

结合TabNet与GBDT的物联网异常流量检测方法

导入包+全局设置

```
import pandas as pd
import numpy as np
import matplotlib.pyplot as plt
import torch
import gc #用于内存回收
from collections import Counter

from sklearn.model_selection import train_test_split
from sklearn.preprocessing import LabelEncoder, StandardScaler
from sklearn.metrics import classification_report, accuracy_score
from sklearn.utils.class_weight import compute_sample_weight

from imblearn.over_sampling import SMOTE
from imblearn.under_sampling import RandomUnderSampler
from imblearn.pipeline import Pipeline

import lightgbm as lgb
import xgboost as xgb
from pytorch_tabnet.tab_model import TabNetClassifier
from pytorch_tabnet.pretraining import TabNetPretrainer
# 全局设置
seed = 42
np.random.seed(seed)
torch.manual_seed(seed)
```

```
<torch._C.Generator at 0x2153cbf0490>
```

数据预处理

```
# 数据处理
print("清洗数据中")
df = pd.read_csv('IoT_Intrusion.csv')

# 清洗无穷值与缺失值
def clean_dataset(df):
    df.replace([np.inf, -np.inf], np.nan, inplace=True)
    df.dropna(inplace=True)
    return df

df = clean_dataset(df)
```

```

# 标签合并
target_col = 'label'
label_group_map = {
    'DDoS-ICMP_Flood': 'DDoS', 'DDoS-UDP_Flood': 'DDoS', 'DDoS-TCP_Flood': 'DDoS',
    'DDoS-PSHACK_Flood': 'DDoS', 'DDoS-SYN_Flood': 'DDoS', 'DDoS-RSTFINFlood':
    'DDoS',
    'DDoS-SynonymousIP_Flood': 'DDoS', 'DDoS-ACK_Fragmentation': 'DDoS',
    'DDoS-UDP_Fragmentation': 'DDoS', 'DDoS-ICMP_Fragmentation': 'DDoS',
    'DDoS-SlowLoris': 'DDoS', 'DDoS-HTTP_Flood': 'DDoS',

    'DoS-UDP_Flood': 'DoS', 'DoS-TCP_Flood': 'DoS', 'DoS-SYN_Flood': 'DoS',
    'DoS-HTTP_Flood': 'DoS',

    'Mirai-greeth_flood': 'Mirai', 'Mirai-greip_flood': 'Mirai', 'Mirai-udplain':
    'Mirai',

    'Recon-HostDiscovery': 'Recon', 'Recon-OSScan': 'Recon', 'Recon-PortScan':
    'Recon',
    'Recon-PingSweep': 'Recon', 'VulnerabilityScan': 'Recon',

    'SqlInjection': 'Web', 'XSS': 'Web', 'Backdoor_Malware': 'Web',
    'BrowserHijacking': 'Web', 'CommandInjection': 'Web', 'Uploading_Attack':
    'Web',

    'DictionaryBruteForce': 'BruteForce',
    'MITM-ArpSpoofing': 'Spoofing', 'DNS_Spoofing': 'Spoofing',
    'BenignTraffic': 'Benign'
}
df[target_col] = df[target_col].map(label_group_map).fillna(df[target_col])

# 标签编码
label_encoder = LabelEncoder()
y_encoded = label_encoder.fit_transform(df[target_col])
# 提取特征名称
feature_names = df.drop(columns=[target_col]).columns.tolist()
X_values = df.drop(columns=[target_col]).values

print(f"标签分布: {Counter(y_encoded)}")
del df # 释放内存
gc.collect()

```

清洗数据中

标签分布: Counter({2: 763525, 3: 181481, 4: 59233, 0: 24476, 6: 11053, 5: 7945, 7: 538, 1: 324})

划分数据集

```
print("切分数据 (Train/Val/Test)")  
X_train_raw, X_temp, y_train_raw, y_temp = train_test_split(  
    X_values, y_encoded, test_size=0.3, random_state=seed, stratify=y_encoded  
)  
X_val_raw, X_test_raw, y_val, y_test = train_test_split(  
    X_temp, y_temp, test_size=0.5, random_state=seed, stratify=y_temp  
)  
  
print(f"训练集: {X_train_raw.shape}, 验证集: {X_val_raw.shape}, 测试集:  
{X_test_raw.shape}")
```

