05_model_training_and_evaluation

September 28, 2024

0.1 Notebook Overview

This notebook builds upon the feature-engineered dataset from the previous notebook (`04_feature_engineering.ipynb`) and focuses on **Model Training and Evaluation**. Our primary goal is to develop a credit risk prediction model that excels at identifying potential loan defaulters, thereby minimizing financial losses for retail banks while also considering their desired balance between risk aversion and loan approval rates. This translates to maximizing the recall of the positive class (loan defaulters) while maintaining acceptable precision and overall model performance.

0.1.1 0.5.1 Objectives

The main objectives of this notebook are:

1. **Model Selection:** Choose algorithms suitable for imbalanced classification problems.
2. **Model Training:** Train models with a focus on identifying potential defaulters.
3. **Hyperparameter Tuning:** Optimize models to increase recall for the positive class.
4. **Model Evaluation:** Assess models primarily on recall, while considering precision, F2-score, AUC-PR, and overall performance.
5. **Model Comparison:** Compare different models based on their ability to identify true positives and balance the precision-recall trade-off.
6. **Threshold Adjustment:** Explore the impact of classification thresholds on recall and precision, collaborating with retail banks to determine the optimal threshold.

0.1.2 0.5.2 Importance of Focusing on Recall

Prioritizing recall for defaulter prediction is crucial for minimizing financial losses, which is the primary business objective in credit risk assessment. The cost of missing a potential defaulter (false negative) is typically much higher than the cost of incorrectly classifying a non-defaulter as high-risk (false positive). While we prioritize recall, we will also carefully consider the precision-recall trade-off and aim for a model that maximizes recall without severely impacting precision. Techniques like threshold adjustment and cost-sensitive learning will be used to balance these metrics effectively. Furthermore, demonstrating a thorough approach to risk identification aligns with regulatory expectations in the financial sector, supporting the banks' compliance needs. This approach also allows for more conservative lending practices, which can be adjusted based on the bank's specific risk tolerance.

0.1.3 0.5.3 Our Approach

In this notebook, we will focus on the following modeling tasks:

1. **Data Preparation:** Address class imbalance using techniques like SMOTE or class weighting.
2. **Baseline Model:** A logistic regression model with class weights inversely proportional to class frequencies will serve as our baseline. This will provide a benchmark for evaluating more complex models.
3. **Advanced Models:** Train and evaluate models known for handling imbalanced data:
   - Decision Trees with adjusted class weights
   - Random Forest with balanced class weights
   - Gradient Boosting (XGBoost, LightGBM) with `scale_pos_weight` adjustment
4. **Hyperparameter Tuning:** We will employ techniques like GridSearchCV or RandomizedSearchCV, optimizing for the F2-score (which gives more weight to recall) or a custom cost-sensitive scoring function.
5. **Model Evaluation:** Prioritize recall in our metrics, while also considering precision, F2-score, AUC-PR, and AUC-ROC.
6. **Threshold Adjustment:** We will experiment with different classification thresholds and work closely with retail banks to determine the optimal threshold that balances their desired level of risk aversion with acceptable loan approval rates.
7. **Ensemble Methods:** Explore ensemble techniques that can improve recall without severely impacting precision.
8. **Cost-Sensitive Learning:** Incorporate misclassification costs to reflect the higher cost of false negatives, aligning the model's objective with the business goal of minimizing financial losses.

By the end of this notebook, we aim to have a model (or ensemble of models) that excels at identifying potential loan defaulters, providing the bank with a powerful tool for risk assessment and mitigation.

