lab02

November 7, 2025

№2

8 -303 -23

```
[60]: %pip install catboost
```

```
Requirement already satisfied: catboost in /home/optert/ML-labs-
Tert/.venv/lib/python3.11/site-packages (1.2.8)
Requirement already satisfied: graphviz in /home/optert/ML-labs-
Tert/.venv/lib/python3.11/site-packages (from catboost) (0.21)
Requirement already satisfied: matplotlib in /home/optert/ML-labs-
Tert/.venv/lib/python3.11/site-packages (from catboost) (3.10.7)
Requirement already satisfied: numpy<3.0,>=1.16.0 in /home/optert/ML-labs-
Tert/.venv/lib/python3.11/site-packages (from catboost) (2.3.4)
Requirement already satisfied: pandas>=0.24 in /home/optert/ML-labs-
Tert/.venv/lib/python3.11/site-packages (from catboost) (2.3.3)
Requirement already satisfied: scipy in /home/optert/ML-labs-
Tert/.venv/lib/python3.11/site-packages (from catboost) (1.16.3)
Requirement already satisfied: plotly in /home/optert/ML-labs-
Tert/.venv/lib/python3.11/site-packages (from catboost) (6.4.0)
Requirement already satisfied: six in /home/optert/ML-labs-
Tert/.venv/lib/python3.11/site-packages (from catboost) (1.17.0)
Requirement already satisfied: python-dateutil>=2.8.2 in /home/optert/ML-labs-
Tert/.venv/lib/python3.11/site-packages (from pandas>=0.24->catboost)
(2.9.0.post0)
Requirement already satisfied: pytz>=2020.1 in /home/optert/ML-labs-
Tert/.venv/lib/python3.11/site-packages (from pandas>=0.24->catboost) (2025.2)
Requirement already satisfied: tzdata>=2022.7 in /home/optert/ML-labs-
Tert/.venv/lib/python3.11/site-packages (from pandas>=0.24->catboost) (2025.2)
Requirement already satisfied: contourpy>=1.0.1 in /home/optert/ML-labs-
Tert/.venv/lib/python3.11/site-packages (from matplotlib->catboost) (1.3.3)
Requirement already satisfied: cycler>=0.10 in /home/optert/ML-labs-
Tert/.venv/lib/python3.11/site-packages (from matplotlib->catboost) (0.12.1)
Requirement already satisfied: fonttools>=4.22.0 in /home/optert/ML-labs-
Tert/.venv/lib/python3.11/site-packages (from matplotlib->catboost) (4.60.1)
Requirement already satisfied: kiwisolver>=1.3.1 in /home/optert/ML-labs-
Tert/.venv/lib/python3.11/site-packages (from matplotlib->catboost) (1.4.9)
Requirement already satisfied: packaging>=20.0 in /home/optert/ML-labs-
Tert/.venv/lib/python3.11/site-packages (from matplotlib->catboost) (25.0)
```

```
Requirement already satisfied: pillow>=8 in /home/optert/ML-labs-
Tert/.venv/lib/python3.11/site-packages (from matplotlib->catboost) (12.0.0)
Requirement already satisfied: pyparsing>=3 in /home/optert/ML-labs-
Tert/.venv/lib/python3.11/site-packages (from matplotlib->catboost) (3.2.5)
Requirement already satisfied: narwhals>=1.15.1 in /home/optert/ML-labs-
Tert/.venv/lib/python3.11/site-packages (from plotly->catboost) (2.10.2)
Note: you may need to restart the kernel to use updated packages.
```

[61]:

```python
import os
from pathlib import Path
import math
import warnings
warnings.filterwarnings("ignore")

import numpy as np
import pandas as pd
import seaborn as sns

import matplotlib.pyplot as plt

from sklearn.model_selection import train_test_split
from sklearn.compose import ColumnTransformer
from sklearn.preprocessing import OneHotEncoder, StandardScaler
from sklearn.impute import SimpleImputer
from sklearn.pipeline import Pipeline
from sklearn.model_selection import GridSearchCV, StratifiedKFold
from sklearn.ensemble import RandomForestClassifier
from sklearn.svm import SVC
from sklearn.neighbors import KNeighborsClassifier
from sklearn.metrics import confusion_matrix

from sklearn.metrics import (
    accuracy_score, precision_score, recall_score,
    f1_score, roc_auc_score
)

from catboost import CatBoostClassifier, Pool, cv
```

[62]:

```python
import os
from pathlib import Path

IN_COLAB = "COLAB_GPU" in os.environ or "google.colab" in str(get_ipython())

if not IN_COLAB:
    ROOT = Path.cwd()

    if ROOT.name == "lab02":
        LAB_ROOT = ROOT
    elif (ROOT / "lab02").exists():
        LAB_ROOT = ROOT / "lab02"
    elif ROOT.name == "notebooks":
        LAB_ROOT = ROOT.parent
    else:
        raise FileNotFoundError("         lab02            .")

    DATA_RAW = LAB_ROOT / "data" / "raw"
    DATA_RAW.mkdir(parents=True, exist_ok=True)

    csv_path = DATA_RAW / "telco.csv"

else:
    from urllib.request import urlretrieve

    url = "https://raw.githubusercontent.com/OlegTertychnyi/ML-labs-Tert/main/
  ↪lab02/data/raw/telco.csv"
    csv_path = Path("/content/telco.csv")

    if not csv_path.exists():
        urlretrieve(url, csv_path)
        print("  Dataset downloaded to Colab")

csv_path
```

```
[62]: PosixPath('/home/optert/ML-labs-Tert/lab02/data/raw/telco.csv')
```

.

```
[63]: df = pd.read_csv(csv_path)
      df
```

```
[63]:       customerID  gender  SeniorCitizen Partner Dependents  tenure  \
      0     7590-VHVEG  Female              0     Yes         No       1
      1     5575-GNVDE    Male              0      No         No      34
      2     3668-QPYBK    Male              0      No         No       2
      3     7795-CFOCW    Male              0      No         No      45
      4     9237-HQITU  Female              0      No         No       2
      …            …     …             …      …          …       …
      7038  6840-RESVB    Male              0     Yes        Yes      24
      7039  2234-XADUH  Female              0     Yes        Yes      72
      7040  4801-JZAZL  Female              0     Yes        Yes      11
      7041  8361-LTMKD    Male              1     Yes         No       4
      7042  3186-AJIEK    Male              0      No         No      66

           PhoneService     MultipleLines InternetService OnlineSecurity  …  \
0              No  No phone service             DSL             No  …
1             Yes                No             DSL            Yes  …
2             Yes                No             DSL            Yes  …
3              No  No phone service             DSL            Yes  …
4             Yes                No     Fiber optic             No  …
…           …                …             …            …  …
7038          Yes               Yes             DSL            Yes  …
7039          Yes               Yes     Fiber optic             No  …
7040           No  No phone service             DSL            Yes  …
7041          Yes               Yes     Fiber optic             No  …
7042          Yes                No     Fiber optic            Yes  …

     DeviceProtection TechSupport StreamingTV StreamingMovies        Contract  \
0                  No          No          No              No  Month-to-month
1                 Yes          No          No              No        One year
2                  No          No          No              No  Month-to-month
3                 Yes         Yes          No              No        One year
4                  No          No          No              No  Month-to-month
…              …          …         …             …             …
7038              Yes         Yes         Yes             Yes        One year
7039              Yes          No         Yes             Yes        One year
7040               No          No          No              No  Month-to-month
7041               No          No          No              No  Month-to-month
7042              Yes         Yes         Yes             Yes        Two year

     PaperlessBilling              PaymentMethod MonthlyCharges  TotalCharges  \
0                 Yes           Electronic check          29.85         29.85
1                  No               Mailed check          56.95        1889.5
2                 Yes               Mailed check          53.85        108.15
3                  No  Bank transfer (automatic)          42.30       1840.75
4                 Yes           Electronic check          70.70        151.65
…              …                        …            …           …
7038              Yes               Mailed check          84.80        1990.5
7039              Yes    Credit card (automatic)         103.20        7362.9
7040              Yes           Electronic check          29.60        346.45
7041              Yes               Mailed check          74.40         306.6
7042              Yes  Bank transfer (automatic)         105.65        6844.5

     Churn
0       No
1       No
2      Yes
3       No
4      Yes
…    …
7038    No
7039    No
```

```
7040     No
7041    Yes
7042     No

[7043 rows x 21 columns]
```