切分数据 (Train/Val/Test)

训练集: (734002, 46), 验证集: (157286, 46), 测试集: (157287, 46)

GBDT

```
print("\nGBDT模型 : ")  
  
#LightGBM  
print("训练 LightGBM : ")  
lgbm = lgb.LGBMClassifier(  
    n_estimators=1000,  
    learning_rate=0.05,  
    num_leaves=31,  
    objective='multiclass',  
    class_weight='balanced',  
    random_state=seed,  
    n_jobs=-1  
)  
  
lgbm.fit(  
    X_train_raw, y_train_raw,  
    eval_set=[(X_val_raw, y_val)],  
    feature_name=feature_names,  
    eval_metric='multi_logloss',  
    callbacks=[lgb.early_stopping(stopping_rounds=50), lgb.log_evaluation(200)]  
)  
  
# XGBoost  
print("训练 XGBoost : ")  
# sample_weight  
sample_weights = compute_sample_weight(class_weight='balanced', y=y_train_raw)  
  
xgb_clf = xgb.XGBClassifier(  
    n_estimators=1000,
```

```

learning_rate=0.05,
max_depth=6,
objective='multi:softprob',
tree_method='hist',
device='cuda',
random_state=seed,
n_jobs=-1,
early_stopping_rounds=50
)

xgb_clf.fit(
    X_train_raw, y_train_raw,
    sample_weight=sample_weights, # 传入样本权重处理不平衡
    eval_set=[(X_val_raw, y_val)],
    verbose=200
)

```

GBDT模型：

训练 LightGBM：

```

[LightGBM] [Info] Total Bins 5325
[LightGBM] [Info] Number of data points in the train set: 734002, number of used
features: 40
[LightGBM] [Info] Start training from score -2.079442
Training until validation scores don't improve for 50 rounds
[200]  valid_0's multi_logloss: 0.017278
Early stopping, best iteration is:
[432]  valid_0's multi_logloss: 0.0162761

```

训练 XGBoost：

```

[0] validation_0-mlogloss:1.89093
[200] validation_0-mlogloss:0.01561
[400] validation_0-mlogloss:0.01260
[600] validation_0-mlogloss:0.01206
[760] validation_0-mlogloss:0.01197

```

TabNet

```

#TabNet 分支
#SMOTE混合采样、StandardScaler、预训练
print("\nTabNet : ")

#SMOTE + UnderSampling
original_counts = Counter(y_train_raw)
min_limit = 2000 # 小类补到 2000
max_limit = 50000 # 大类砍到 50000

sampling_strategy_over = {cls: min_limit for cls, count in original_counts.items()}

```

```
if count < min_limit}
sampling_strategy_under = {cls: max_limit for cls, count in
original_counts.items() if count > max_limit}

# 如果没有需要采样的类 · Pipeline 会自动跳过
pipeline_steps = []
if sampling_strategy_over:
    pipeline_steps.append(('o', SMOTE(sampling_strategy=sampling_strategy_over,
random_state=seed)))
if sampling_strategy_under:
    pipeline_steps.append(('u',
RandomUnderSampler(sampling_strategy=sampling_strategy_under, random_state=seed)))

if pipeline_steps:
    print("SMOTE + UnderSampling : ")
    resample_pipe = Pipeline(steps=pipeline_steps)
    X_train_tab, y_train_tab = resample_pipe.fit_resample(X_train_raw,
y_train_raw)
else:
    print("无需重采样")
    X_train_tab, y_train_tab = X_train_raw, y_train_raw

print(f"TabNet 训练集形状: {X_train_tab.shape}")

# 标准化
scaler = StandardScaler()
X_train_tab = scaler.fit_transform(X_train_tab)
X_val_tab = scaler.transform(X_val_raw)
X_test_tab = scaler.transform(X_test_raw)

#TabNet 预训练
tabnet_params = dict(
    n_d=64, n_a=64, n_steps=5,
    optimizer_fn=torch.optim.Adam,
    optimizer_params=dict(lr=2e-2),
    scheduler_params={"step_size":10, "gamma":0.9},
    scheduler_fn=torch.optim.lr_scheduler.StepLR,
    mask_type='entmax',
    device_name='auto'
)

print("TabNet 预训练 : ")
unsupervised_model = TabNetPretrainer(**tabnet_params)

unsupervised_model.fit(
    X_train=X_train_tab,
    eval_set=[X_val_tab],
    max_epochs=15, # 预训练轮数
    patience=5,
    batch_size=2048,
    virtual_batch_size=128,
    num_workers=0,
    drop_last=False,
    pretraining_ratio=0.5
```

```

)
# TabNet 分类器
print("训练 TabNet : ")
clf_tabnet = TabNetClassifier(**tabnet_params)

clf_tabnet.fit(
    X_train=X_train_tab, y_train=y_train_tab,
    eval_set=[(X_val_tab, y_val)],
    eval_name=['valid'],
    eval_metric=['accuracy'],
    max_epochs=50,
    patience=15,
    batch_size=2048,
    virtual_batch_size=256,
    num_workers=0,
    drop_last=False,
    from_unsupervised=unsupervised_model # 加载预训练权重
)

