Predicting academic success of undergraduate students

by Catherine Meng, Jenson Chang, Jingyuan Wang, Siddarth Subrahmanian 2024/11/23

In [1]:
```
import pandas as pd
import altair as alt
from sklearn.model_selection import train_test_split
from sklearn.preprocessing import StandardScaler, OneHotEncoder
from sklearn.compose import make_column_transformer
from sklearn.pipeline import make_pipeline
from sklearn.neighbors import KNeighborsClassifier
from sklearn.model_selection import RandomizedSearchCV
from scipy.stats import randint
```

Summary

In this analysis, we attempt to build a classification model using the k-nearest neighbors algorithm to predict student dropout and academic success based on information available at enrollment (including academic path, demographics, and socio-economic factors). Our final classifier performed consistently on unseen test data, achieving a cross-validation training score of 0.71, with a similar test score. Although the model's accuracy is moderate, it performs consistently. Given that the data was collected from a single institution, a larger dataset may be necessary to generalize predictions to other institutions or countries. We believe this model is close to supporting dropout prediction for the institution from which the data was collected, though further research to improve performance and better understand characteristics of incorrectly predicted students would still be beneficial.

Introduction

Higher education institutions worldwide face the ongoing challenge of academic dropout and student failure, which affect not only individual students' futures but also the institution's reputation and resources. The ability to predict and anticipate students' potential difficulties is valuable not only for supporting individual students in achieving their goals but also for institutions aiming to implement strategies that support and guide students who may be at risk of academic failure or dropout.

The goal of this analysis is to help reduce academic dropout and failure in higher education by applying machine learning techniques to identify at-risk students early in their academic journey, enabling institutions to implement targeted support strategies.

Methods

Data

The data set is created by Mónica Vieira Martins, Jorge Machado, Luís Baptista and Valentim Realinho at the Instituto Politécnico de Portalegre (M.V.Martins, D. Tolledo, J. Machado, L. M.T. Baptista, V.Realinho. 2021). It is sourced from UC Irvine's Machine Learning Repository and can be found here. The data contains demographic, enrollment and academic (1st and 2nd semesters) information on the students. Each row in the data set represents a student record. Using these data, a model would be built to predict the academic outcome of the student. There are 36 columns in total.

Analysis

The k-nearest neighbors (k-nn) algorithm was used to build a classification model to predict whether a student is at risk of dropping out. All variables included in the original data set, with the exception of the Course, Nacionality, Gender, Unemployment rate, Inflation rate, GDP, Previous qualification, Mother qualification Mother occupation, Father qualification, Father occupation columns were used to fit the model. Data was split with 80% being partitioned into the training set and 20% being partitioned into the test set. The hyperparameter K was chosen using 5-fold cross validation. All numeric features were standardized just prior to model fitting. We leave the categorical features as they are because they all have integer data type.

Results & Discussion

To look at whether each of the predictors might be useful to predict the tumour class, we plotted the distributions of each predictor from the training data set and coloured the distribution by class (Dropout: blue, Enrolled: orange, and Graduate: red).

In [2]:
```
# Import and split data
df = pd.read_csv('../data/raw/data.csv', delimiter = ';')
train, test = train_test_split(df, train_size = 0.8, random_state = 123)
```

In [3]:
```
train.nunique()
```

Out[3]:
```
Marital status                                    6
Application mode                                 17
Application order                                 7
Course                                           17
Daytime/evening attendance\t                      2
Previous qualification                           17
Previous qualification (grade)                   97
Nacionality                                      21
Mother's qualification                           29
Father's qualification                           30
Mother's occupation                              31
Father's occupation                              44
Admission grade                                 585
Displaced                                         2
Educational special needs                         2
Debtor                                            2
Tuition fees up to date                           2
Gender                                            2
Scholarship holder                                2
Age at enrollment                                46
International                                     2
Curricular units 1st sem (credited)              21
Curricular units 1st sem (enrolled)              22
Curricular units 1st sem (evaluations)           34
Curricular units 1st sem (approved)              22
Curricular units 1st sem (grade)                693
Curricular units 1st sem (without evaluations)   11
Curricular units 2nd sem (credited)              19
Curricular units 2nd sem (enrolled)              21
Curricular units 2nd sem (evaluations)           29
Curricular units 2nd sem (approved)              20
Curricular units 2nd sem (grade)                685
Curricular units 2nd sem (without evaluations)   10
Unemployment rate                                10
Inflation rate                                    9
GDP                                              10
Target                                            3
dtype: int64
```