[8]:
```
import pandas as pd
import numpy as np
import os
import re
from sklearn.preprocessing import FunctionTransformer
from lightgbm.callback import early_stopping

from sklearn.model_selection import (
    train_test_split,
    StratifiedKFold,
    GridSearchCV,
    RandomizedSearchCV,
    cross_val_score,
)
from sklearn.model_selection import cross_val_predict

from sklearn.preprocessing import StandardScaler
from sklearn.linear_model import LogisticRegression
from sklearn.ensemble import RandomForestClassifier
from sklearn.dummy import DummyClassifier
from sklearn.tree import DecisionTreeClassifier
```

```
from sklearn.pipeline import Pipeline
import xgboost as xgb
import lightgbm as lgb
from sklearn.metrics import (
    classification_report,
    roc_auc_score,
    precision_recall_curve,
    auc,
    confusion_matrix,
    f1_score,
    recall_score,
    precision_score,
    make_scorer,
)
from sklearn.utils.class_weight import compute_class_weight

from retail_bank_risk.model_training_utils import downscale_dtypes
from retail_bank_risk.advanced_visualizations_utils import (
    plot_confusion_matrix,
    plot_model_performance,
    shap_summary_plot,
    shap_force_plot,
    plot_roc_curve,
    plot_precision_recall_curve,
    plot_combined_confusion_matrices,
    plot_learning_curve,
)

from joblib import Parallel, delayed
import warnings
warnings.filterwarnings('ignore')  # Suppress warnings for cleaner output

import matplotlib.pyplot as plt
import seaborn as sns
import shap

from sklearn.pipeline import Pipeline
from sklearn.preprocessing import StandardScaler, FunctionTransformer
from sklearn.linear_model import LogisticRegression
from sklearn.tree import DecisionTreeClassifier
from sklearn.ensemble import RandomForestClassifier, GradientBoostingClassifier
from sklearn.dummy import DummyClassifier
from sklearn.model_selection import cross_val_score, StratifiedKFold
from sklearn.feature_selection import SelectFromModel
```

[2]:
```
train_df = pd.read_parquet("../data/processed/application_train_engineered.
↪parquet")
```

```
test_df = pd.read_parquet("../data/processed/application_test_engineered.
 ↪parquet")

print(f"Training Data Shape: {train_df.shape}")
print(f"Test Data Shape: {test_df.shape}")
```

```
Training Data Shape: (307511, 78)
Test Data Shape: (48744, 77)
```