[64]:
```
df.info()
```

```
<class 'pandas.core.frame.DataFrame'>
RangeIndex: 7043 entries, 0 to 7042
Data columns (total 21 columns):
 #   Column            Non-Null Count  Dtype
---  ------            --------------  -----
 0   customerID        7043 non-null   object
 1   gender            7043 non-null   object
 2   SeniorCitizen     7043 non-null   int64
 3   Partner           7043 non-null   object
 4   Dependents        7043 non-null   object
 5   tenure            7043 non-null   int64
 6   PhoneService      7043 non-null   object
 7   MultipleLines     7043 non-null   object
 8   InternetService   7043 non-null   object
 9   OnlineSecurity    7043 non-null   object
 10  OnlineBackup      7043 non-null   object
 11  DeviceProtection  7043 non-null   object
 12  TechSupport       7043 non-null   object
 13  StreamingTV       7043 non-null   object
 14  StreamingMovies   7043 non-null   object
 15  Contract          7043 non-null   object
 16  PaperlessBilling  7043 non-null   object
 17  PaymentMethod     7043 non-null   object
 18  MonthlyCharges    7043 non-null   float64
 19  TotalCharges      7043 non-null   object
 20  Churn             7043 non-null   object
dtypes: float64(1), int64(2), object(18)
memory usage: 1.1+ MB
```

, object, TotalCharges, , « » . . customerID , Churn 0/1.

[65]:
```
for col in df.select_dtypes(include=['object']).columns:
    df[col] = df[col].astype(str).str.strip()
df["TotalCharges"] = pd.to_numeric(df["TotalCharges"], errors="coerce")
df["Churn"] = (df["Churn"] == "Yes").astype(int)
df["TotalCharges"] = df["TotalCharges"].fillna(df["TotalCharges"].median())
```

[66]:

```
print("    :", df.shape)
df.info()
```

```
   : (7043, 21)
<class 'pandas.core.frame.DataFrame'>
RangeIndex: 7043 entries, 0 to 7042
Data columns (total 21 columns):
 #   Column            Non-Null Count  Dtype  
---  ------            --------------  -----  
 0   customerID        7043 non-null   object 
 1   gender            7043 non-null   object 
 2   SeniorCitizen     7043 non-null   int64  
 3   Partner           7043 non-null   object 
 4   Dependents        7043 non-null   object 
 5   tenure            7043 non-null   int64  
 6   PhoneService      7043 non-null   object 
 7   MultipleLines     7043 non-null   object 
 8   InternetService   7043 non-null   object 
 9   OnlineSecurity    7043 non-null   object 
 10  OnlineBackup      7043 non-null   object 
 11  DeviceProtection  7043 non-null   object 
 12  TechSupport       7043 non-null   object 
 13  StreamingTV       7043 non-null   object 
 14  StreamingMovies   7043 non-null   object 
 15  Contract          7043 non-null   object 
 16  PaperlessBilling  7043 non-null   object 
 17  PaymentMethod     7043 non-null   object 
 18  MonthlyCharges    7043 non-null   float64
 19  TotalCharges      7043 non-null   float64
 20  Churn             7043 non-null   int64  
dtypes: float64(2), int64(3), object(16)
memory usage: 1.1+ MB
```

target

[67]:

```
TARGET = "Churn"
ID_COLS = ["customerID"] if "customerID" in df.columns else []

X = df.drop(columns=[TARGET] + ID_COLS)

num_cols = X.select_dtypes(include=[np.number]).columns.tolist()
cat_cols = X.select_dtypes(include=["object"]).columns.tolist()

num_cols, cat_cols
```

[67]:

```
(['SeniorCitizen', 'tenure', 'MonthlyCharges', 'TotalCharges'],
 ['gender',
  'Partner',
  'Dependents',
  'PhoneService',
  'MultipleLines',
  'InternetService',
  'OnlineSecurity',
  'OnlineBackup',
  'DeviceProtection',
  'TechSupport',
  'StreamingTV',
  'StreamingMovies',
  'Contract',
  'PaperlessBilling',
  'PaymentMethod'])
```

.   ,   ,

```
[68]: df.isna().sum().sort_values(ascending=False)
```

```
[68]: customerID          0
      gender              0
      SeniorCitizen       0
      Partner             0
      Dependents          0
      tenure              0
      PhoneService        0
      MultipleLines       0
      InternetService     0
      OnlineSecurity      0
      OnlineBackup        0
      DeviceProtection    0
      TechSupport         0
      StreamingTV         0
      StreamingMovies     0
      Contract            0
      PaperlessBilling    0
      PaymentMethod       0
      MonthlyCharges      0
      TotalCharges        0
      Churn               0
      dtype: int64
```

.

```
[69]: df[num_cols].describe().T
```

```
[69]:                  count       mean        std   min     25%     50%  \
      SeniorCitizen   7043.0   0.162147   0.368612  0.00   0.000   0.000
      tenure          7043.0  32.371149  24.559481  0.00   9.000  29.000
```

```
MonthlyCharges  7043.0    64.761692    30.090047  18.25   35.500    70.350
TotalCharges    7043.0  2281.916928  2265.270398  18.80  402.225  1397.475

                    75%      max
SeniorCitizen      0.00     1.00
tenure            55.00    72.00
MonthlyCharges    89.85   118.75
TotalCharges    3786.60  8684.80
```