```

TabNet :

SMOTE + UnderSampling :

TabNet 训练集形状: (175894, 46)

TabNet 预训练 :

```
D:\ComputerEnvironment\Anaconda\envs\pytorch\lib\site-
packages\pytorch_tabnet\abstract_model.py:82: UserWarning: Device used : cuda
warnings.warn(f"Device used : {self.device}")
```

```

epoch 0 | loss: -6685867.27994| val_0_unsup_loss_numpy: 251878.5625| 0:00:26s
epoch 1 | loss: -1119245108.26275| val_0_unsup_loss_numpy: 27120562.0| 0:00:53s
epoch 2 | loss: -7670153265.94863| val_0_unsup_loss_numpy: 1213511936.0|
0:01:19s
epoch 3 | loss: -18439608590.14962| val_0_unsup_loss_numpy: 2799540480.0|
0:01:45s
epoch 4 | loss: -30972791698.12146| val_0_unsup_loss_numpy: 24957145088.0|
0:02:11s
epoch 5 | loss: -48239964502.82758| val_0_unsup_loss_numpy: 11104331776.0|
0:02:37s

```

Early stopping occurred at epoch 5 with best_epoch = 0 and
best_val_0_unsup_loss_numpy = 251878.5625

训练 TabNet :

```
D:\ComputerEnvironment\Anaconda\envs\pytorch\lib\site-
packages\pytorch_tabnet\callbacks.py:172: UserWarning: Best weights from best
```

```
epoch are automatically used!
    warnings.warn(wrn_msg)
D:\ComputerEnvironment\Anaconda\envs\pytorch\lib\site-
packages\pytorch_tabnet\abstract_model.py:82: UserWarning: Device used : cuda
    warnings.warn(f"Device used : {self.device}")
D:\ComputerEnvironment\Anaconda\envs\pytorch\lib\site-
packages\pytorch_tabnet\abstract_model.py:248: UserWarning: Loading weights from
unsupervised pretraining
    warnings.warn("Loading weights from unsupervised pretraining")
```

