)

train_phi = gamma_sum / N
train_mu = mu_sum / gamma_sum.unsqueeze(-1)
train_cov = cov_sum / gamma_sum.unsqueeze(-1).unsqueeze(-1)

print("N:",N)
print("phi :\n",train_phi)
print("mu :\n",train_mu)
print("cov :\n",train_cov)
```

```
train_energy = []
train_labels = []
train_z = []
for it, (input_data, labels) in enumerate(solver.data_loader):
    input_data = solver.to_var(input_data)
    enc, dec, z, gamma = solver.dagmm(input_data)
    sample_energy, cov_diag = solver.dagmm.compute_energy(z, phi=train_phi, mu=trai

    train_energy.append(sample_energy.data.cpu().numpy())
    train_z.append(z.data.cpu().numpy())
    train_labels.append(labels.numpy())
```

```
train_energy = np.concatenate(train_energy,axis=0)
train_z = np.concatenate(train_z,axis=0)
train_labels = np.concatenate(train_labels,axis=0)
```

Compute the energy of every sample in the test data

```
solver.data_loader.dataset.mode="test"
test_energy = []
test_labels = []
test_z = []
for it, (input_data, labels) in enumerate(solver.data_loader):
    input_data = solver.to_var(input_data)
    enc, dec, z, gamma = solver.dagmm(input_data)
    sample_energy, cov_diag = solver.dagmm.compute_energy(z, size_average=False)
    test_energy.append(sample_energy.data.cpu().numpy())
    test_z.append(z.data.cpu().numpy())
    test_labels.append(labels.numpy())


test_energy = np.concatenate(test_energy,axis=0)
test_z = np.concatenate(test_z,axis=0)
test_labels = np.concatenate(test_labels,axis=0)
```

```
combined_energy = np.concatenate([train_energy, test_energy], axis=0)
combined_z = np.concatenate([train_z, test_z], axis=0)
combined_labels = np.concatenate([train_labels, test_labels], axis=0)
```

Compute for the threshold energy. Following the paper I just get the highest 20% and treat it as an anomaly. That corresponds to setting the threshold at the 80th percentile.

```
thresh = np.percentile(combined_energy, 100 - 20)
print("Threshold :", thresh)
```

```
pred = (test_energy>thresh).astype(int)
gt = test_labels.astype(int)
```

```
from sklearn.metrics import precision_recall_fscore_support as prf, accuracy_score
```

```
accuracy = accuracy_score(gt,pred)
precision, recall, f_score, support = prf(gt, pred, average='binary')
```

```
print("Accuracy : {:0.4f}, Precision : {:0.4f}, Recall : {:0.4f}, F-score : {:0.4f}
```

Visualizing the z space

It's a little different from the paper's figure but I assume that's because of the small changes in my implementation.

```
from mpl_toolkits.mplot3d import Axes3D
import matplotlib.pyplot as plt
%matplotlib notebook
fig = plt.figure()
ax = fig.add_subplot(111, projection='3d')
ax.scatter(test_z[:,1],test_z[:,0], test_z[:,2], c=test_labels.astype(int))
ax.set_xlabel('Encoded')
ax.set_ylabel('Euclidean')
ax.set_zlabel('Cosine')
plt.show()
```