[70]:

```
df[cat_cols].describe().T
```

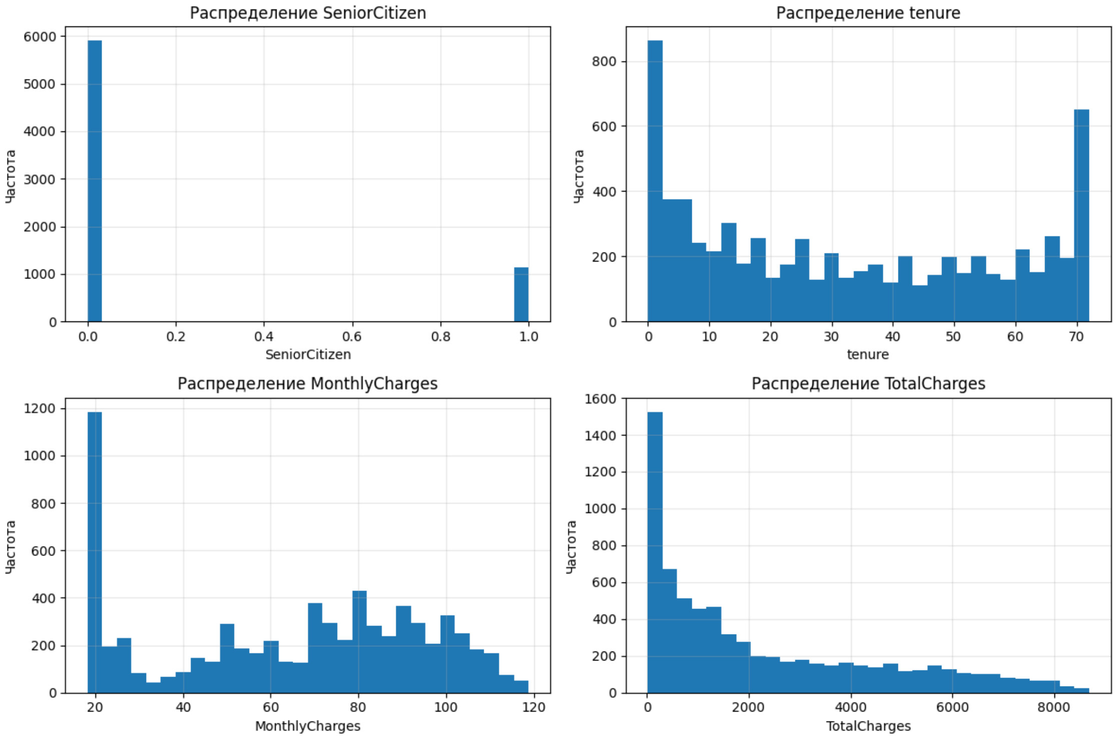
[70]:

```
                 count unique               top  freq
gender            7043      2              Male  3555
Partner           7043      2                No  3641
Dependents        7043      2                No  4933
PhoneService      7043      2               Yes  6361
MultipleLines     7043      3                No  3390
InternetService   7043      3       Fiber optic  3096
OnlineSecurity    7043      3                No  3498
OnlineBackup      7043      3                No  3088
DeviceProtection  7043      3                No  3095
TechSupport       7043      3                No  3473
StreamingTV       7043      3                No  2810
StreamingMovies   7043      3                No  2785
Contract          7043      3    Month-to-month  3875
PaperlessBilling  7043      2               Yes  4171
PaymentMethod     7043      4  Electronic check  2365
```

tenure TotalCharges, . MonthlyCharges . «No» «Month-to-month», .

[71]:

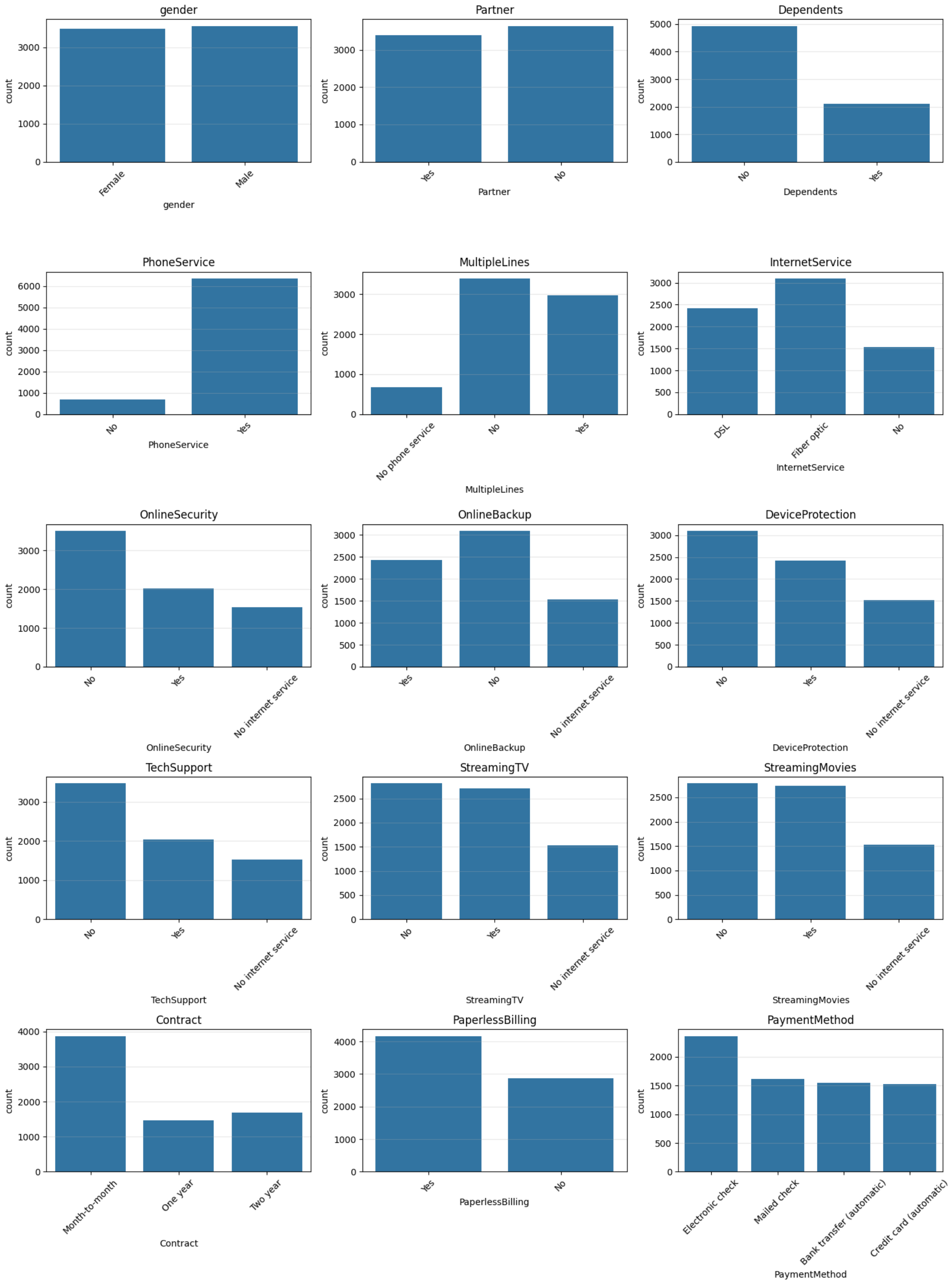
```
n = len(num_cols)
rows = (n + 1) // 2

fig, axes = plt.subplots(rows, 2, figsize=(12, 4 * rows))
axes = axes.flatten()

for i, col in enumerate(num_cols):
    axes[i].hist(df[col], bins=30)
    axes[i].set_title(f"        {col}")
    axes[i].set_xlabel(col)
    axes[i].set_ylabel("    ")
    axes[i].grid(alpha=0.3)

for j in range(i+1, len(axes)):
    fig.delaxes(axes[j])

plt.tight_layout()
plt.show()
```



SeniorCitizen : — . tenure , . MonthlyCharges , . TotalCharges : , . .