epoch 0	loss: 0.73167	valid_accuracy: 0.62905	0:00:14s
epoch 1	loss: 0.47758	valid_accuracy: 0.60382	0:00:28s
epoch 2	loss: 0.45953	valid_accuracy: 0.6066	0:00:42s
epoch 3	loss: 0.45586	valid_accuracy: 0.70486	0:00:56s
epoch 4	loss: 0.45345	valid_accuracy: 0.60943	0:01:11s
epoch 5	loss: 0.2369	valid_accuracy: 0.81483	0:01:26s
epoch 6	loss: 0.18443	valid_accuracy: 0.59598	0:01:40s
epoch 7	loss: 0.19676	valid_accuracy: 0.54074	0:01:55s
epoch 8	loss: 0.18939	valid_accuracy: 0.80059	0:02:09s
epoch 9	loss: 0.19656	valid_accuracy: 0.72958	0:02:23s
epoch 10	loss: 0.19733	valid_accuracy: 0.54651	0:02:38s
epoch 11	loss: 0.18664	valid_accuracy: 0.56803	0:02:53s
epoch 12	loss: 0.17577	valid_accuracy: 0.51006	0:03:07s
epoch 13	loss: 0.17201	valid_accuracy: 0.9273	0:03:21s
epoch 14	loss: 0.18096	valid_accuracy: 0.69248	0:03:36s
epoch 15	loss: 0.18307	valid_accuracy: 0.733	0:03:50s
epoch 16	loss: 0.17528	valid_accuracy: 0.64661	0:04:05s
epoch 17	loss: 0.17915	valid_accuracy: 0.71495	0:04:20s
epoch 18	loss: 0.16347	valid_accuracy: 0.97665	0:04:34s
epoch 19	loss: 0.15941	valid_accuracy: 0.66351	0:04:49s
epoch 20	loss: 0.15299	valid_accuracy: 0.96314	0:05:03s
epoch 21	loss: 0.15379	valid_accuracy: 0.98786	0:05:18s
epoch 22	loss: 0.1641	valid_accuracy: 0.41128	0:05:33s
epoch 23	loss: 0.20345	valid_accuracy: 0.98151	0:05:47s
epoch 24	loss: 0.19281	valid_accuracy: 0.78168	0:06:02s
epoch 25	loss: 0.17832	valid_accuracy: 0.53291	0:06:16s
epoch 26	loss: 0.17107	valid_accuracy: 0.4107	0:06:31s
epoch 27	loss: 0.16169	valid_accuracy: 0.80227	0:06:46s
epoch 28	loss: 0.15877	valid_accuracy: 0.59192	0:06:59s
epoch 29	loss: 0.15583	valid_accuracy: 0.41611	0:07:14s
epoch 30	loss: 0.15294	valid_accuracy: 0.81703	0:07:28s
epoch 31	loss: 0.17251	valid_accuracy: 0.97433	0:07:42s
epoch 32	loss: 0.30507	valid_accuracy: 0.39073	0:07:56s
epoch 33	loss: 0.28175	valid_accuracy: 0.57701	0:08:10s
epoch 34	loss: 0.25754	valid_accuracy: 0.77206	0:08:24s
epoch 35	loss: 0.25675	valid_accuracy: 0.53196	0:08:38s
epoch 36	loss: 0.25002	valid_accuracy: 0.69946	0:08:52s

Early stopping occurred at epoch 36 with best_epoch = 21 and best_valid_accuracy = 0.98786

```
D:\ComputerEnvironment\Anaconda\envs\pytorch\lib\site-packages\pytorch_tabnet\callbacks.py:172: UserWarning: Best weights from best epoch are automatically used!
  warnings.warn(wrn_msg)
```

动态权重融合

```
from scipy.optimize import minimize
from sklearn.metrics import f1_score, log_loss
import shap

# 动态权重融合
print("\n寻找最佳融合权重：")

# 获取验证集上的概率预测
probs_val_lgbm = lgbm.predict_proba(X_val_raw)
probs_val_xgb = xgb_clf.predict_proba(X_val_raw)
probs_val_tabnet = clf_tabnet.predict_proba(X_val_tab)

# 最小化 Log Loss
def loss_func(weights):
    # 归一化权重
    weights = np.array(weights)
    weights /= weights.sum()

    # 融合概率
    final_probs = (weights[0] * probs_val_lgbm +
                   weights[1] * probs_val_xgb +
                   weights[2] * probs_val_tabnet)

    final_probs = np.clip(final_probs, 1e-15, 1 - 1e-15)

    return log_loss(y_val, final_probs)

# 初始设定：平均分配
init_weights = [1/3, 1/3, 1/3]
bounds = [(0, 1)] * 3
constraints = ({'type': 'eq', 'fun': lambda w: 1 - sum(w)})

res = minimize(loss_func, init_weights, method='SLSQP', bounds=bounds,
               constraints=constraints)

best_weights = res.x / res.x.sum()
print(f"最佳权重 -> LGBM: {best_weights[0]:.4f}, XGB: {best_weights[1]:.4f},
      TabNet: {best_weights[2]:.4f}")
```