In [4]:
```
# Remove extra '\t' from the column name
train.rename(columns = {"Daytime/evening attendance\t" : "Daytime/evening at
test.rename(columns = {"Daytime/evening attendance\t" : "Daytime/evening att

# Remove ' from column name to prevent issues with Altair plots
train.columns = train.columns.str.replace("'s", "", regex=False)
test.columns = test.columns.str.replace("'s", "", regex=False)
```

In [5]:
```
# Group feature types based on feature description from source data
categorical_features = ["Application order", "Course", "Nacionality", "Gende
                        "Marital status", "Application mode", "Daytime/eveni
                        "Previous qualification", "Mother qualification",  "
                        "Father qualification", "Father occupation", "Displa
                        "Educational special needs", "Debtor", "Tuition fees
                        "Scholarship holder", "International"]
```

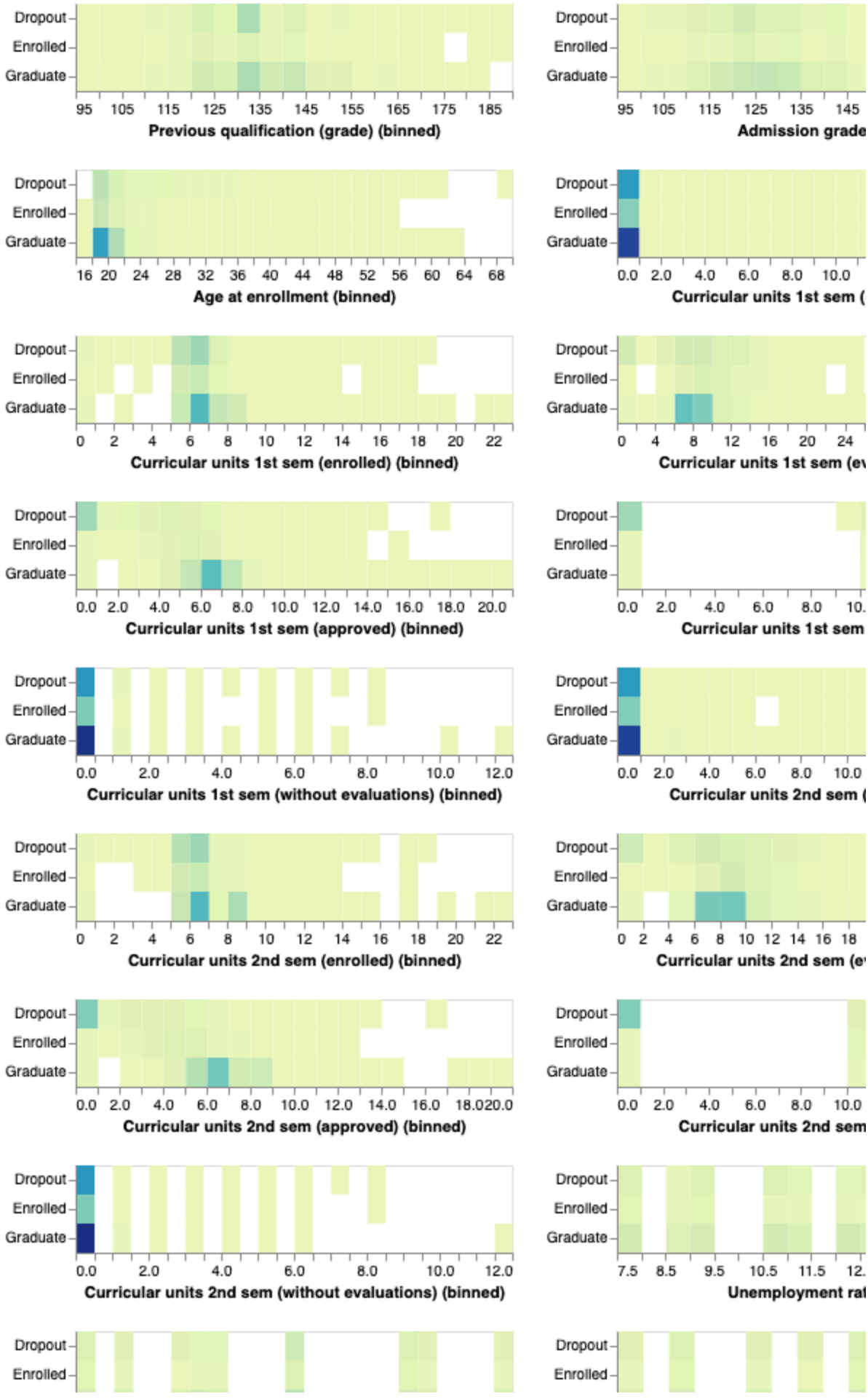
```
numeric_features = ["Previous qualification (grade)", "Admission grade", "Ag
                    "Curricular units 1st sem (credited)", "Curricular uni
                    "Curricular units 1st sem (evaluations)", "Curricular
                    "Curricular units 1st sem (grade)", "Curricular units
                    "Curricular units 2nd sem (credited)", "Curricular uni
                    "Curricular units 2nd sem (evaluations)", "Curricular
                    "Curricular units 2nd sem (grade)", "Curricular units
                    "Unemployment rate", "Inflation rate", "GDP"]

# len(categorical_features) + len(continuous_features) + len(boolean_feature
```