[72]:

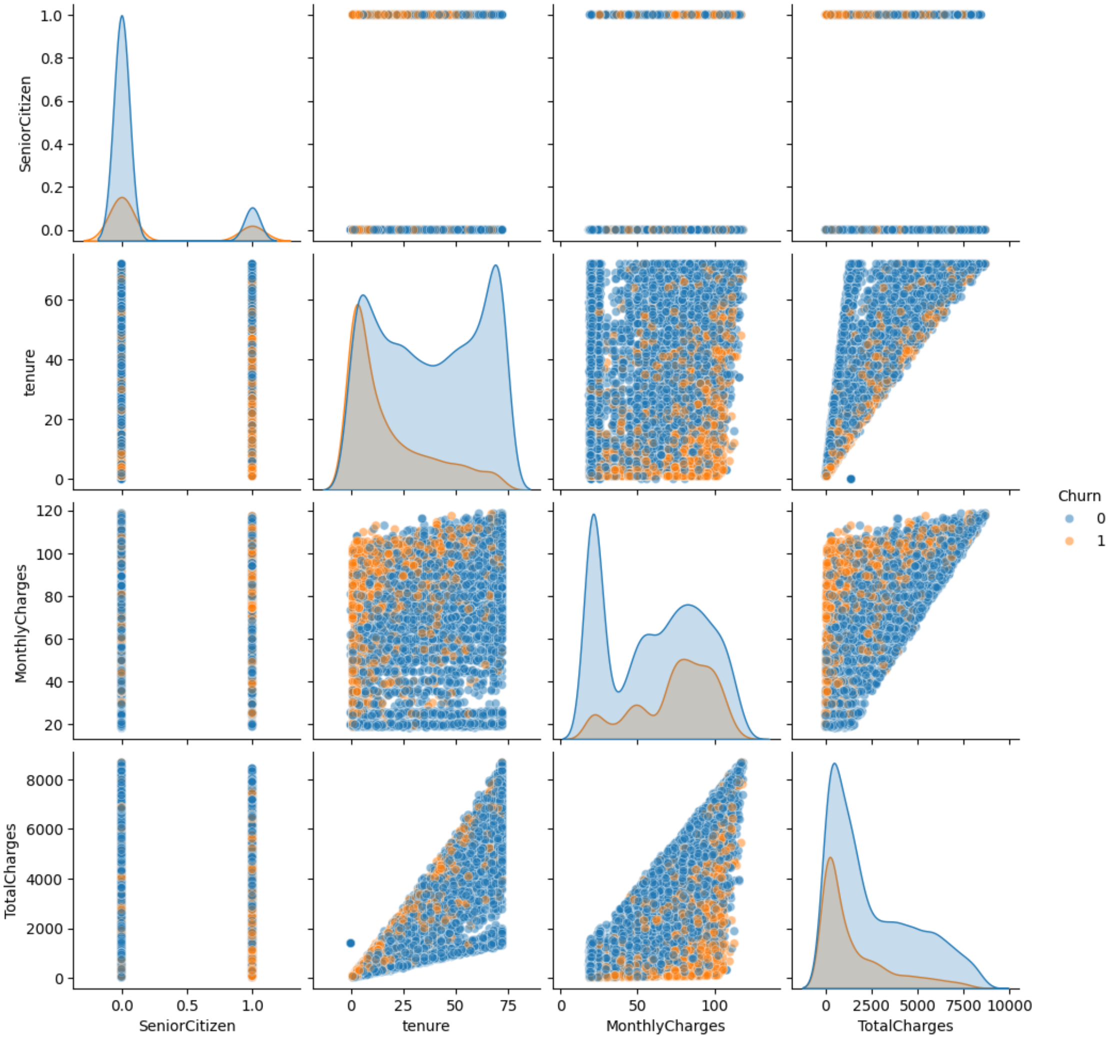
```
n_cols = 3
n_rows = math.ceil(len(cat_cols) / n_cols)

fig, axes = plt.subplots(n_rows, n_cols, figsize=(5 * n_cols, 4 * n_rows))
axes = axes.flatten()

for ax, col in zip(axes, cat_cols):
    sns.countplot(data=df, x=col, ax=ax)
    ax.set_title(col)
    ax.tick_params(axis="x", rotation=45, labelrotation=45)
    ax.grid(axis="y", alpha=0.3)

for ax in axes[len(cat_cols):]:
    fig.delaxes(ax)

plt.tight_layout()
plt.show()
```



, «No» — OnlineSecurity,
TechSupport DeviceProtection. — «Month-to-month»,
. , — Electronic check.

[74]:

```
sns.pairplot(df[num_cols + ['Churn']], hue='Churn', plot_kws={'alpha': 0.5})
plt.show()
```

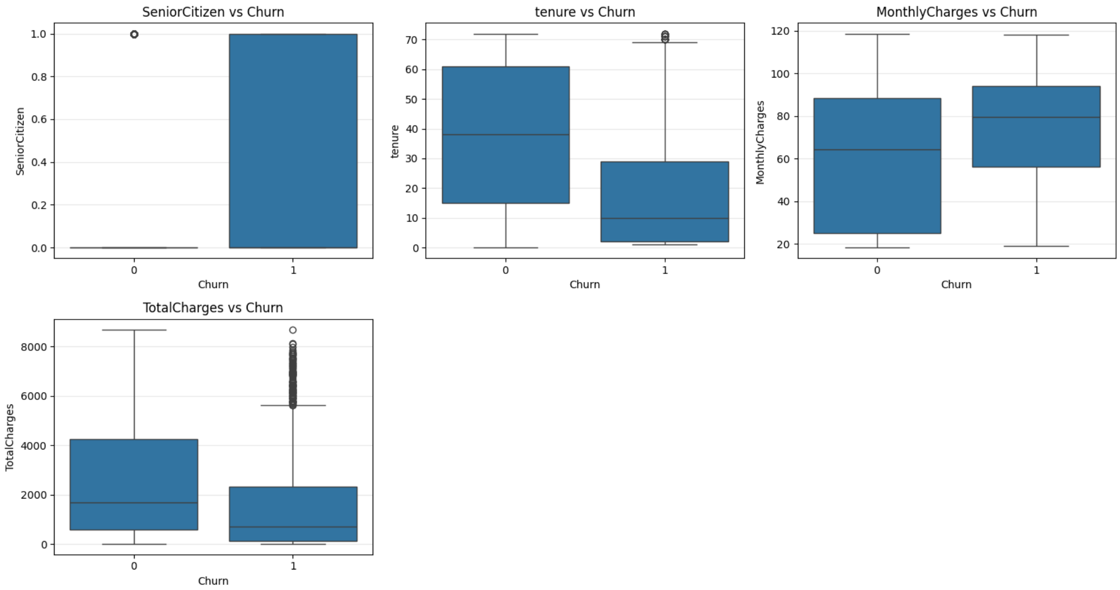


, churn,
.

[75]:

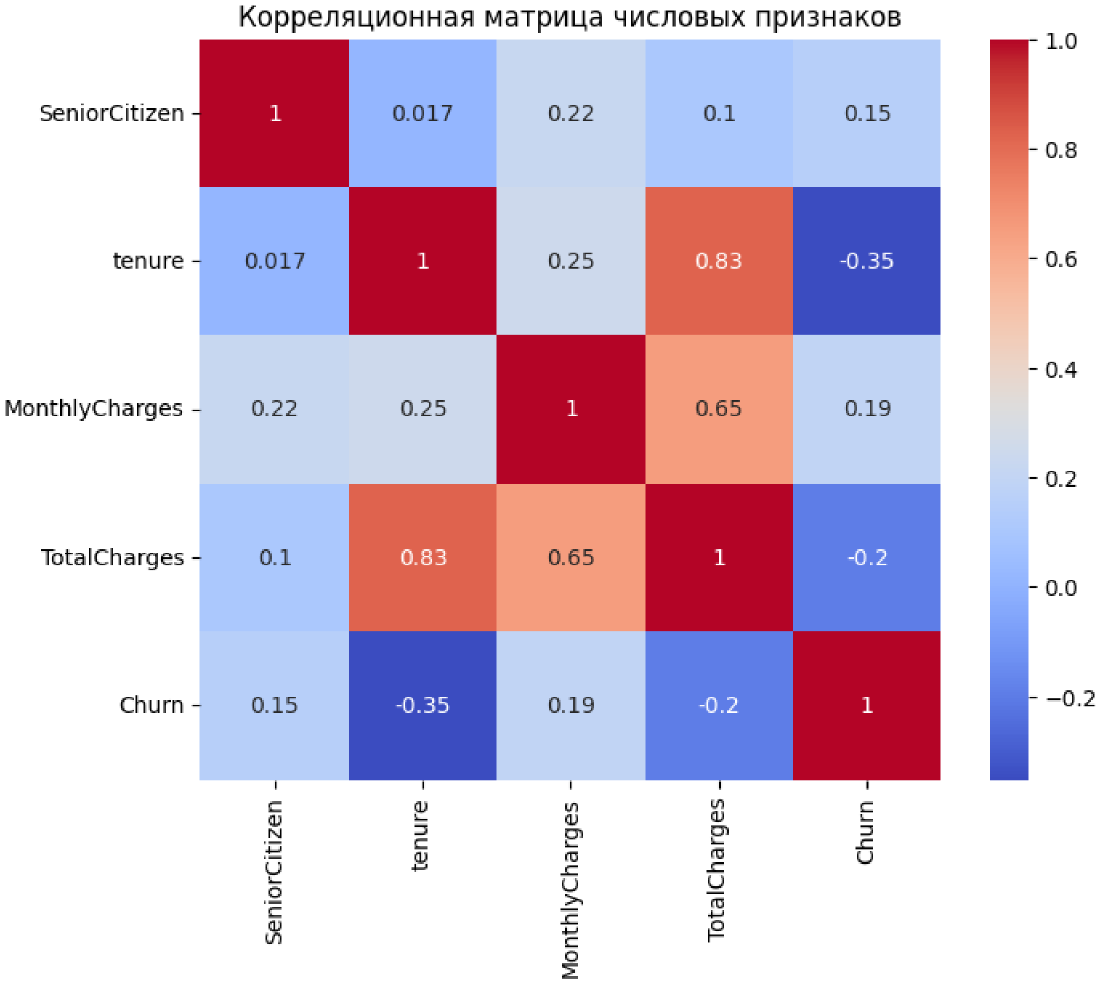
```
n_cols = 3
n_rows = math.ceil(len(num_cols) / n_cols)
```

```
fig, axes = plt.subplots(n_rows, n_cols, figsize=(5 * n_cols, 4 * n_rows))
axes = axes.flatten()

for ax, col in zip(axes, num_cols):
    sns.boxplot(data=df, x="Churn", y=col, ax=ax)
    ax.set_title(f"{col} vs Churn")
    ax.set_xlabel("Churn")
    ax.set_ylabel(col)
    ax.grid(axis="y", alpha=0.3)

for ax in axes[len(num_cols):]:
    fig.delaxes(ax)

plt.tight_layout()
plt.show()
```



churn tenure MonthlyCharges,
. TotalCharges, , .

[76]:
```
corr = df[num_cols + ["Churn"]].corr()

plt.figure(figsize=(8, 6))
sns.heatmap(
    corr,
    annot=True,
    cmap="coolwarm",
    square=True,
    cbar=True
)
plt.title("                       ")
plt.show()
```



Корреляционная матрица числовых признаков

, tenure TotalCharges , . Churn tenure — . , , .

: customerID, Churn, train/test- (20%). : — One-Hot (preproc_trees), SVM/KNN — StandardScaler (preproc_svm_knn). CatBoost (cat_features_idx), (depth, learning_rate, iterations) 5-fold - ; Pool.

```
[77]: TARGET = "Churn"
ID_COLS = ["customerID"] if "customerID" in df.columns else []
```

```
X = df.drop(columns=[TARGET] + ID_COLS)
y = df[TARGET]

X_train, X_test, y_train, y_test = train_test_split(
    X, y, test_size=0.2, random_state=42, stratify=y
)
```

[78]:

```
num_cols = X.select_dtypes(include=["number"]).columns.tolist()
cat_cols = X.select_dtypes(include=["object"]).columns.tolist()

num_pipe = Pipeline([
    ("imputer", SimpleImputer(strategy="median"))
])

cat_pipe = Pipeline([
    ("imputer", SimpleImputer(strategy="most_frequent")),
    ("onehot", OneHotEncoder(handle_unknown="ignore"))
])

preproc_trees = ColumnTransformer(
    transformers=[
        ("num", num_pipe, num_cols),
        ("cat", cat_pipe, cat_cols)
    ]
)
```

[79]:

```
num_pipe_scaled = Pipeline([
    ("imputer", SimpleImputer(strategy="median")),
    ("scaler", StandardScaler())
])

cat_pipe = Pipeline([
    ("imputer", SimpleImputer(strategy="most_frequent")),
    ("onehot", OneHotEncoder(handle_unknown="ignore"))
])

preproc_svm_knn = ColumnTransformer(
    transformers=[
        ("num", num_pipe_scaled, num_cols),
        ("cat", cat_pipe, cat_cols)
    ]
)
```

[80]:

```
cat_features_idx = [X.columns.get_loc(c) for c in cat_cols]
```

[81]:

```python
param_grid = [
    {"depth": 4, "learning_rate": 0.1, "iterations": 600},
    {"depth": 6, "learning_rate": 0.05, "iterations": 800},
    {"depth": 8, "learning_rate": 0.03, "iterations": 1000},
]
```

[82]:

```python
skf = StratifiedKFold(n_splits=5, shuffle=True, random_state=42)
```

[83]:

```python
train_pool = Pool(X_train, y_train, cat_features=cat_features_idx)
```

CatBoost - . 5-fold CV , ROC-AUC . , .

[84]:

```python
results = []

for params in param_grid:
    print(f"           : {params}")

    cv_results = cv(
        params={
            "loss_function": "Logloss",
            "eval_metric": "AUC",
            "random_seed": 42,
            "early_stopping_rounds": 50,
            **params
        },
        pool=train_pool,
        fold_count=5,
        shuffle=True,
        partition_random_seed=42,
        verbose=False
    )

    best_auc = cv_results["test-AUC-mean"].max()
    best_iter = cv_results["test-AUC-mean"].idxmax()

    results.append({
        "params": params,
        "best_auc": best_auc,
        "best_iter": best_iter
    })

results_df = pd.DataFrame(results)
results_df
```

```
          : {'depth': 4, 'learning_rate': 0.1, 'iterations': 600}
Training on fold [0/5]
```

```
bestTest = 0.8684847236
bestIteration = 106

Training on fold [1/5]

bestTest = 0.8321700354
bestIteration = 148

Training on fold [2/5]

bestTest = 0.851707786
bestIteration = 88

Training on fold [3/5]

bestTest = 0.8548361689
bestIteration = 70

Training on fold [4/5]

bestTest = 0.8440347308
bestIteration = 260

           : {'depth': 6, 'learning_rate': 0.05, 'iterations': 800}
Training on fold [0/5]

bestTest = 0.8670164639
bestIteration = 132

Training on fold [1/5]

bestTest = 0.8289507699
bestIteration = 77

Training on fold [2/5]

bestTest = 0.8498093484
bestIteration = 97

Training on fold [3/5]

bestTest = 0.8553935825
bestIteration = 51

Training on fold [4/5]

bestTest = 0.842360468
```

```
bestIteration = 259

          : {'depth': 8, 'learning_rate': 0.03, 'iterations': 1000}
Training on fold [0/5]

bestTest = 0.8671497585
bestIteration = 179

Training on fold [1/5]

bestTest = 0.8309259529
bestIteration = 143

Training on fold [2/5]

bestTest = 0.8521965327
bestIteration = 117

Training on fold [3/5]

bestTest = 0.8549432084
bestIteration = 93

Training on fold [4/5]

bestTest = 0.8393698463
bestIteration = 280
```

[84]:

```
                                              params  best_auc  best_iter
0  {'depth': 4, 'learning_rate': 0.1, 'iterations…  0.849032        148
1  {'depth': 6, 'learning_rate': 0.05, 'iteration…  0.848564        259
2  {'depth': 8, 'learning_rate': 0.03, 'iteration…  0.848585        142
```

CatBoost, iterations, -
, . , Pool.

[85]:

```python
best_cfg = results_df.iloc[results_df["best_auc"].idxmax()]
best_cfg
```

[85]:

```
params       {'depth': 4, 'learning_rate': 0.1, 'iterations…
best_auc                                             0.849032
best_iter                                                 148
Name: 0, dtype: object
```

[86]:

```python
best_params = best_cfg["params"].copy()
best_params.pop("iterations")
best_iter = int(best_cfg["best_iter"])
```

```
model_cat = CatBoostClassifier(
    loss_function="Logloss",
    eval_metric="AUC",
    random_seed=42,
    iterations=best_iter,
    **best_params
)

model_cat.fit(train_pool, verbose=False)
```

```
[86]: <catboost.core.CatBoostClassifier at 0x7fc598572e10>
```

- GridSearchCV

```
[87]: rf_param_grid = {
          "model__n_estimators": [200, 400, 800],
          "model__max_depth": [None, 10, 15],
          "model__min_samples_leaf": [1, 3]
      }
```

```
[88]: rf_pipeline = Pipeline([
          ("preprocess", preproc_trees),
          ("model", RandomForestClassifier(
              class_weight="balanced",
              random_state=42,
              n_jobs=-1
          ))
      ])
```

```
[89]: skf = StratifiedKFold(n_splits=5, shuffle=True, random_state=42)
```

```
[90]: rf_grid = GridSearchCV(
          estimator=rf_pipeline,
          param_grid=rf_param_grid,
          scoring="roc_auc",
          cv=skf,
          n_jobs=-1,
          verbose=1
      )

      rf_grid.fit(X_train, y_train)
```

```
Fitting 5 folds for each of 18 candidates, totalling 90 fits
```

```
[90]: GridSearchCV(cv=StratifiedKFold(n_splits=5, random_state=42, shuffle=True),
                   estimator=Pipeline(steps=[('preprocess',
                                              ColumnTransformer(transformers=[('num',
      Pipeline(steps=[('imputer',
                SimpleImputer(strategy='median'))]),
      ['SeniorCitizen',
      'tenure',
      'MonthlyCharges',
      'TotalCharges']),
                                                                              ('cat',
      Pipeline(steps=[('imputer',
                SimpleImputer(strategy='most_frequent')),…
      'DeviceProtection',
      'TechSupport',
      'StreamingTV',
      'StreamingMovies',
      'Contract',
      'PaperlessBilling',
      'PaymentMethod'])])),
                                             ('model',
      RandomForestClassifier(class_weight='balanced',
                                                                     n_jobs=-1,
      random_state=42))]),
                   n_jobs=-1,
                   param_grid={'model__max_depth': [None, 10, 15],
                               'model__min_samples_leaf': [1, 3],
                               'model__n_estimators': [200, 400, 800]},
                   scoring='roc_auc', verbose=1)
```

[91]:
```
best_rf = rf_grid.best_estimator_
best_rf_params = rf_grid.best_params_
best_rf_score = rf_grid.best_score_

best_rf_params, best_rf_score
```

[91]:
```
({'model__max_depth': 10,
  'model__min_samples_leaf': 3,
  'model__n_estimators': 800},
 np.float64(0.8452849518294346))
```

SVM   kNN

[92]:
```
svc_param_grid = {
    "model__C": [0.5, 1, 2, 4],
    "model__kernel": ["rbf"],
}
```

[93]:
```
svc_pipeline = Pipeline([
    ("preprocess", preproc_svm_knn),
    ("model", SVC(
        probability=True,
        class_weight="balanced",
        random_state=42
    ))
])
```

[94]:

```
skf = StratifiedKFold(n_splits=5, shuffle=True, random_state=42)
```

[95]:

```
svc_grid = GridSearchCV(
    estimator=svc_pipeline,
    param_grid=svc_param_grid,
    scoring="roc_auc",
    cv=skf,
    n_jobs=-1,
    verbose=1
)

svc_grid.fit(X_train, y_train)
```

```
Fitting 5 folds for each of 4 candidates, totalling 20 fits
```

[95]:

```
GridSearchCV(cv=StratifiedKFold(n_splits=5, random_state=42, shuffle=True),
             estimator=Pipeline(steps=[('preprocess',
                                        ColumnTransformer(transformers=[('num',
Pipeline(steps=[('imputer',
          SimpleImputer(strategy='median')),
         ('scaler',
          StandardScaler())]),
['SeniorCitizen',
'tenure',
'MonthlyCharges',
'TotalCharges']),
                                                                        ('cat',
Pipeline(steps=[('imputer',
          SimpleImputer…
'MultipleLines',
'InternetService',
'OnlineSecurity',
'OnlineBackup',
'DeviceProtection',
'TechSupport',
'StreamingTV',
'StreamingMovies',
'Contract',
'PaperlessBilling',
'PaymentMethod'])])),
                                       ('model',
                                        SVC(class_weight='balanced',
                                            probability=True,
                                            random_state=42))]),
             n_jobs=-1,
             param_grid={'model__C': [0.5, 1, 2, 4], 'model__kernel': ['rbf']},
             scoring='roc_auc', verbose=1)
```

[96]:

```
best_svc = svc_grid.best_estimator_
best_svc_params = svc_grid.best_params_
best_svc_score = svc_grid.best_score_

best_svc_params, best_svc_score
```

[96]:

```
({'model__C': 0.5, 'model__kernel': 'rbf'}, np.float64(0.8322140234176816))
```

[97]:

```
knn_param_grid = {
    "model__n_neighbors": [5, 9, 15, 25],
    "model__weights": ["uniform", "distance"],
    "model__p": [1, 2]
}
```

[98]:

```
knn_pipeline = Pipeline([
    ("preprocess", preproc_svm_knn),
    ("model", KNeighborsClassifier())
])
```

[99]:

```
skf = StratifiedKFold(n_splits=5, shuffle=True, random_state=42)
```

[100]:

```
knn_grid = GridSearchCV(
    estimator=knn_pipeline,
    param_grid=knn_param_grid,
    scoring="roc_auc",
    cv=skf,
    n_jobs=-1,
    verbose=1
)

knn_grid.fit(X_train, y_train)
```

```
Fitting 5 folds for each of 16 candidates, totalling 80 fits
```

[100]:

```
GridSearchCV(cv=StratifiedKFold(n_splits=5, random_state=42, shuffle=True),
             estimator=Pipeline(steps=[('preprocess',
                                        ColumnTransformer(transformers=[('num',
Pipeline(steps=[('imputer',
          SimpleImputer(strategy='median')),
         ('scaler',
          StandardScaler())]),
['SeniorCitizen',
'tenure',
'MonthlyCharges',
'TotalCharges']),
                                                                        ('cat',
Pipeline(steps=[('imputer',
          SimpleImputer…
'MultipleLines',
'InternetService',
'OnlineSecurity',
'OnlineBackup',
'DeviceProtection',
'TechSupport',
'StreamingTV',
'StreamingMovies',
'Contract',
'PaperlessBilling',
'PaymentMethod'])])),
                                       ('model', KNeighborsClassifier())]),
             n_jobs=-1,
             param_grid={'model__n_neighbors': [5, 9, 15, 25],
                         'model__p': [1, 2],
                         'model__weights': ['uniform', 'distance']},
             scoring='roc_auc', verbose=1)
```

[101]:

```python
best_knn = knn_grid.best_estimator_
best_knn_params = knn_grid.best_params_
best_knn_score = knn_grid.best_score_

best_knn_params, best_knn_score
```

[101]:

```
({'model__n_neighbors': 25, 'model__p': 2, 'model__weights': 'uniform'},
 np.float64(0.8319873215684025))
```

[102]:

```python
def evaluate_model(name, model, X_test, y_test, proba=True):
    if name == "CatBoost":
        y_pred = model.predict(Pool(X_test, cat_features=cat_features_idx))
        y_proba = model.predict_proba(Pool(X_test,␣
 ↪cat_features=cat_features_idx))[:, 1]
    else:
        y_pred = model.predict(X_test)
        y_proba = model.predict_proba(X_test)[:, 1] if proba else None

    return {
        "model": name,
        "accuracy": accuracy_score(y_test, y_pred),
        "precision": precision_score(y_test, y_pred),
        "recall": recall_score(y_test, y_pred),
        "f1": f1_score(y_test, y_pred),
        "roc_auc": roc_auc_score(y_test, y_proba)
    }
```

[103]:

```
results = []

results.append(evaluate_model("CatBoost", model_cat, X_test, y_test))
results.append(evaluate_model("RandomForest", best_rf, X_test, y_test))
results.append(evaluate_model("SVC", best_svc, X_test, y_test))
results.append(evaluate_model("KNN", best_knn, X_test, y_test))

df_results = pd.DataFrame(results)
df_results
```

[103]:

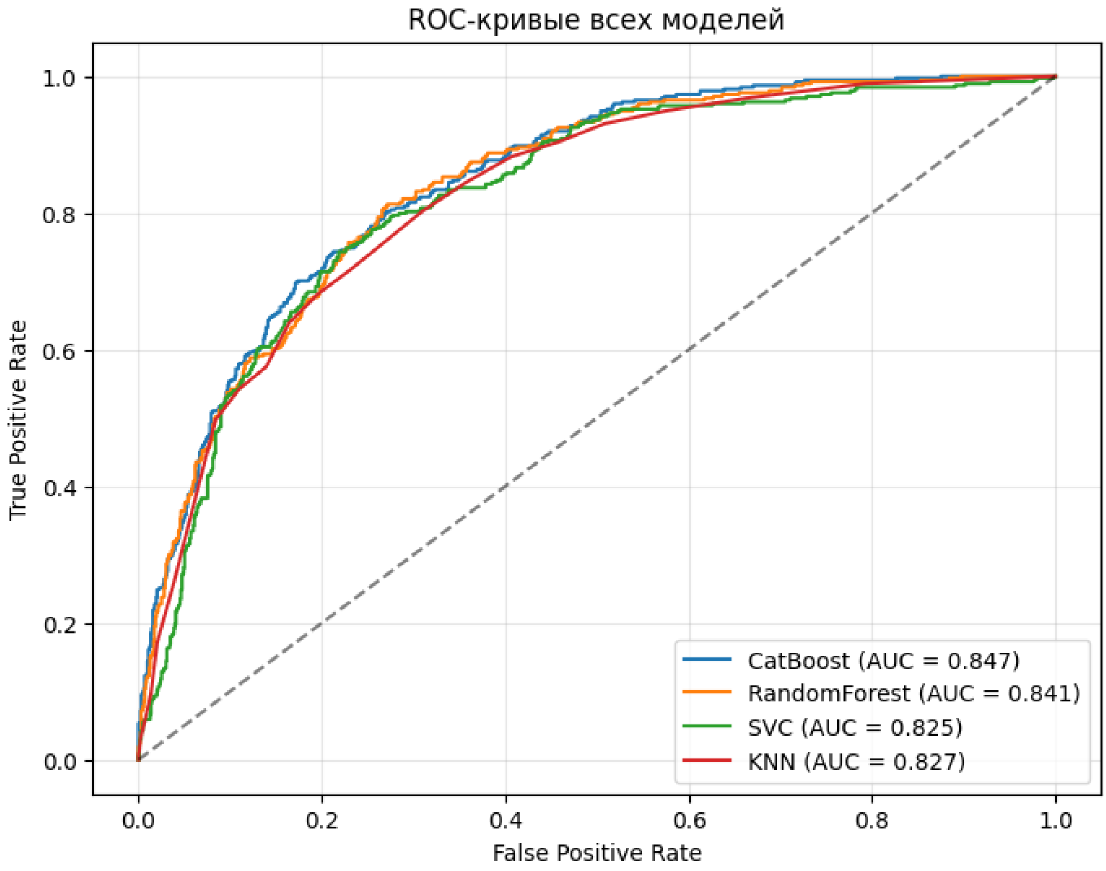
```
          model  accuracy  precision    recall        f1   roc_auc
0      CatBoost  0.804826   0.668942  0.524064  0.587706  0.846785
1  RandomForest  0.767921   0.546906  0.732620  0.626286  0.841058
2           SVC  0.743790   0.511304  0.786096  0.619600  0.825052
3           KNN  0.784954   0.598886  0.574866  0.586630  0.827011
```

. CatBoost , ROC-AUC precision,
RandomForest SVC recall. KNN , .

[104]:

```
import matplotlib.pyplot as plt
from sklearn.metrics import roc_curve, auc

plt.figure(figsize=(8, 6))

y_proba = model_cat.predict_proba(Pool(X_test, cat_features=cat_features_idx))[:
 ↪, 1]
fpr, tpr, _ = roc_curve(y_test, y_proba)
plt.plot(fpr, tpr, label=f"CatBoost (AUC = {auc(fpr, tpr):.3f})")

y_proba = best_rf.predict_proba(X_test)[:, 1]
fpr, tpr, _ = roc_curve(y_test, y_proba)
plt.plot(fpr, tpr, label=f"RandomForest (AUC = {auc(fpr, tpr):.3f})")

y_proba = best_svc.predict_proba(X_test)[:, 1]
fpr, tpr, _ = roc_curve(y_test, y_proba)
plt.plot(fpr, tpr, label=f"SVC (AUC = {auc(fpr, tpr):.3f})")

y_proba = best_knn.predict_proba(X_test)[:, 1]
fpr, tpr, _ = roc_curve(y_test, y_proba)
```