[3]:
```
train_df, test_df = downscale_dtypes(train_df, test_df, target_column='target')

train_df.info(memory_usage='deep')
```

```
<class 'pandas.core.frame.DataFrame'>
RangeIndex: 307511 entries, 0 to 307510
Data columns (total 78 columns):
 #   Column                                  Non-Null Count   Dtype
---  ------                                  --------------   -----
 0   reg_city_not_work_city_0                307511 non-null  uint8
 1   reg_city_not_work_city_1                307511 non-null  uint8
 2   region_rating_client_w_city             307511 non-null  float32
 3   region_rating_client                    307511 non-null  float32
 4   name_contract_type_cash loans           307511 non-null  uint8
 5   name_contract_type_revolving loans      307511 non-null  uint8
 6   code_gender_m                           307511 non-null  uint8
 7   code_gender_f                           307511 non-null  uint8
 8   flag_own_car_n                          307511 non-null  uint8
 9   flag_own_car_y                          307511 non-null  uint8
 10  flag_own_realty_y                       307511 non-null  uint8
 11  flag_own_realty_n                       307511 non-null  uint8
 12  name_type_suite_unaccompanied           307511 non-null  uint8
 13  name_type_suite_family                  307511 non-null  uint8
 14  name_type_suite_spouse, partner         307511 non-null  uint8
 15  name_type_suite_children                307511 non-null  uint8
 16  name_type_suite_other_a                 307511 non-null  uint8
 17  name_type_suite_mode                    307511 non-null  uint8
 18  name_type_suite_other_b                 307511 non-null  uint8
 19  name_type_suite_group of people         307511 non-null  uint8
 20  name_income_type_working                307511 non-null  uint8
 21  name_income_type_state servant          307511 non-null  uint8
 22  name_income_type_commercial associate   307511 non-null  uint8
 23  name_income_type_pensioner              307511 non-null  uint8
 24  name_income_type_unemployed             307511 non-null  uint8
 25  name_income_type_student                307511 non-null  uint8
 26  name_income_type_businessman            307511 non-null  uint8
 27  name_income_type_maternity leave        307511 non-null  uint8
 28  name_education_type                     307511 non-null  float32
 29  name_family_status_single / not married 307511 non-null  uint8
```

```
30  name_family_status_married                307511 non-null  uint8
31  name_family_status_civil marriage         307511 non-null  uint8
32  name_family_status_widow                  307511 non-null  uint8
33  name_family_status_separated              307511 non-null  uint8
34  name_family_status_unknown                307511 non-null  uint8
35  name_housing_type_house / apartment       307511 non-null  uint8
36  name_housing_type_rented apartment        307511 non-null  uint8
37  name_housing_type_with parents            307511 non-null  uint8
38  name_housing_type_municipal apartment     307511 non-null  uint8
39  name_housing_type_office apartment        307511 non-null  uint8
40  name_housing_type_co-op apartment         307511 non-null  uint8
41  occupation_type                           307511 non-null  float32
42  weekday_appr_process_start_wednesday      307511 non-null  uint8
43  weekday_appr_process_start_monday         307511 non-null  uint8
44  weekday_appr_process_start_thursday       307511 non-null  uint8
45  weekday_appr_process_start_sunday         307511 non-null  uint8
46  weekday_appr_process_start_saturday       307511 non-null  uint8
47  weekday_appr_process_start_friday         307511 non-null  uint8
48  weekday_appr_process_start_tuesday        307511 non-null  uint8
49  organization_type                         307511 non-null  float32
50  housetype_mode_block of flats             307511 non-null  uint8
51  housetype_mode_mode                       307511 non-null  uint8
52  housetype_mode_terraced house             307511 non-null  uint8
53  housetype_mode_specific housing           307511 non-null  uint8
54  emergencystate_mode_no                    307511 non-null  uint8
55  emergencystate_mode_mode                  307511 non-null  uint8
56  emergencystate_mode_yes                   307511 non-null  uint8
57  days_last_phone_change                    307511 non-null  float32
58  days_birth                                307511 non-null  float32
59  days_id_publish                           307511 non-null  float32
60  ext_source_3                              307511 non-null  float32
61  ext_source_2                              307511 non-null  float32
62  sk_id_curr                                307511 non-null  float32
63  amt_income_total                          307511 non-null  float32
64  amt_credit                                307511 non-null  float32
65  amt_annuity                               307511 non-null  float32
66  amt_goods_price                           307511 non-null  float32
67  is_anomaly_false                          307511 non-null  uint8
68  is_anomaly_true                           307511 non-null  uint8
69  age_group                                 307511 non-null  float32
70  income_group                              307511 non-null  float32
71  credit_amount_group                       307511 non-null  float32
72  debt_to_income_ratio                      307511 non-null  float32
73  credit_to_goods_ratio                     307511 non-null  float32
74  annuity_to_income_ratio                   307511 non-null  float32
75  ext_source_mean                           307511 non-null  float32
76  credit_exceeds_goods                      307511 non-null  uint8
77  target                                    307511 non-null  uint8
```

```
dtypes: float32(22), uint8(56)
memory usage: 42.2 MB
```

[4]:
```
X = train_df.drop(["target", "sk_id_curr"], axis=1)
y = train_df["target"]

X_train, X_val, y_train, y_val = train_test_split(X, y, test_size=0.2,␣
 ↪random_state=42, stratify=y)

X_test = test_df.drop("sk_id_curr", axis=1)
sk_id_curr = test_df["sk_id_curr"]

print(f"Training set shape: {X_train.shape}")
print(f"Validation set shape: {X_val.shape}")
print(f"Test set shape: {X_test.shape}")
```

```
Training set shape: (246008, 76)
Validation set shape: (61503, 76)
Test set shape: (48744, 76)
```

[5]:
```
def sanitize_feature_names(X):
    return X.rename(columns=lambda x: re.sub(r'[^\w]+', '_', x))
sanitize_transformer = FunctionTransformer(sanitize_feature_names)
```