寻找最佳融合权重：

最佳权重 -> LGBM: 0.3338, XGB: 0.3415, TabNet: 0.3247

分类指标

```

probs_test_lgbm = lgbm.predict_proba(X_test_raw)
probs_test_xgb = xgb_clf.predict_proba(X_test_raw)
probs_test_tab = clf_tabnet.predict_proba(X_test_tab)

#加权融合
final_test_probs = (best_weights[0] * probs_test_lgbm +
                     best_weights[1] * probs_test_xgb +
                     best_weights[2] * probs_test_tab)

final_preds = np.argmax(final_test_probs, axis=1)

#综合评估指标
acc = accuracy_score(y_test, final_preds)
macro_f1 = f1_score(y_test, final_preds, average='macro')
weighted_f1 = f1_score(y_test, final_preds, average='weighted')

print("融合模型评估:")
print(f"Accuracy : {acc:.4f}")
print(f"Macro F1 : {macro_f1:.4f} ")
print(f"Weighted F1 : {weighted_f1:.4f} ")
print("-" * 60)
print("详细分类报告:\n")
print(classification_report(y_test, final_preds,
target_names=label_encoder.classes_))

```

```

D:\ComputerEnvironment\Anaconda\envs\pytorch\lib\site-
packages\sklearn\utils\validation.py:2739: UserWarning: X does not have valid
feature names, but LGBMClassifier was fitted with feature names
warnings.warn(

```

融合模型评估：

```

Accuracy : 0.9955
Macro F1 : 0.8624
Weighted F1 : 0.9954
-----
```

详细分类报告：

	precision	recall	f1-score	support
Benign	0.93	0.95	0.94	3672

BruteForce	0.96	0.52	0.68	48
DDoS	1.00	1.00	1.00	114529
Dos	1.00	1.00	1.00	27222
Mirai	1.00	1.00	1.00	8885
Recon	0.84	0.82	0.83	1192
Spoofing	0.89	0.87	0.88	1658
Web	0.69	0.49	0.58	81
accuracy			1.00	157287
macro avg	0.91	0.83	0.86	157287
weighted avg	1.00	1.00	1.00	157287

结果可视化分析

```

import shap
import matplotlib.pyplot as plt
import os

# SHAP
print("\nSHAP 分析：")

# SHAP 随机抽取样本进行解释
sample_idx = np.random.choice(X_test_raw.shape[0], 1000, replace=False)
X_shap_raw = X_test_raw[sample_idx]
X_shap_tab = X_test_tab[sample_idx] # TabNet 使用标准化后的数据

if not os.path.exists('results'):
    os.makedirs('results')
#LightGBM
print("LightGBM:")
explainer_lgbm = shap.TreeExplainer(lgbm)
shap_values_lgbm = explainer_lgbm.shap_values(X_shap_raw)

plt.figure(figsize=(12, 8))
shap.summary_plot(shap_values_lgbm, X_shap_raw, feature_names=feature_names,
plot_type="bar", show=False)
plt.tight_layout()
plt.savefig('results/LGBM_SHAP_Global_Bar.png', dpi=300, bbox_inches='tight')
plt.show()
# TabNet
print("TabNet:")
feat_importances = clf_tabnet.feature_importances_
indices = np.argsort(feat_importances)[::-1]

#前 20 个重要特征
top_k = 20
top_indices = indices[:top_k]
top_importances = feat_importances[top_indices]
top_names = [feature_names[i] for i in top_indices]

plt.figure(figsize=(12, 8))