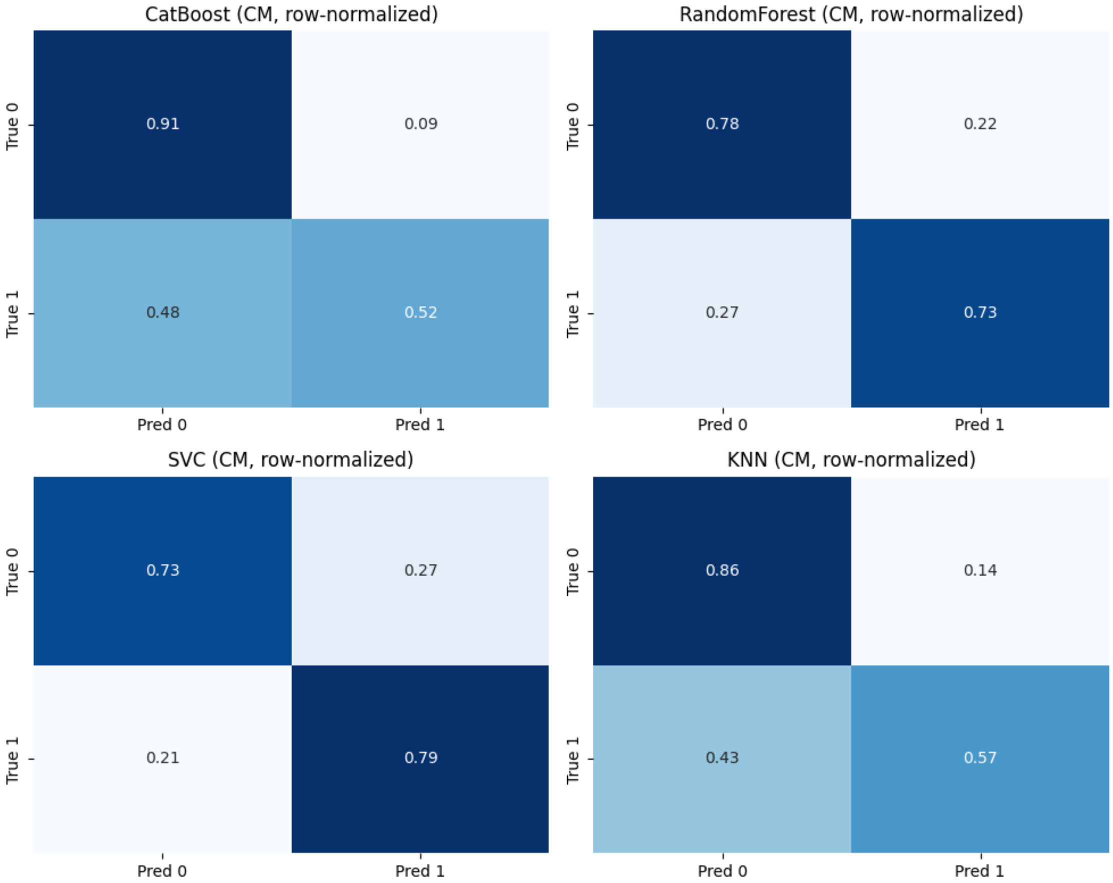
```
plt.plot(fpr, tpr, label=f"KNN (AUC = {auc(fpr, tpr):.3f})")

plt.plot([0, 1], [0, 1], "k--", alpha=0.5)
plt.xlabel("False Positive Rate")
plt.ylabel("True Positive Rate")
plt.title("ROC-           ")
plt.legend()
plt.grid(alpha=0.3)
plt.show()
```



ROC- , CatBoost , RandomForest . SVC KNN
, . AUC, , .

Precision-matrix

```
[105]: def plot_cm(ax, y_true, y_pred, title, normalize=True):
           cm = confusion_matrix(y_true, y_pred, labels=[0,1])
           if normalize:
               cm = cm.astype(float) / cm.sum(axis=1, keepdims=True)
           sns.heatmap(cm, annot=True, fmt=".2f" if normalize else "d",
                       cmap="Blues", cbar=False, ax=ax,
                       xticklabels=["Pred 0","Pred 1"], yticklabels=["True 0","True␣
        ↪1"])
           ax.set_title(title)
           ax.set_xlabel("")
           ax.set_ylabel("")

       y_pred_cat = model_cat.predict(Pool(X_test, cat_features=cat_features_idx))
       y_pred_rf  = best_rf.predict(X_test)
       y_pred_svc = best_svc.predict(X_test)
       y_pred_knn = best_knn.predict(X_test)

       fig, axes = plt.subplots(2, 2, figsize=(10, 8))
       axes = axes.ravel()

       plot_cm(axes[0], y_test, y_pred_cat, "CatBoost (CM, row-normalized)")
       plot_cm(axes[1], y_test, y_pred_rf,  "RandomForest (CM, row-normalized)")
       plot_cm(axes[2], y_test, y_pred_svc, "SVC (CM, row-normalized)")
       plot_cm(axes[3], y_test, y_pred_knn, "KNN (CM, row-normalized)")

       plt.tight_layout()
       plt.show()
```

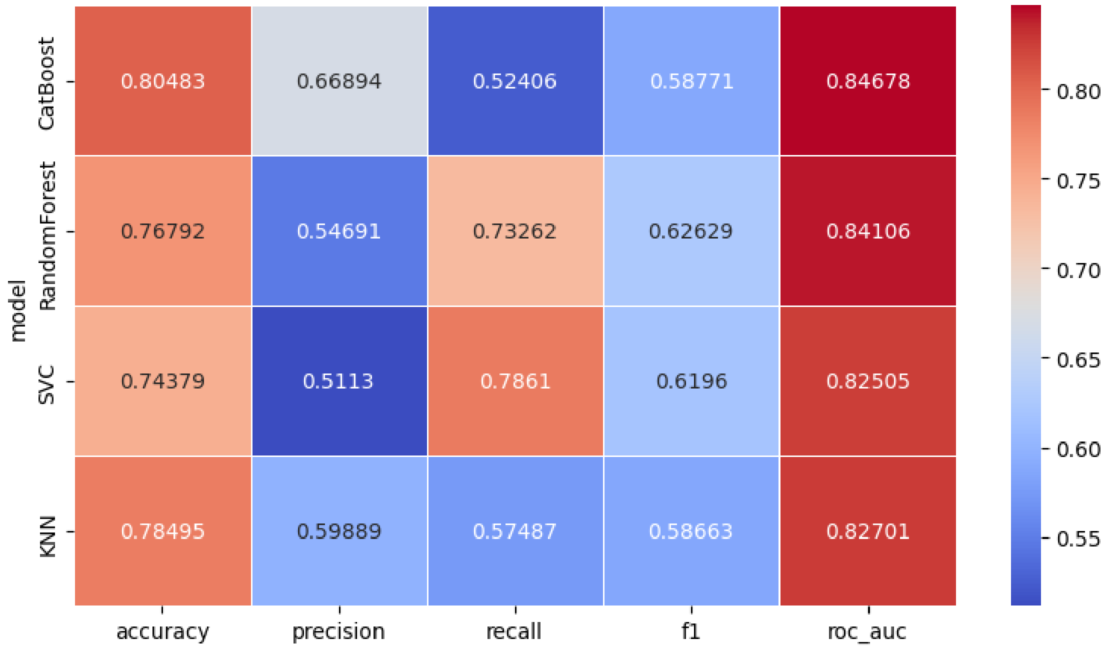


RandomForest SVC , (True 1), CatBoost KNN
(True 0). precision recall .

, heatmap

[106]:

```
df_hm = df_results.copy()
df_hm = df_hm.set_index("model")

plt.figure(figsize=(8, 4.5))

sns.heatmap(
    df_hm,
    annot=True,
    fmt='.5g',
    cmap="coolwarm",
    linewidths=.5,
    cbar=True
)

plt.tight_layout()
plt.show()
```



CatBoost ROC-AUC precision, RandomForest SVC , (recall). , CatBoost.

CatBoost - , , Telco Customer Churn . RandomForest, SVC KNN, CatBoost One-Hot , target-based (ordinal / target statistics), . .

, CatBoost , . Ordered Boosting , .