In [6]:

```
# Plot numerical features
alt.Chart(train).mark_rect().encode(
    x = alt.X(alt.repeat()).bin(maxbins=30),
    y = alt.Y('Target', title=None),
    color = 'count()'
).repeat(
    numeric_features,
    columns = 2
)
```

Out[6]:


Dropout
Enrolled
Graduate
95 105 115 125 135 145 155 165 175 185
Previous qualification (grade) (binned)
95 105 115 125 135 145
Admission grade
16 20 24 28 32 36 40 44 48 52 56 60 64 68
Age at enrollment (binned)
0.0 2.0 4.0 6.0 8.0 10.0
Curricular units 1st sem (
0 2 4 6 8 10 12 14 16 18 20 22
Curricular units 1st sem (enrolled) (binned)
0 4 8 12 16 20 24
Curricular units 1st sem (ev
0.0 2.0 4.0 6.0 8.0 10.0 12.0 14.0 16.0 18.0 20.0
Curricular units 1st sem (approved) (binned)
0.0 2.0 4.0 6.0 8.0 10.
Curricular units 1st sem
0.0 2.0 4.0 6.0 8.0 10.0 12.0
Curricular units 1st sem (without evaluations) (binned)
0.0 2.0 4.0 6.0 8.0 10.0
Curricular units 2nd sem (
0 2 4 6 8 10 12 14 16 18 20 22
Curricular units 2nd sem (enrolled) (binned)
0 2 4 6 8 10 12 14 16 18
Curricular units 2nd sem (ev
0.0 2.0 4.0 6.0 8.0 10.0 12.0 14.0 16.0 18.0 20.0
Curricular units 2nd sem (approved) (binned)
0.0 2.0 4.0 6.0 8.0 10.0
Curricular units 2nd sem
0.0 2.0 4.0 6.0 8.0 10.0 12.0
Curricular units 2nd sem (without evaluations) (binned)
7.5 8.5 9.5 10.5 11.5 12.
Unemployment rat

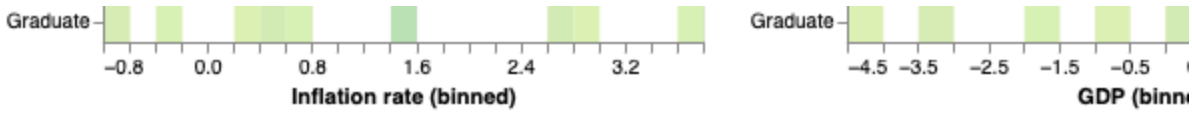
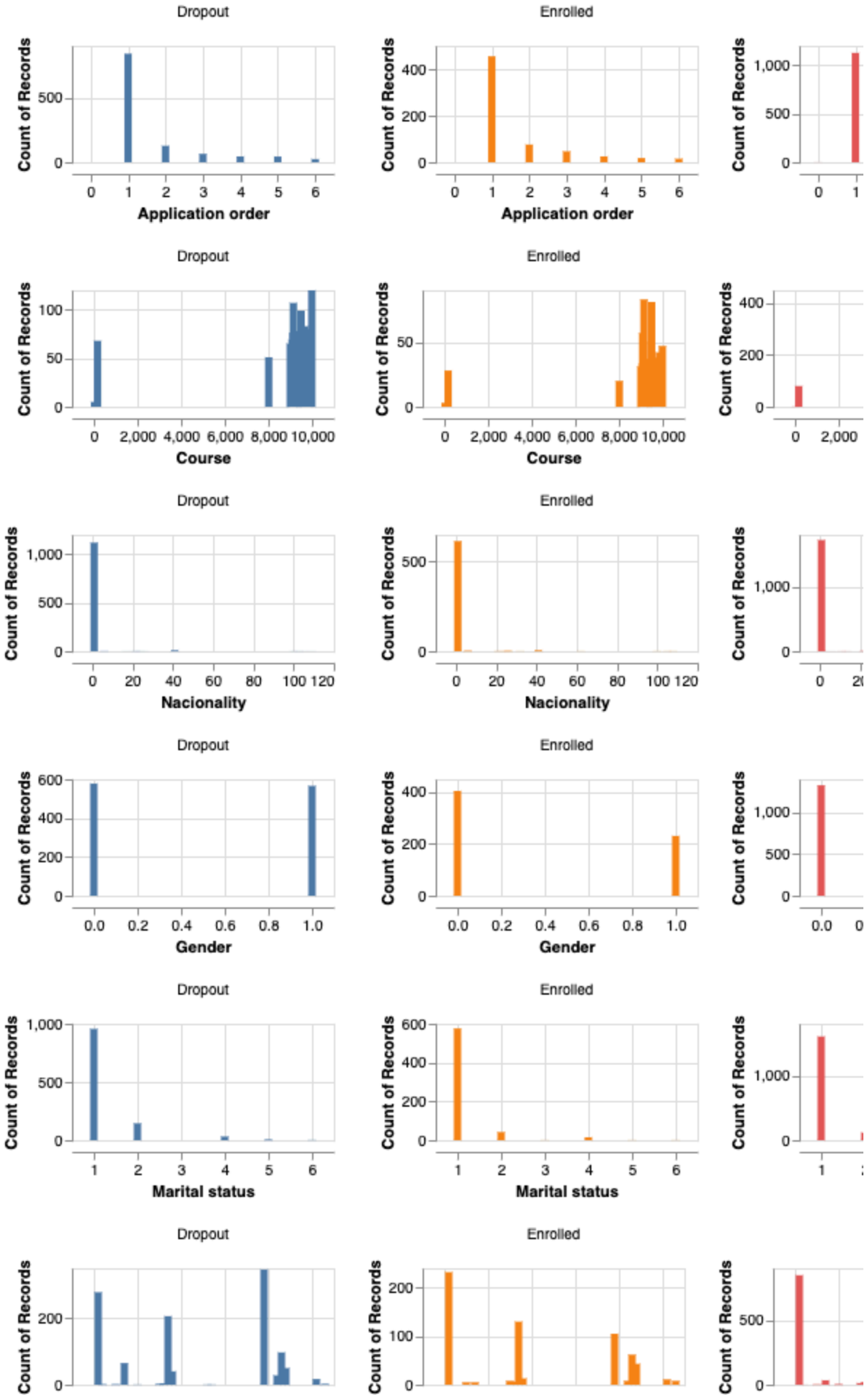
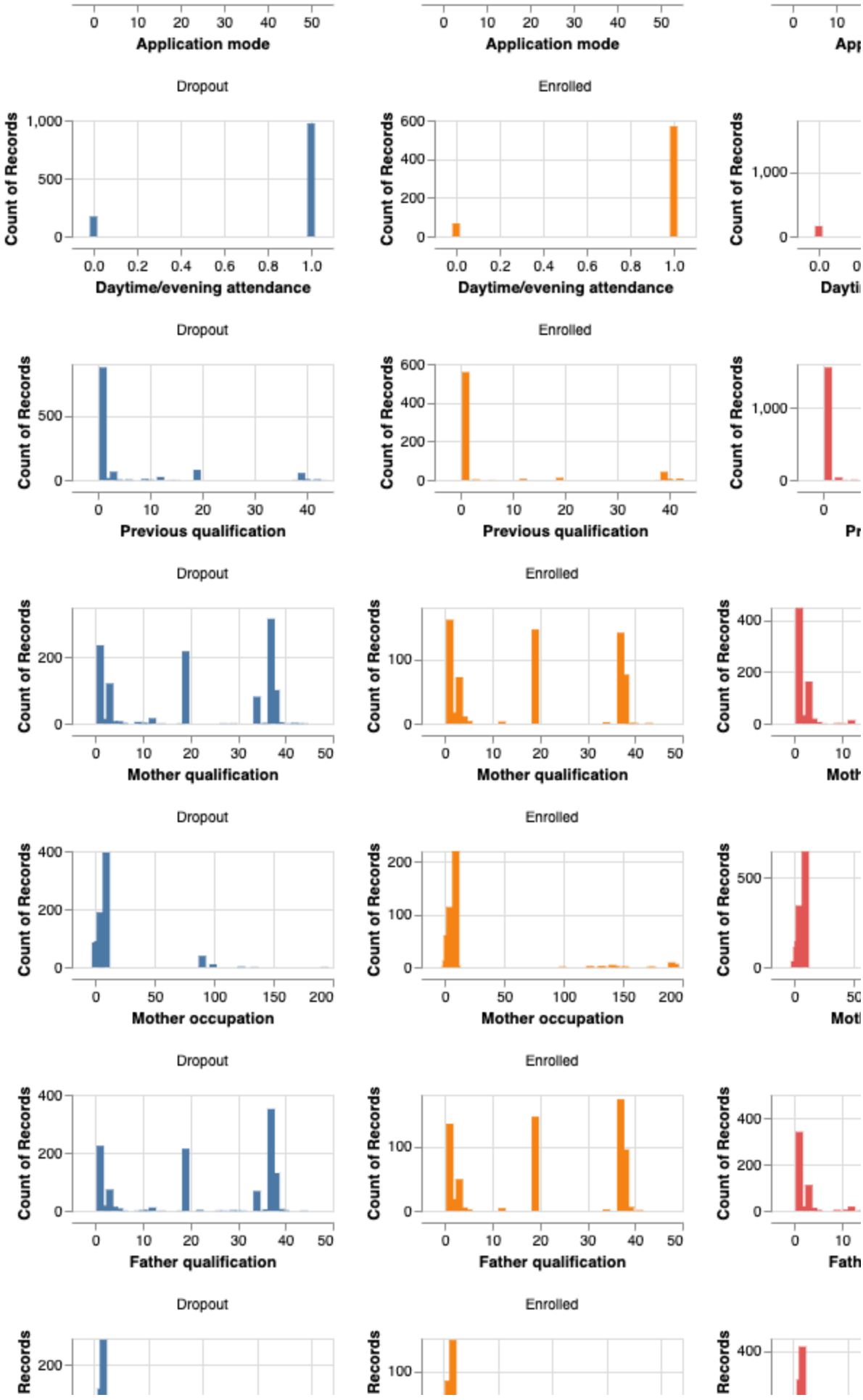


Figure 1. Distribution of Numerical Variable per Academic Outcome

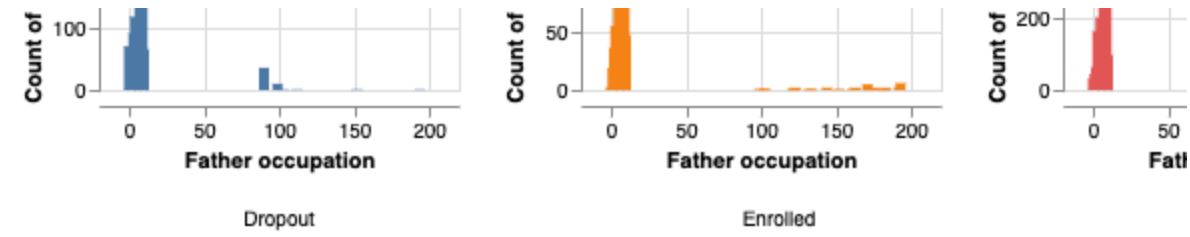
In [7]:
```
# Plot categorical and boolean features
alt.Chart(train).mark_bar().encode(
    x = alt.X(alt.repeat()).type('quantitative'),
    y = 'count()',
    column = alt.Column('Target', title=None),
    color = 'Target'
).properties(
    width = 180,
    height = 80
).resolve_scale(
    y = 'independent'
).repeat(
    categorical_features,
    columns = 1
)
```

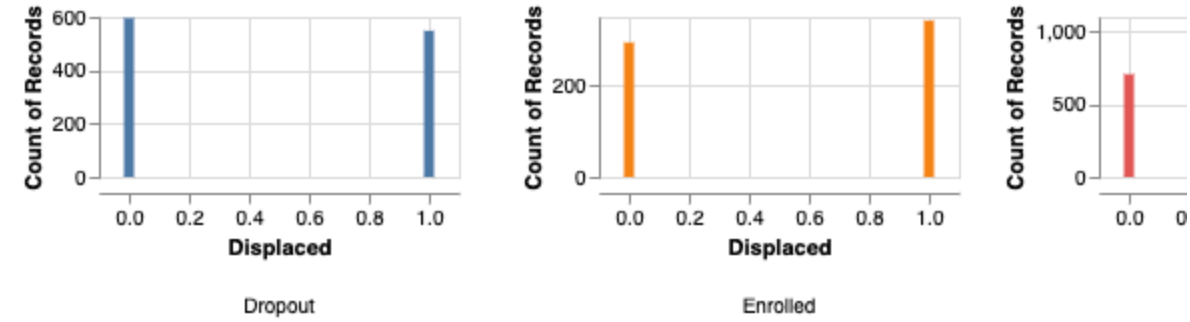
Out[7]:

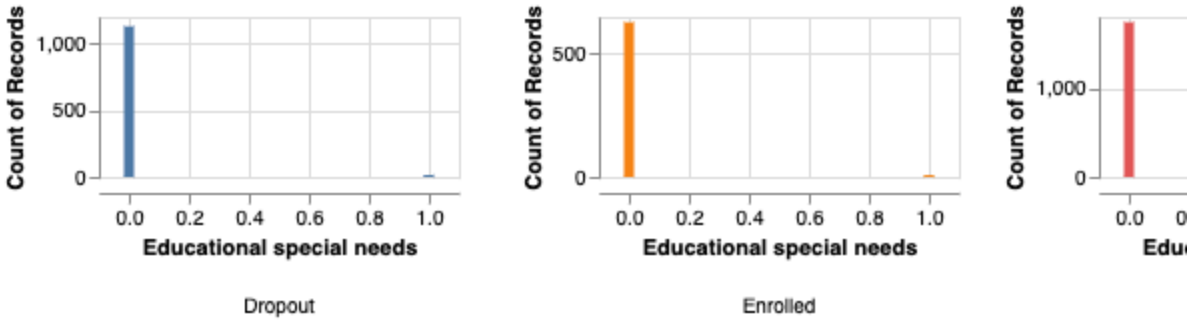

Dropout
Enrolled
Count of Records
Application order
Course
Nacionality
Gender
Marital status


Application mode
Application mode
Dropout
Enrolled
Count of Records
Daytime/evening attendance
Daytime/evening attendance
Dropout
Enrolled
Previous qualification
Previous qualification
Dropout
Enrolled
Mother qualification
Mother qualification
Dropout
Enrolled
Mother occupation
Mother occupation
Dropout
Enrolled
Father qualification
Father qualification
Dropout
Enrolled
Records

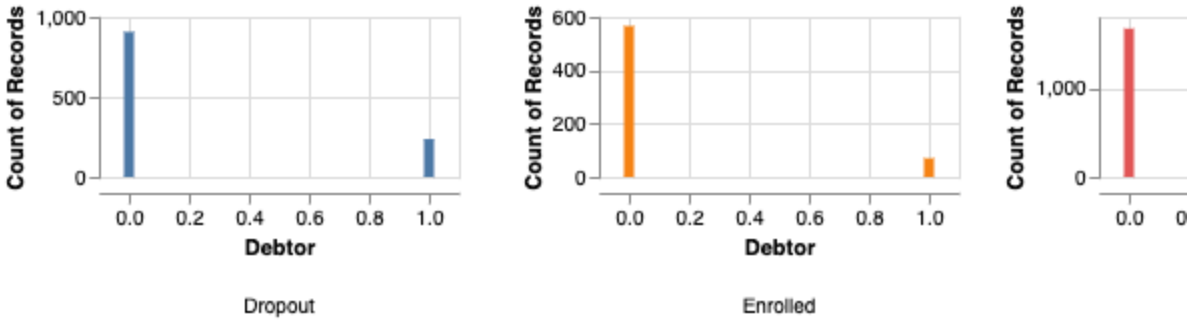
In [8]:



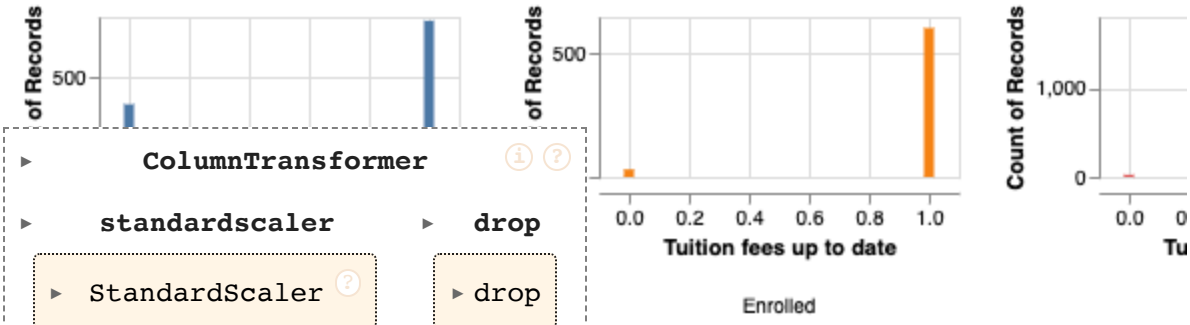




In [9]:



Out[9]:



ColumnTransformer

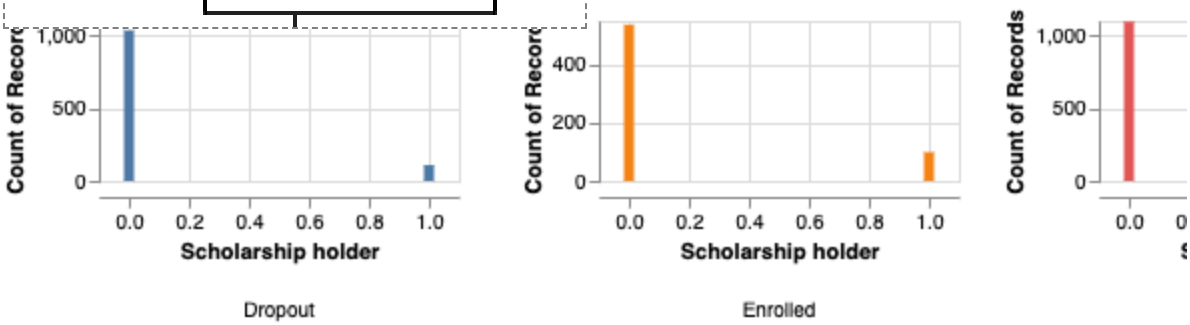
standardscaler

StandardScaler

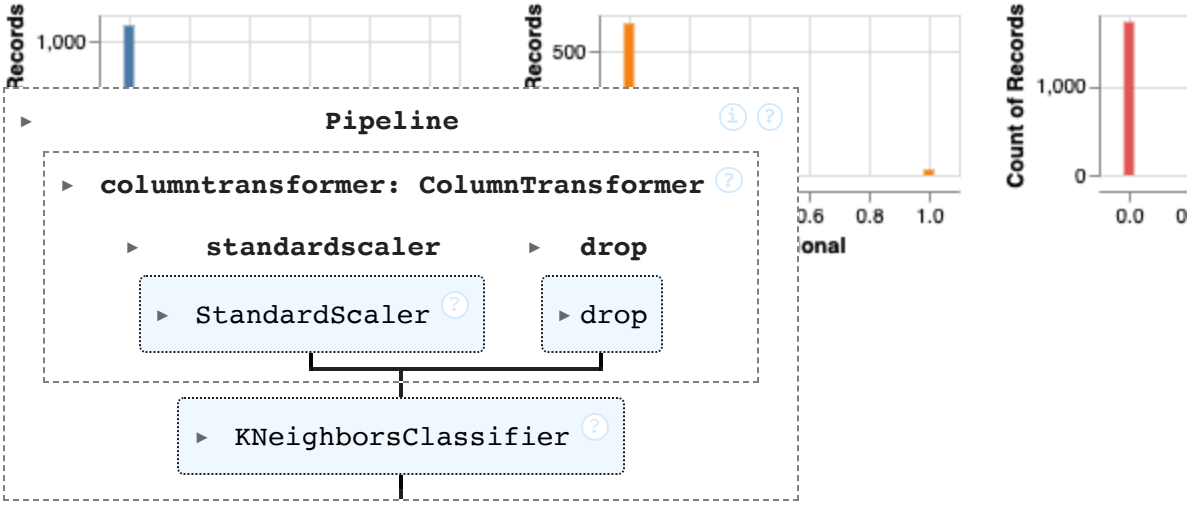
drop

drop

In [10]:



Out[10]:



In [11]:

```
# use RandomizedSearchCV to tune hyperparameters

param_distributions = {
    'kneighborsclassifier__n_neighbors': randint(1, 30)
}

random_search = RandomizedSearchCV(
    estimator=my_pipeline,
    param_distributions=param_distributions,
    n_iter=50,
    cv=5,
    scoring='accuracy',
    random_state=42,
    n_jobs=-1
)

random_search.fit(X_train, y_train)

print("Best Parameters:", random_search.best_params_)
print("Best CV Accuracy:", random_search.best_score_)
```

```
Best Parameters: {'kneighborsclassifier__n_neighbors': 17}
Best CV Accuracy: 0.7143280671892855
```

We utilized the KNN to train the dataset and employed RandomizedSearchCV to fine-tune the hyperparameters. Based on the results, the optimal hyperparameter value is k=12, achieving a best cross-validation score of 0.71. Using this value, we retrained the model and evaluated its performance on the test set, obtaining a final test score of 0.71.

In [12]:

```
my_pipeline_best = make_pipeline(
    preprocessor,
    KNeighborsClassifier(n_neighbors=12)
)

my_pipeline_best.fit(X_train, y_train)

test_score = my_pipeline_best.score(X_test, y_test)
print(f"Test accuracy: {test_score}")
```

```
Test accuracy: 0.7129943502824859
```

References

1. Martins, M. V., D. Tolledo, J. Machado, L. M. T. Baptista, and V. Realinho. “Early Prediction of Student’s Performance in Higher Education: A Case Study.” In Trends and Applications in Information Systems and Technologies, vol. 1, Advances in Intelligent Systems and Computing series. Springer, 2021. https://archive.ics.uci.edu/dataset/697/predict+students+dropout+and+academic+succ DOI: 10.1007/978-3-030-72657-7_16.

2. Scikit-learn Developers. “Scikit-learn: Machine Learning in Python – API Reference Documentation.” Accessed November 20, 2024. https://scikit-learn.org/dev/api/index.html.

3. Vega-Altair Developers. “Altair User Guide.” Accessed November 20, 2024. https://altair-viz.github.io/user_guide/data.html#.

4. Timbers, T., J. Ostblom, and M. Lee. “Predicting Breast Cancer from Digitized Images of Breast Mass.” Accessed November 21, 2024. https://github.com/ttimbers/breast-cancer-predictor/blob/0.0.1/notebooks/breast_cancer_predictor_report.ipynb.