[6]:
```
pipelines = {
    'Dummy Classifier': Pipeline([
        ('sanitizer', FunctionTransformer(sanitize_feature_names)),
        ('classifier', DummyClassifier(strategy='stratified', random_state=42))
    ]),
    'Logistic Regression': Pipeline([
        ('sanitizer', FunctionTransformer(sanitize_feature_names)),
        ('scaler', StandardScaler()),
        ('feature_selection',␣
 ↪SelectFromModel(LogisticRegression(random_state=42))),
        ('classifier', LogisticRegression(random_state=42,␣
 ↪class_weight='balanced',
                                          max_iter=1000, penalty='l2', C=0.1))
    ]),
    'Decision Tree': Pipeline([
        ('sanitizer', FunctionTransformer(sanitize_feature_names)),
        ('feature_selection',␣
 ↪SelectFromModel(DecisionTreeClassifier(random_state=42))),
        ('classifier', DecisionTreeClassifier(random_state=42,␣
 ↪class_weight='balanced',
                                              max_depth=3, min_samples_split=5))
    ]),
    'Random Forest': Pipeline([
        ('sanitizer', FunctionTransformer(sanitize_feature_names)),
```

```
        ('feature_selection',␣
↪SelectFromModel(RandomForestClassifier(random_state=42))),
        ('classifier', RandomForestClassifier(random_state=42,␣
↪class_weight='balanced',
                                              n_jobs=1, max_depth=5,␣
↪n_estimators=100,
                                              min_samples_split=5,␣
↪bootstrap=True))
    ]),
    'Gradient Boosting': Pipeline([
        ('sanitizer', FunctionTransformer(sanitize_feature_names)),
        ('feature_selection',␣
↪SelectFromModel(GradientBoostingClassifier(random_state=42))),
        ('classifier', GradientBoostingClassifier(random_state=42, max_depth=3,
                                                  n_estimators=100,␣
↪learning_rate=0.01,
                                                  subsample=0.8,␣
↪min_samples_split=5))
    ]),
    'XGBoost': Pipeline([
        ('sanitizer', FunctionTransformer(sanitize_feature_names)),
        ('feature_selection', SelectFromModel(xgb.
↪XGBClassifier(random_state=42))),
        ('classifier', xgb.XGBClassifier(use_label_encoder=False,␣
↪eval_metric='logloss',
                                         random_state=42,␣
↪scale_pos_weight=len(y)/sum(y),
                                         max_depth=3, n_estimators=100,␣
↪learning_rate=0.01,
                                         subsample=0.8, colsample_bytree=0.8,
                                         min_child_weight=5, n_jobs=1))
    ]),
    'LightGBM': Pipeline([
        ('sanitizer', FunctionTransformer(sanitize_feature_names)),
        ('feature_selection', SelectFromModel(lgb.
↪LGBMClassifier(random_state=42))),
        ('classifier', lgb.LGBMClassifier(random_state=42,␣
↪class_weight='balanced',
                                          max_depth=3, n_estimators=100,␣
↪learning_rate=0.01,
                                          subsample=0.8, colsample_bytree=0.8,
                                          min_child_samples=5, n_jobs=1))
    ])
}
```

[9]:
```python
def evaluate_model(name, model, X, y):
    print(f"Evaluating {name}...")
    cv = StratifiedKFold(n_splits=5, shuffle=True, random_state=42)

    # Predictions
    y_pred = cross_val_predict(model, X, y, cv=cv, method='predict')
    y_pred_proba = cross_val_predict(model, X, y, cv=cv,␣
 ↪method='predict_proba')[:, 1]

    # Metrics
    precision = precision_score(y, y_pred)
    recall = recall_score(y, y_pred)
    f1 = f1_score(y, y_pred)
    auc_roc = roc_auc_score(y, y_pred_proba)

    print(f"{name} Cross-validation results:")
    print(f"Precision: {precision:.4f}")
    print(f"Recall: {recall:.4f}")
    print(f"F1-Score: {f1:.4f}")
    print(f"AUC-ROC: {auc_roc:.4f}")
    print("=" * 60 + "\n")

    return {
        'model': name,
        'precision': precision,
        'recall': recall,
        'f1_score': f1,
        'auc_roc': auc_roc
    }

# Evaluate models
results = []
for name, pipeline in pipelines.items():
    result = evaluate_model(name, pipeline, X, y)
    results.append(result)

# Sort and print final ranking
print("Model Performance Ranking:")
for metric in ['precision', 'recall', 'f1_score', 'auc_roc']:
    print(f"\nRanking by {metric}:")
    sorted_results = sorted(results, key=lambda x: x[metric], reverse=True)
    for i, result in enumerate(sorted_results, 1):
        print(f"{i}. {result['model']}: {metric} = {result[metric]:.4f}")
```

```
Evaluating Dummy Classifier…
Dummy Classifier Cross-validation results:
Precision: 0.0831
Recall: 0.0822
```

```
F1-Score: 0.0826
AUC-ROC: 0.5013
============================================================

Evaluating Logistic Regression…
Logistic Regression Cross-validation results:
Precision: 0.1566
Recall: 0.6663
F1-Score: 0.2536
AUC-ROC: 0.7372
============================================================

Evaluating Decision Tree…
Decision Tree Cross-validation results:
Precision: 0.2039
Recall: 0.6926
F1-Score: 0.3151
AUC-ROC: 0.7981
============================================================

Evaluating Random Forest…
Random Forest Cross-validation results:
Precision: 0.2550
Recall: 0.7633
F1-Score: 0.3822
AUC-ROC: 0.8873
============================================================

Evaluating Gradient Boosting…
Gradient Boosting Cross-validation results:
Precision: 1.0000
Recall: 0.1291
F1-Score: 0.2287
AUC-ROC: 0.8503
============================================================

Evaluating XGBoost…
XGBoost Cross-validation results:
Precision: 0.3213
Recall: 0.8750
F1-Score: 0.4700
AUC-ROC: 0.9448
============================================================

Evaluating LightGBM…
[LightGBM] [Info] Number of positive: 19860, number of negative: 226148
[LightGBM] [Info] Auto-choosing row-wise multi-threading, the overhead of
testing was 0.017542 seconds.
```

```
You can set `force_row_wise=true` to remove the overhead.
And if memory is not enough, you can set `force_col_wise=true`.
[LightGBM] [Info] Total Bins 3535
[LightGBM] [Info] Number of data points in the train set: 246008, number of used
features: 72
[LightGBM] [Info] [binary:BoostFromScore]: pavg=0.080729 -> initscore=-2.432482
[LightGBM] [Info] Start training from score -2.432482
[LightGBM] [Info] Number of positive: 19860, number of negative: 226148
[LightGBM] [Info] Auto-choosing row-wise multi-threading, the overhead of
testing was 0.000939 seconds.
You can set `force_row_wise=true` to remove the overhead.
And if memory is not enough, you can set `force_col_wise=true`.
[LightGBM] [Info] Total Bins 407
[LightGBM] [Info] Number of data points in the train set: 246008, number of used
features: 3
[LightGBM] [Info] [binary:BoostFromScore]: pavg=0.500000 -> initscore=-0.000000
[LightGBM] [Info] Start training from score -0.000000
[LightGBM] [Warning] No further splits with positive gain, best gain: -inf
[LightGBM] [Warning] No further splits with positive gain, best gain: -inf
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[LightGBM] [Warning] No further splits with positive gain, best gain: -inf
[LightGBM] [Info] Number of positive: 19860, number of negative: 226149
[LightGBM] [Info] Auto-choosing row-wise multi-threading, the overhead of
testing was 0.013664 seconds.
You can set `force_row_wise=true` to remove the overhead.
And if memory is not enough, you can set `force_col_wise=true`.
[LightGBM] [Info] Total Bins 3542
[LightGBM] [Info] Number of data points in the train set: 246009, number of used
features: 72
[LightGBM] [Info] [binary:BoostFromScore]: pavg=0.080729 -> initscore=-2.432486
[LightGBM] [Info] Start training from score -2.432486
[LightGBM] [Info] Number of positive: 19860, number of negative: 226149
[LightGBM] [Info] Auto-choosing row-wise multi-threading, the overhead of
testing was 0.000837 seconds.
You can set `force_row_wise=true` to remove the overhead.
And if memory is not enough, you can set `force_col_wise=true`.
[LightGBM] [Info] Total Bins 154
[LightGBM] [Info] Number of data points in the train set: 246009, number of used
features: 2
[LightGBM] [Info] [binary:BoostFromScore]: pavg=0.500000 -> initscore=-0.000000
[LightGBM] [Info] Start training from score -0.000000
[LightGBM] [Warning] No further splits with positive gain, best gain: -inf
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[LightGBM] [Warning] No further splits with positive gain, best gain: -inf
[LightGBM] [Warning] No further splits with positive gain, best gain: -inf
[LightGBM] [Info] Number of positive: 19860, number of negative: 226149
[LightGBM] [Info] Auto-choosing row-wise multi-threading, the overhead of
testing was 0.014133 seconds.
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You can set `force_row_wise=true` to remove the overhead.
And if memory is not enough, you can set `force_col_wise=true`.
[LightGBM] [Info] Total Bins 3530
[LightGBM] [Info] Number of data points in the train set: 246009, number of used
features: 71
[LightGBM] [Info] [binary:BoostFromScore]: pavg=0.080729 -> initscore=-2.432486
[LightGBM] [Info] Start training from score -2.432486
[LightGBM] [Info] Number of positive: 19860, number of negative: 226149
[LightGBM] [Info] Auto-choosing row-wise multi-threading, the overhead of
testing was 0.000938 seconds.
You can set `force_row_wise=true` to remove the overhead.
And if memory is not enough, you can set `force_col_wise=true`.
[LightGBM] [Info] Total Bins 407
[LightGBM] [Info] Number of data points in the train set: 246009, number of used
features: 3
[LightGBM] [Info] [binary:BoostFromScore]: pavg=0.500000 -> initscore=-0.000000
[LightGBM] [Info] Start training from score -0.000000
[LightGBM] [Warning] No further splits with positive gain, best gain: -inf
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[LightGBM] [Warning] No further splits with positive gain, best gain: -inf
[LightGBM] [Warning] No further splits with positive gain, best gain: -inf
[LightGBM] [Info] Number of positive: 19860, number of negative: 226149
[LightGBM] [Info] Auto-choosing row-wise multi-threading, the overhead of
testing was 0.018620 seconds.
You can set `force_row_wise=true` to remove the overhead.
And if memory is not enough, you can set `force_col_wise=true`.
[LightGBM] [Info] Total Bins 3529
[LightGBM] [Info] Number of data points in the train set: 246009, number of used
features: 71
[LightGBM] [Info] [binary:BoostFromScore]: pavg=0.080729 -> initscore=-2.432486
[LightGBM] [Info] Start training from score -2.432486
[LightGBM] [Info] Number of positive: 19860, number of negative: 226149
[LightGBM] [Info] Auto-choosing row-wise multi-threading, the overhead of
testing was 0.000935 seconds.
You can set `force_row_wise=true` to remove the overhead.
And if memory is not enough, you can set `force_col_wise=true`.
[LightGBM] [Info] Total Bins 407
[LightGBM] [Info] Number of data points in the train set: 246009, number of used
features: 3
[LightGBM] [Info] [binary:BoostFromScore]: pavg=0.500000 -> initscore=-0.000000
[LightGBM] [Info] Start training from score -0.000000
[LightGBM] [Warning] No further splits with positive gain, best gain: -inf
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[LightGBM] [Warning] No further splits with positive gain, best gain: -inf
[LightGBM] [Warning] No further splits with positive gain, best gain: -inf
[LightGBM] [Info] Number of positive: 19860, number of negative: 226149
[LightGBM] [Info] Auto-choosing row-wise multi-threading, the overhead of
testing was 0.015290 seconds.
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You can set `force_row_wise=true` to remove the overhead.
And if memory is not enough, you can set `force_col_wise=true`.
[LightGBM] [Info] Total Bins 3537
[LightGBM] [Info] Number of data points in the train set: 246009, number of used
features: 72
[LightGBM] [Info] [binary:BoostFromScore]: pavg=0.080729 -> initscore=-2.432486
[LightGBM] [Info] Start training from score -2.432486
[LightGBM] [Info] Number of positive: 19860, number of negative: 226149
[LightGBM] [Info] Auto-choosing row-wise multi-threading, the overhead of
testing was 0.000983 seconds.
You can set `force_row_wise=true` to remove the overhead.
And if memory is not enough, you can set `force_col_wise=true`.
[LightGBM] [Info] Total Bins 407
[LightGBM] [Info] Number of data points in the train set: 246009, number of used
features: 3
[LightGBM] [Info] [binary:BoostFromScore]: pavg=0.500000 -> initscore=-0.000000
[LightGBM] [Info] Start training from score -0.000000
[LightGBM] [Warning] No further splits with positive gain, best gain: -inf
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[LightGBM] [Warning] No further splits with positive gain, best gain: -inf
[LightGBM] [Warning] No further splits with positive gain, best gain: -inf
[LightGBM] [Info] Number of positive: 19860, number of negative: 226148
[LightGBM] [Info] Auto-choosing row-wise multi-threading, the overhead of
testing was 0.018129 seconds.
You can set `force_row_wise=true` to remove the overhead.
And if memory is not enough, you can set `force_col_wise=true`.
[LightGBM] [Info] Total Bins 3535
[LightGBM] [Info] Number of data points in the train set: 246008, number of used
features: 72
[LightGBM] [Info] [binary:BoostFromScore]: pavg=0.080729 -> initscore=-2.432482
[LightGBM] [Info] Start training from score -2.432482
[LightGBM] [Info] Number of positive: 19860, number of negative: 226148
[LightGBM] [Info] Auto-choosing row-wise multi-threading, the overhead of
testing was 0.000948 seconds.
You can set `force_row_wise=true` to remove the overhead.
And if memory is not enough, you can set `force_col_wise=true`.
[LightGBM] [Info] Total Bins 407
[LightGBM] [Info] Number of data points in the train set: 246008, number of used
features: 3
[LightGBM] [Info] [binary:BoostFromScore]: pavg=0.500000 -> initscore=-0.000000
[LightGBM] [Info] Start training from score -0.000000
[LightGBM] [Warning] No further splits with positive gain, best gain: -inf
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[LightGBM] [Warning] No further splits with positive gain, best gain: -inf
[LightGBM] [Warning] No further splits with positive gain, best gain: -inf
[LightGBM] [Info] Number of positive: 19860, number of negative: 226149
[LightGBM] [Info] Auto-choosing row-wise multi-threading, the overhead of
testing was 0.013992 seconds.
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You can set `force_row_wise=true` to remove the overhead.
And if memory is not enough, you can set `force_col_wise=true`.
[LightGBM] [Info] Total Bins 3542
[LightGBM] [Info] Number of data points in the train set: 246009, number of used
features: 72
[LightGBM] [Info] [binary:BoostFromScore]: pavg=0.080729 -> initscore=-2.432486
[LightGBM] [Info] Start training from score -2.432486
[LightGBM] [Info] Number of positive: 19860, number of negative: 226149
[LightGBM] [Info] Auto-choosing row-wise multi-threading, the overhead of
testing was 0.000849 seconds.
You can set `force_row_wise=true` to remove the overhead.
And if memory is not enough, you can set `force_col_wise=true`.
[LightGBM] [Info] Total Bins 154
[LightGBM] [Info] Number of data points in the train set: 246009, number of used
features: 2
[LightGBM] [Info] [binary:BoostFromScore]: pavg=0.500000 -> initscore=-0.000000
[LightGBM] [Info] Start training from score -0.000000
[LightGBM] [Warning] No further splits with positive gain, best gain: -inf
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[LightGBM] [Warning] No further splits with positive gain, best gain: -inf
[LightGBM] [Warning] No further splits with positive gain, best gain: -inf
[LightGBM] [Info] Number of positive: 19860, number of negative: 226149
[LightGBM] [Info] Auto-choosing row-wise multi-threading, the overhead of
testing was 0.016368 seconds.
You can set `force_row_wise=true` to remove the overhead.
And if memory is not enough, you can set `force_col_wise=true`.
[LightGBM] [Info] Total Bins 3530
[LightGBM] [Info] Number of data points in the train set: 246009, number of used
features: 71
[LightGBM] [Info] [binary:BoostFromScore]: pavg=0.080729 -> initscore=-2.432486
[LightGBM] [Info] Start training from score -2.432486
[LightGBM] [Info] Number of positive: 19860, number of negative: 226149
[LightGBM] [Info] Auto-choosing row-wise multi-threading, the overhead of
testing was 0.000979 seconds.
You can set `force_row_wise=true` to remove the overhead.
And if memory is not enough, you can set `force_col_wise=true`.
[LightGBM] [Info] Total Bins 407
[LightGBM] [Info] Number of data points in the train set: 246009, number of used
features: 3
[LightGBM] [Info] [binary:BoostFromScore]: pavg=0.500000 -> initscore=-0.000000
[LightGBM] [Info] Start training from score -0.000000
[LightGBM] [Warning] No further splits with positive gain, best gain: -inf
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[LightGBM] [Warning] No further splits with positive gain, best gain: -inf
[LightGBM] [Info] Number of positive: 19860, number of negative: 226149
[LightGBM] [Info] Auto-choosing row-wise multi-threading, the overhead of
testing was 0.013838 seconds.
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You can set `force_row_wise=true` to remove the overhead.
And if memory is not enough, you can set `force_col_wise=true`.
[LightGBM] [Info] Total Bins 3529
[LightGBM] [Info] Number of data points in the train set: 246009, number of used
features: 71
[LightGBM] [Info] [binary:BoostFromScore]: pavg=0.080729 -> initscore=-2.432486
[LightGBM] [Info] Start training from score -2.432486
[LightGBM] [Info] Number of positive: 19860, number of negative: 226149
[LightGBM] [Info] Auto-choosing row-wise multi-threading, the overhead of
testing was 0.000941 seconds.
You can set `force_row_wise=true` to remove the overhead.
And if memory is not enough, you can set `force_col_wise=true`.
[LightGBM] [Info] Total Bins 407
[LightGBM] [Info] Number of data points in the train set: 246009, number of used
features: 3
[LightGBM] [Info] [binary:BoostFromScore]: pavg=0.500000 -> initscore=-0.000000
[LightGBM] [Info] Start training from score -0.000000
[LightGBM] [Warning] No further splits with positive gain, best gain: -inf
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[LightGBM] [Warning] No further splits with positive gain, best gain: -inf
[LightGBM] [Info] Number of positive: 19860, number of negative: 226149
[LightGBM] [Info] Auto-choosing row-wise multi-threading, the overhead of
testing was 0.014930 seconds.
You can set `force_row_wise=true` to remove the overhead.
And if memory is not enough, you can set `force_col_wise=true`.
[LightGBM] [Info] Total Bins 3537
[LightGBM] [Info] Number of data points in the train set: 246009, number of used
features: 72
[LightGBM] [Info] [binary:BoostFromScore]: pavg=0.080729 -> initscore=-2.432486
[LightGBM] [Info] Start training from score -2.432486
[LightGBM] [Info] Number of positive: 19860, number of negative: 226149
[LightGBM] [Info] Auto-choosing row-wise multi-threading, the overhead of
testing was 0.000939 seconds.
You can set `force_row_wise=true` to remove the overhead.
And if memory is not enough, you can set `force_col_wise=true`.
[LightGBM] [Info] Total Bins 407
[LightGBM] [Info] Number of data points in the train set: 246009, number of used
features: 3
[LightGBM] [Info] [binary:BoostFromScore]: pavg=0.500000 -> initscore=-0.000000
[LightGBM] [Info] Start training from score -0.000000
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LightGBM Cross-validation results:
Precision: 0.2963
Recall: 0.8415
```

```
F1-Score: 0.4383
AUC-ROC: 0.9262
============================================================

Model Performance Ranking:

Ranking by precision:
1. Gradient Boosting: precision = 1.0000
2. XGBoost: precision = 0.3213
3. LightGBM: precision = 0.2963
4. Random Forest: precision = 0.2550
5. Decision Tree: precision = 0.2039
6. Logistic Regression: precision = 0.1566
7. Dummy Classifier: precision = 0.0831

Ranking by recall:
1. XGBoost: recall = 0.8750
2. LightGBM: recall = 0.8415
3. Random Forest: recall = 0.7633
4. Decision Tree: recall = 0.6926
5. Logistic Regression: recall = 0.6663
6. Gradient Boosting: recall = 0.1291
7. Dummy Classifier: recall = 0.0822

Ranking by f1_score:
1. XGBoost: f1_score = 0.4700
2. LightGBM: f1_score = 0.4383
3. Random Forest: f1_score = 0.3822
4. Decision Tree: f1_score = 0.3151
5. Logistic Regression: f1_score = 0.2536
6. Gradient Boosting: f1_score = 0.2287
7. Dummy Classifier: f1_score = 0.0826

Ranking by auc_roc:
1. XGBoost: auc_roc = 0.9448
2. LightGBM: auc_roc = 0.9262
3. Random Forest: auc_roc = 0.8873
4. Gradient Boosting: auc_roc = 0.8503
5. Decision Tree: auc_roc = 0.7981
6. Logistic Regression: auc_roc = 0.7372
7. Dummy Classifier: auc_roc = 0.5013
```