```

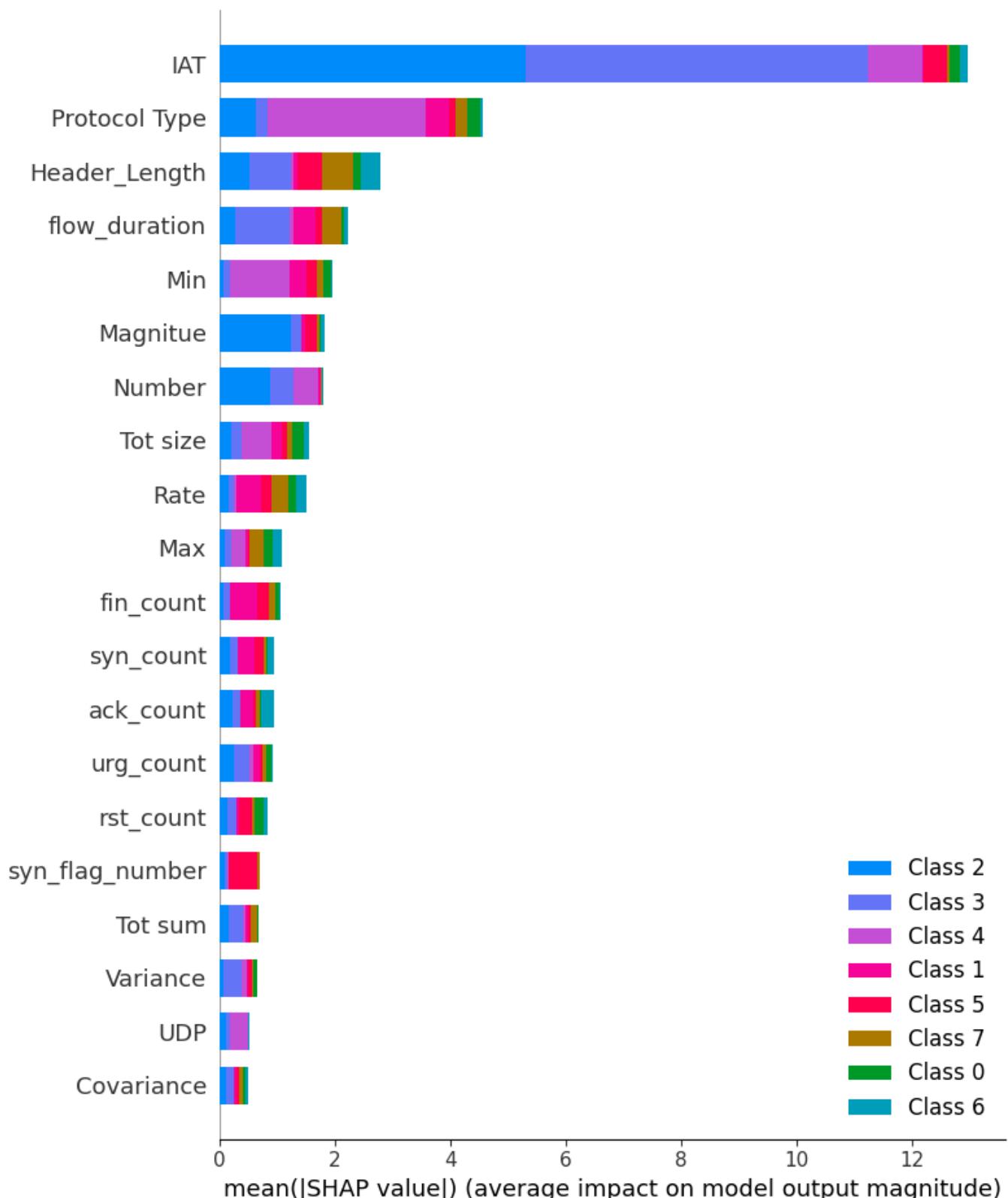
```
plt.title(f"TabNet Global Feature Importance (Top {top_k})")
plt.bar(range(top_k), top_importances, align='center', color='skyblue')
plt.xticks(range(top_k), top_names, rotation=45, ha='right')
plt.ylabel("Importance Score")
plt.xlabel("Features")
plt.tight_layout()
plt.savefig('results/TabNet_Feature_Importance.png', dpi=300, bbox_inches='tight')
plt.show()
```

SHAP 分析：

LightGBM:

```
C:\Users\李承宇\AppData\Local\Temp\ipykernel_21000\345184338.py:21: FutureWarning:
The NumPy global RNG was seeded by calling `np.random.seed`. In a future version
this function will no longer use the global RNG. Pass `rng` explicitly to opt-in
to the new behaviour and silence this warning.
```

```
    shap.summary_plot(shap_values_lgbm, X_shap_raw, feature_names=feature_names,
plot_type="bar", show=False)
```



TabNet:

