

Binary classification

This lecture is about binary classification in a discrete space. We will setup a ML processing pipeline to achieve our goals. The dataset relates to the domain of banking industry, specifically about credit-cards (fraud detection and/or consuming profile)

ML pipelines

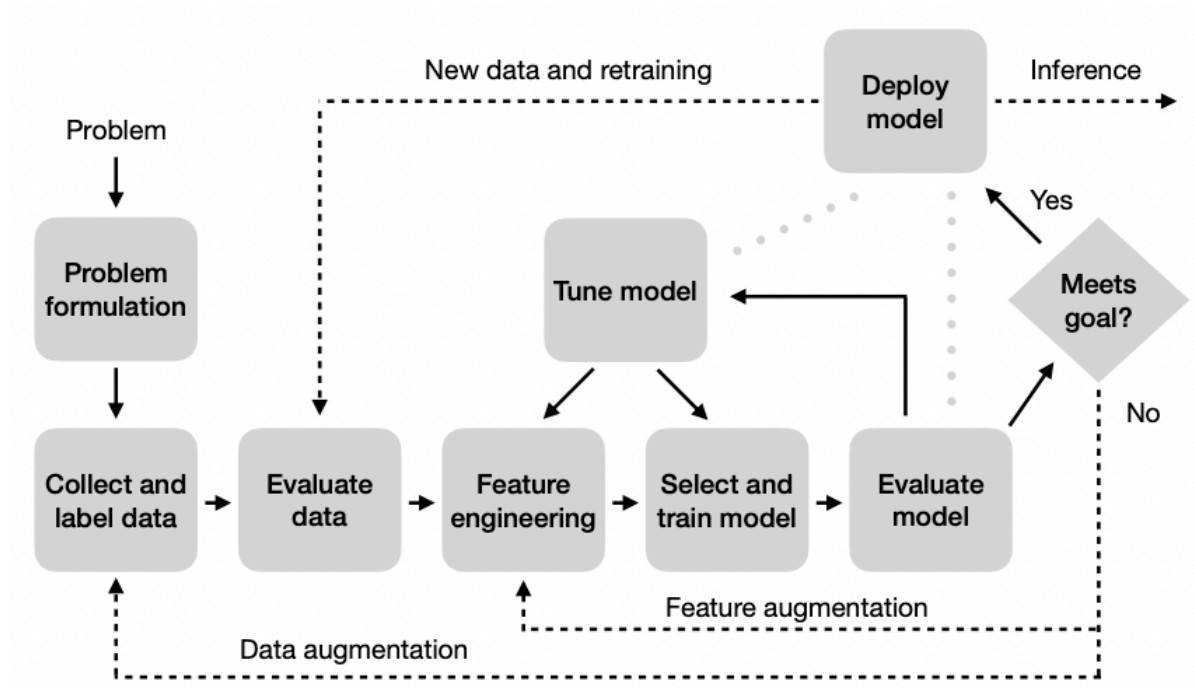
As stated in the Spark's programming guide, **"ML Pipelines provide a uniform set of high-level APIs built on top of DataFrames that help users create and tune practical machine learning pipelines."**

Hence, it is possible to combine multiple algorithms into a single pipeline, or workflow. Besides DataFrames, it involves the following:

1. Transformer: an algorithm which can transform one DataFrame into another DataFrame. For example, an ML model is a Transformer which transforms a DataFrame with features into a DataFrame with predictions.
2. Estimator: an algorithm which can be fit on a DataFrame to produce a Transformer. For example, a learning algorithm is an Estimator which trains on a DataFrame and produces a model.
3. Pipeline: the way to chain multiple Transformers and Estimators together to specify an ML workflow.
4. Parameter: all Transformers and Estimators share a common API for specifying parameters.

Further details can be found in <http://spark.apache.org/docs/latest/ml-pipeline.html>

Recall that, in general, a typical ML workflow is designed to work as depicted below:



Problem formulation

This exercise is about credit card fraud detection. Our case-study is based on a Kaggle dataset that has been generated by Erik

Altman, who was aiming to provide realistic synthetic data about credit card transactions. Details can be found in <https://www.kaggle.com/datasets/ealtman2019/credit-card-transactions> .

In the end, it is a binary classification problem.

Basically, the functional requirements for the Spark program we are about to create are as follows:

1. To load the dataset under analysis and making sure it can be further processed by a ML classifier.
2. To create a classification model supported by a SVM algorithm that is fit for the purpose.
3. To evaluate the quality of the classifier that has been built.

As for data availability, you can find the archive **credit-card-transaction.zip** in the location mentioned in the Moodle's PMBD page.

Context

There is no great availability of credit card transaction data for training fraud detection models and other uses, such as analyzing similar purchase patterns. Indeed, this type of data is critical to the owners like banks and alike, but quite understandably it would not be made public. (And if so, with few transactions and short time-span)

Market data

This set of data has more than 20 million transactions generated from a multi-agent virtual world simulation performed by IBM. The data covers 2000 (synthetic) consumers resident in the United States, but who travel the world. The data also covers decades of purchases, and includes multiple cards from many of the consumers.

Analyses of the data suggest that it is a reasonable match for real data in many dimensions, e.g. fraud rates, purchase amounts, Merchant Category Codes (MCCs), and other metrics. In addition, all columns except merchant name have their "natural" value. Such natural values can be helpful in feature engineering of models.

F1 (F-score or F-measure) will provide a useful score for models predicting whether a particular transaction is fraudulent or not.

Notice that there are three files available, respectively with information about cards, users and transactions.

If we need to install some packages, e.g. matplotlib # Better execute the commands in a Terminal # # ! pip3 install matplotlib, seaborn

Initial settings

Prior to any computation, let us set some imports and useful functions

Additional packages and imports

```
In [1]: # Some general imports

import os
import sys

import numpy as np
import pandas as pd

import matplotlib.pyplot as plt
import seaborn as sns

# from ydata_profiling import ProfileReport
import warnings
warnings.filterwarnings("ignore")
```

Useful visualization functions

Some functions that we can use to plot data but as Python dataframes.

Disclaimer: these functions are broadly distributed among users. Further adjustments are needed and/or advisable. Feel free to use your own plotting functions. See <https://seaborn.pydata.org/>

Remember: "A picture is worth a thousand words"

```

In [2]: def plotLine(df, xcol, ycol):
        return sns.lineplot(data=df, x=xcol, y=ycol)

In [3]: def plotBar(df, xcol, ycol, huecol=None):
        return sns.barplot(data=df, x=xcol, y=ycol, hue=huecol)

In [4]: def plotScatter(df, xcol, ycol, huecol=None):
        return sns.scatterplot(data=df, x=xcol, y=ycol, hue=huecol)

In [5]: def plotScatterMatrix(df, huecol=None):
        return sns.pairplot(data=df, hue=huecol)

In [6]: def plotCorrelationMatrix(df, annot=False):
        # compute the correlation matrix
        corr = df.corr()

        # generate a mask for the upper triangle
        mask = np.triu(np.ones_like(corr, dtype=bool))

        # set up the matplotlib figure
        f, ax = plt.subplots(figsize=(11, 9))

        # generate a custom colormap
        #cmap = sns.divergent_palette(230, 20, as_cmap=True)

        cmap='coolwarm'

        # draw the heatmap with the mask and correct aspect ratio
        return sns.heatmap(corr, mask=mask, cmap=cmap, vmax=.3, center=0, annot=annot,
                           square=True, linewidths=.5, cbar_kws={"shrink": .5})

In [7]: def plotBox(df, xcol, ycol, huecol=None, kind='box'):
        return sns.catplot(data=df, x=xcol, y=ycol, hue=huecol, kind=kind)

```

Collect and label data

Data ingestion

Checking working directory and data files

```
# ! pwd # ! ls -la credit-card-transactions
```

```

In [8]: ! head -n 2 credit-card-transactions/sd254_cards.csv
        ! tail -n 1 credit-card-transactions/sd254_cards.csv

User,CARD INDEX,Card Brand,Card Type,Card Number,Expires,CVV,Has Chip,Cards Issued,Credit Limit,Acct Open Date,Y
ear PIN last Changed,Card on Dark Web
0,0,Visa,Debit,4344676511950444,12/2022,623,YES,2,$24295,09/2002,2008,No
1999,1,Visa,Credit,4994011318343994,12/2020,120,YES,1,$14400,05/2017,2017,No

In [9]: ! head -n 2 credit-card-transactions/sd254_users.csv
        ! tail -n 1 credit-card-transactions/sd254_users.csv

Person,Current Age,Retirement Age,Birth Year,Birth Month,Gender,Address,Apartment,City,State,Zipcode,Latitude,Lo
ngitude,Per Capita Income - Zipcode,Yearly Income - Person,Total Debt,FICO Score,Num Credit Cards
Hazel Robinson,53,66,1966,11,Female,462 Rose Lane,,La Verne,CA,91750,34.15,-117.76,$29278,$59696,$127613,787,5
Kenia Harris,21,60,1998,11,Female,472 Ocean View Street,,Merrimack,NH,03054,42.86,-71.48,$32325,$65909,$181261,6
73,2

In [10]: ! head -n 2
         ! tail -n 1

User,Card,Year,Month,Day,Time,Amount,Use Chip,Merchant Name,Merchant City,Merchant State,Zip,MCC,Errors?,Is Frau
d?
0,0,2002,9,1,06:21,$134.09,Swipe Transaction,3527213246127876953,La Verne,CA,91750.0,5300,,No
1999,1,2020,2,28,23:10,$45.13,Chip Transaction,4751695835751691036,Merrimack,NH,3054.0,5814,,No

```

```
In [11]: # Some Spark related imports we will use hereafter

import sys

from pyspark.sql import SparkSession
import pyspark.sql.functions as F
from pyspark.sql.types import *

from pyspark.ml import Pipeline
from pyspark.ml.stat import Correlation
from pyspark.ml.feature import VectorAssembler, StringIndexer, OneHotEncoder
from pyspark.ml.classification import LinearSVC
from pyspark.ml.evaluation import BinaryClassificationEvaluator
```

Build a SparkSession instance if one does not exist. We can only have one per JVM. # Notice however that, when using a PySpark kernel, a default SparkSession has been created with # the name spark. But if we want to use different settings, then we have to create our own. spark = SparkSession\ .builder\ .appName("FireDepartmentCalls") \ .config("spark.sql.shuffle.partitions",6) \ .getOrCreate()

Reading the datasets

```
In [12]: filename = "credit-card-transactions/sd254_cards.csv"
df_cards = spark.read.csv(filename, header="true", inferSchema="true", sep=',')
```

```
In [13]: filename = "credit-card-transactions/sd254_users.csv"
df_users =
```

```
In [14]: # We may ask to inferSchema now, but later on we can provide the schema to speed up
# reading, as the file is quite big

filename = "credit-card-transactions/credit_card_transactions-ibm_v2.csv"
df_transactions =
```

Checking data

Schema, show and count

Cards

```
In [15]: # check the data - schema and count

df_cards.
df_cards.
cards_count =
cards_count
```

```

root
|-- User: integer (nullable = true)
|-- CARD INDEX: integer (nullable = true)
|-- Card Brand: string (nullable = true)
|-- Card Type: string (nullable = true)
|-- Card Number: long (nullable = true)
|-- Expires: string (nullable = true)
|-- CVV: integer (nullable = true)
|-- Has Chip: string (nullable = true)
|-- Cards Issued: integer (nullable = true)
|-- Credit Limit: string (nullable = true)
|-- Acct Open Date: string (nullable = true)
|-- Year PIN last Changed: integer (nullable = true)
|-- Card on Dark Web: string (nullable = true)

-RECORD 0-----
User                | 0
CARD INDEX          | 0
Card Brand          | Visa
Card Type           | Debit
Card Number         | 4344676511950444
Expires             | 12/2022
CVV                 | 623
Has Chip            | YES
Cards Issued        | 2
Credit Limit        | $24295
Acct Open Date      | 09/2002
Year PIN last Changed | 2008
Card on Dark Web    | No
only showing top 1 row

```

Out[15]: 6146

Users

```

In [16]: df_users.
df_users.
users_count =
users_count

```

```

root
|-- Person: string (nullable = true)
|-- Current Age: integer (nullable = true)
|-- Retirement Age: integer (nullable = true)
|-- Birth Year: integer (nullable = true)
|-- Birth Month: integer (nullable = true)
|-- Gender: string (nullable = true)
|-- Address: string (nullable = true)
|-- Apartment: integer (nullable = true)
|-- City: string (nullable = true)
|-- State: string (nullable = true)
|-- Zipcode: integer (nullable = true)
|-- Latitude: double (nullable = true)
|-- Longitude: double (nullable = true)
|-- Per Capita Income - Zipcode: string (nullable = true)
|-- Yearly Income - Person: string (nullable = true)
|-- Total Debt: string (nullable = true)
|-- FICO Score: integer (nullable = true)
|-- Num Credit Cards: integer (nullable = true)

-RECORD 0-----
Person              | Hazel Robinson
Current Age         | 53
Retirement Age     | 66
Birth Year          | 1966
Birth Month         | 11
Gender              | Female
Address             | 462 Rose Lane
Apartment           | null
City                | La Verne
State               | CA
Zipcode             | 91750
Latitude            | 34.15
Longitude           | -117.76

```

```
Per Capita Income - Zipcode | $29278
Yearly Income - Person     | $59696
Total Debt                 | $127613
FICO Score                 | 787
Num Credit Cards           | 5
only showing top 1 row
```

Out[16]: 2000

Transactions

```
In [17]: df_transactions.
df_transactions.
transactions_count =
transactions_count
```

```
root
|-- User: integer (nullable = true)
|-- Card: integer (nullable = true)
|-- Year: integer (nullable = true)
|-- Month: integer (nullable = true)
|-- Day: integer (nullable = true)
|-- Time: timestamp (nullable = true)
|-- Amount: string (nullable = true)
|-- Use Chip: string (nullable = true)
|-- Merchant Name: long (nullable = true)
|-- Merchant City: string (nullable = true)
|-- Merchant State: string (nullable = true)
|-- Zip: double (nullable = true)
|-- MCC: integer (nullable = true)
|-- Errors?: string (nullable = true)
|-- Is Fraud?: string (nullable = true)
```

-RECORD 0-----

User	0
Card	0
Year	2002
Month	9
Day	1
Time	2023-03-17 06:21:00
Amount	\$134.09
Use Chip	Swipe Transaction
Merchant Name	3527213246127876953
Merchant City	La Verne
Merchant State	CA
Zip	91750.0
MCC	5300
Errors?	null
Is Fraud?	No

only showing top 1 row

Out[17]: 24386900

Evaluate data

Let us get some data insight, with some **exploratory data analysis** based on descriptive statistics and visualizations.

Datatypes

There are problems in the dataframes regarding columns holding currency values: they have the dollar symbol so columns are considered as strings. Let us create new ones but correctly, that is, removing the dollar symbol and returning a float.

```
In [18]: # Auxiliar functions to remove the $ symbol

def get_amount(amount):
    return float(amount.split("$")[1])

udf_amount = F.udf(get_amount, FloatType())

In [19]: df_cards = ( df_cards
                    .withColumn('Credit Limit - OK',udf_amount(F.col('Credit Limit')))
                    )

In [20]: df_users = ( df_users
                    .withColumn('Correct Per Capita Income - Zipcode',udf_amount(F.col('Per Capita Income - Zipcode')))
                    .withColumn('Correct Yearly Income - Person',udf_amount(F.col('Yearly Income - Person')))
                    .withColumn('Correct Total Debt',udf_amount(F.col('Total Debt')))
                    )

In [21]: df_transactions = ( df_transactions
                            .withColumn('Correct Amount',udf_amount(F.col('Amount')))
                            )
```

```
In [ ]: # Check the changes made in cards, users and transactions,
        # with schema and showing 1st record

df_cards
```

Nulls

Identify number of nulls or NaN in columns.

```
In [23]: print('\nNulls in Cards:')
        cols_to_forget = ['Credit Limit']
        cards_cols_interest = [x for x in df_cards.columns if x not in cols_to_forget]
        for cl in cards_cols_interest:
            k = df_cards.select(cl).filter(F.col(cl).isNull() | F.isnan(cl)).count()
            if k > 0:
                print(f'Column {cl} with {k} nulls or NaN, out of {cards_count} records ({k*100/cards_count:.2f}%)')

Nulls in Cards:

In [24]: print('\nNulls in Users:')
        cols_to_forget = ['Per Capita Income - Zipcode', 'Yearly Income - Person', 'Total Debt']

Nulls in Users:
Column Apartment with 1472 nulls or NaN, out of 2000 records (73.60%)

In [25]: # Taking the decision to forget it right now (but not deleting)

users_cols_interest.remove('Apartment')
```

```
In [26]: print('\nNulls in Transactions:')
        cols_to_forget = ['Amount']
        transactions_cols_interest =
        for cl in
            if (cl == 'Time'):
                k = df_transactions.select(cl).filter(F.col(cl).isNull()).count()
            else:
```

Nulls in Transactions:

Column Merchant State with 2720821 nulls or NaN, out of 24386900 records (11.16%)

Column Zip with 2878135 nulls or NaN, out of 24386900 records (11.80%)

Column Errors? with 23998469 nulls or NaN, out of 24386900 records (98.41%)

```
In [27]: # Taking the decision to forget it right now (but not deleting)

        transactions_cols_interest.remove('Errors?')
```

Summary to figure out outliers

Summary of values for columns of interest. Use of describe() or summary()

```
In [ ]: df_cards.
```

```
In [ ]: df_users.
```

```
In [30]: # ... notice that dataframe is big
        # df_transactions.describe(transactions_cols_interest).show(vertical=True)
```

Uniqueness

Find unique values for columns of interest.

Collected information can be helpful to guide us to further investigating columns of concern.

```
In [31]: print('\nUniqueness in Cards:')
        for cl in cards_cols_interest:
            k =
            print(f'Column {cl} with {k} distinct values, out of {cards_count} records ({k*100/cards_count:.2f}%)')
```

Uniqueness in Cards:

Column User with 2000 distinct values, out of 6146 records (32.54%)

Column CARD INDEX with 9 distinct values, out of 6146 records (0.15%)

Column Card Brand with 4 distinct values, out of 6146 records (0.07%)

Column Card Type with 3 distinct values, out of 6146 records (0.05%)

Column Card Number with 6146 distinct values, out of 6146 records (100.00%)

Column Expires with 259 distinct values, out of 6146 records (4.21%)

Column CVV with 998 distinct values, out of 6146 records (16.24%)

Column Has Chip with 2 distinct values, out of 6146 records (0.03%)

Column Cards Issued with 3 distinct values, out of 6146 records (0.05%)

Column Acct Open Date with 303 distinct values, out of 6146 records (4.93%)

Column Year PIN last Changed with 19 distinct values, out of 6146 records (0.31%)

Column Card on Dark Web with 1 distinct values, out of 6146 records (0.02%)

Column Credit Limit - OK with 3654 distinct values, out of 6146 records (59.45%)

```
In [32]: print('\nUniqueness in Users:')
        for cl in users_cols_interest:
            k =
            print(f'Column {cl} with {k} distinct values, out of {users_count} records ({k*100/users_count:.2f}%)')
```


Uniqueness in Users:

- Column Person with 1993 distinct values, out of 2000 records (99.65%)
- Column Current Age with 80 distinct values, out of 2000 records (4.00%)
- Column Retirement Age with 29 distinct values, out of 2000 records (1.45%)
- Column Birth Year with 80 distinct values, out of 2000 records (4.00%)
- Column Birth Month with 12 distinct values, out of 2000 records (0.60%)
- Column Gender with 2 distinct values, out of 2000 records (0.10%)
- Column Address with 1999 distinct values, out of 2000 records (99.95%)
- Column City with 1286 distinct values, out of 2000 records (64.30%)
- Column State with 51 distinct values, out of 2000 records (2.55%)
- Column Zipcode with 1815 distinct values, out of 2000 records (90.75%)
- Column Latitude with 989 distinct values, out of 2000 records (49.45%)
- Column Longitude with 1224 distinct values, out of 2000 records (61.20%)
- Column FICO Score with 321 distinct values, out of 2000 records (16.05%)
- Column Num Credit Cards with 9 distinct values, out of 2000 records (0.45%)
- Column Correct Per Capita Income – Zipcode with 1754 distinct values, out of 2000 records (87.70%)
- Column Correct Yearly Income – Person with 1948 distinct values, out of 2000 records (97.40%)
- Column Correct Total Debt with 1880 distinct values, out of 2000 records (94.00%)

```
In [33]: print('\nUniqueness in Transactions:')
        for cl in transactions_cols_interest:
            k =
            print(f'Column {cl} with {k} distinct values, out of {transactions_count} records ({k*100/transactions_count})')
```

Uniqueness in Transactions:

- Column User with 2000 distinct values, out of 24386900 records (0.01%)
- Column Card with 9 distinct values, out of 24386900 records (0.00%)
- Column Year with 30 distinct values, out of 24386900 records (0.00%)
- Column Month with 12 distinct values, out of 24386900 records (0.00%)
- Column Day with 31 distinct values, out of 24386900 records (0.00%)
- Column Time with 1440 distinct values, out of 24386900 records (0.01%)

- Column Use Chip with 3 distinct values, out of 24386900 records (0.00%)
- Column Merchant Name with 100343 distinct values, out of 24386900 records (0.41%)
- Column Merchant City with 13429 distinct values, out of 24386900 records (0.06%)
- Column Merchant State with 224 distinct values, out of 24386900 records (0.00%)
- Column Zip with 27322 distinct values, out of 24386900 records (0.11%)
- Column MCC with 109 distinct values, out of 24386900 records (0.00%)
- Column Is Fraud? with 2 distinct values, out of 24386900 records (0.00%)
- [Stage 423:=====> (17 + 1) / 18]
- Column Correct Amount with 98952 distinct values, out of 24386900 records (0.41%)

Recall also that: Column Merchant State with 2720821 nulls or NaN, out of 24386900 records (11.16%) Column Zip with 2878135 nulls or NaN, out of 24386900 records (11.80%)

Feature Engineering

Now we have to prepare data in a way that it can be properly used by ML algorithms, which includes selection and extraction of features, as well as dealing with poor data quality if that is the case.

Hereafter we will use primarily credit card transactions, as the focus is on realising whether there is a credit card fraud or not.

Saving clean data

Saving data for further use if needed.

```
In [34]: # Drop columns that will not be used anymore (columns to forget)
# ... or select just the ones of interest

df_cards = df_cards.select(cards_cols_interest)
df_users = df_users.select(users_cols_interest)
df_transactions = df_transactions.select(transactions_cols_interest)
```

```
In [35]: # As we have a large dataset of transactions, we should also have a smaller one,
# just for the purpose of working locally

# and one should understand the implications of sampling

# from count= 24386900, 2.35GB to

seed = 5
with_replacement = False
fraction = 0.2 # reduce to 20%
small_df_transactions = df_transactions.sample(withReplacement=with_replacement,
                                                fraction=fraction, seed=seed)
small_df_transactions.count()
```

Out[35]: 4878276

```
In [ ]: # Save the smaller version to a file for future use in case of need

small_df_transactions.write.mode("overwrite").parquet("small-credit_card_transactions")

# and later on, we can use spark.read.parquet() to load files
```

```
In [ ]: # Also, it may be convenient to have the original data stored in
# the parquet format as well, now with the changes made.
# It will be the normal dataset to be used

df_cards.
df_users.
df_transactions.
```

Check in the running directory if that was accomplished # in the terminal! # ! ls -la
! ls -la small-credit_card_transactions
! ls -la eventually check the others files as well

Data to be used hereafter

Credit card transactions.

```
In [38]: df_clean = small_df_transactions
# df_clean = df_transactions
```

```
In [39]: # Delete memory consuming variables that are no longer needed

del df_cards, df_users
# del small_df_transactions
del df_transactions
```

Final overview

After establishing the clean data to be used, **df_clean**, let us get an overview about what we have achieved, with some statistics and visualizations. Now we may look at specific columns in more detail.

```
In [40]: # But first adding useful time related columns (derived data)

df_clean = ( df_clean
              .withColumn("Hour", F.hour(F.col('Time')))
              .withColumn("Min", F.minute(F.col('Time')))
              )
```

```
In [41]: transactions_count = df_clean.count()
transactions_count
```

Out[41]: 4878276

```
In [42]: # Transactions columns of interest
# Time is no longer needed,
# nor Errors?, which was checked above as not appropriate - too many nulls

cols_to_forget = ['Time', 'Errors?']
transactions_cols_interest =
transactions_cols_interest
```

```
Out[42]: ['User',
'Card',
'Year',
'Month',
'Day',
'Use Chip',
'Merchant Name',
'Merchant City',
'Merchant State',
'Zip',
'MCC',
'Is Fraud?',
'Correct Amount',
'Hour',
'Min']
```

Descriptive statistics about the data to be used in the model

See also results above regarding transactions in general (summary and uniqueness)

```
In [43]: print('\nNulls in Transactions:')
for cl in transactions_cols_interest:
```

Nulls in Transactions:

Column Merchant State with 545700 nulls or NaN, out of 4878276 records (11.19%)

Column Zip with 577192 nulls or NaN, out of 4878276 records (11.83%)

```
In [44]: # Some lists of columns for convenience

# few distincts
cls_1 = ['Card', 'Year', 'Month', 'Day', 'Use Chip', 'Is Fraud?']

# numeric types but no nulls
cls_2 = ['User', 'Card', 'Year', 'Month', 'Day', 'Merchant Name',
'MCC', 'Correct Amount', 'Hour', 'Min']
```

```
In [ ]: print('\nShowing few uniques in Transactions:')
for cl in cls_1:
```

Correlations

```

In [ ]: # Checking correlations among some columns
#
# Correlation needs vectors so we convert to vector column first
# See VectorAssembler in the Spark's documentation

# The columns to compute correlations - numeric types but no nulls
cols_corr = cls_2

# Assemble columns
vector_col = "corr_features"
assembler = VectorAssembler(inputCols=cols_corr, outputCol=vector_col)
df_vector = assembler.transform(df_clean).select(vector_col)

# Get correlation matrix - it can be Pearson's (default) or Spearman's correlation

# corr = Correlation.corr(df_vector, vector_col).head()
# print("Pearson correlation matrix:\n" + str(corr[0]))

# corr = Correlation.corr(df_vector, vector_col, "spearman").head()
# print("Spearman correlation matrix:\n" + str(corr[0]))

corr_matrix = Correlation.corr(df_vector, vector_col).collect()[0][0].toArray().tolist()
# corr_matrix

```

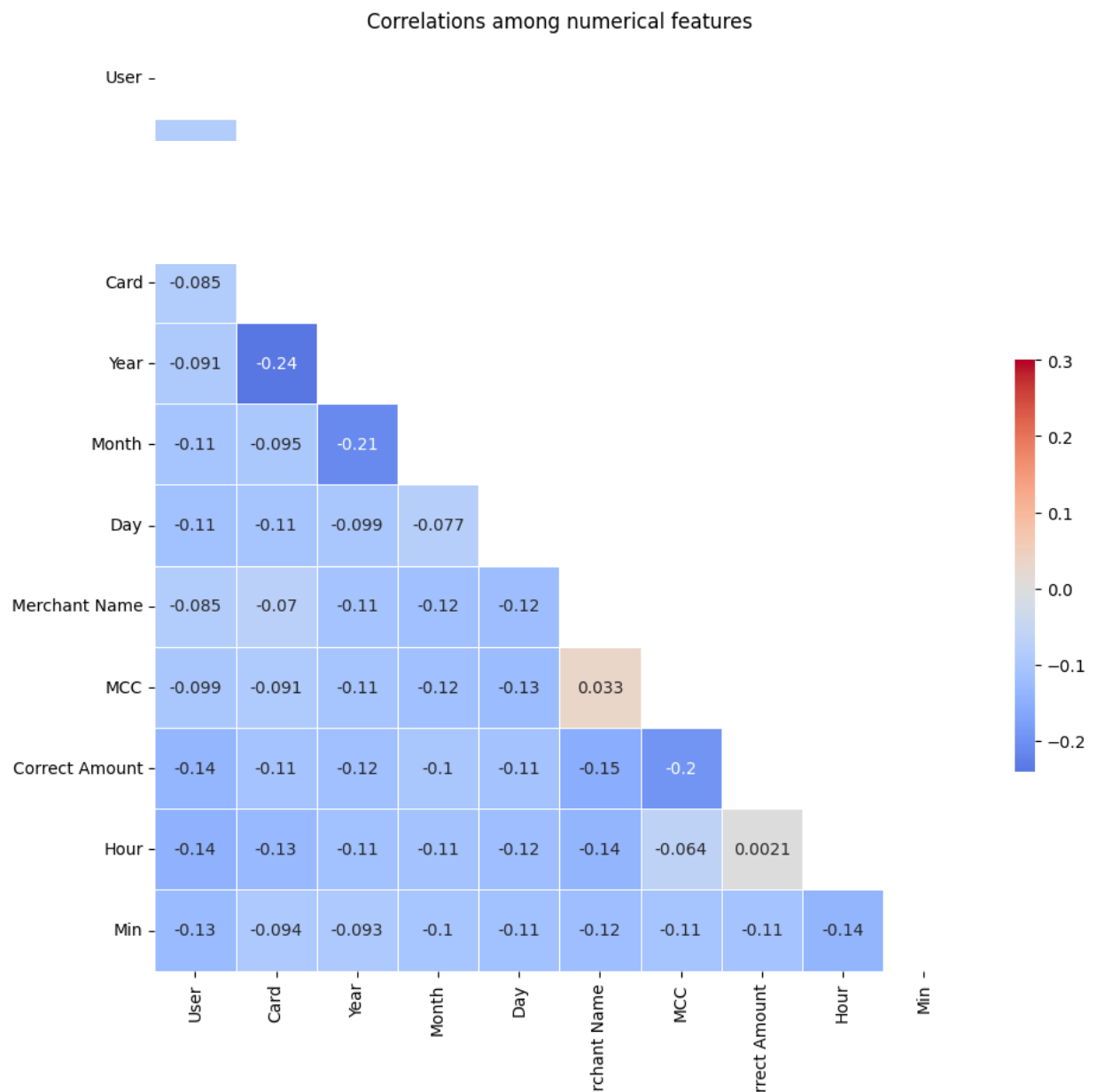
In order to visualize, one first has to convert to Pandas dataframe and then plot it

```

In [47]: # Plot computed correlation

df_plot = pd.DataFrame(data = corr_matrix, index=cols_corr, columns=cols_corr)
plotCorrelationMatrix(df_plot, annot=True)
plt.title('Correlations among numerical features')
plt.show()

```



Get the overall picture

Besides the correlation matrix above, we are going to view and/or visualize data to learn about different trends like:

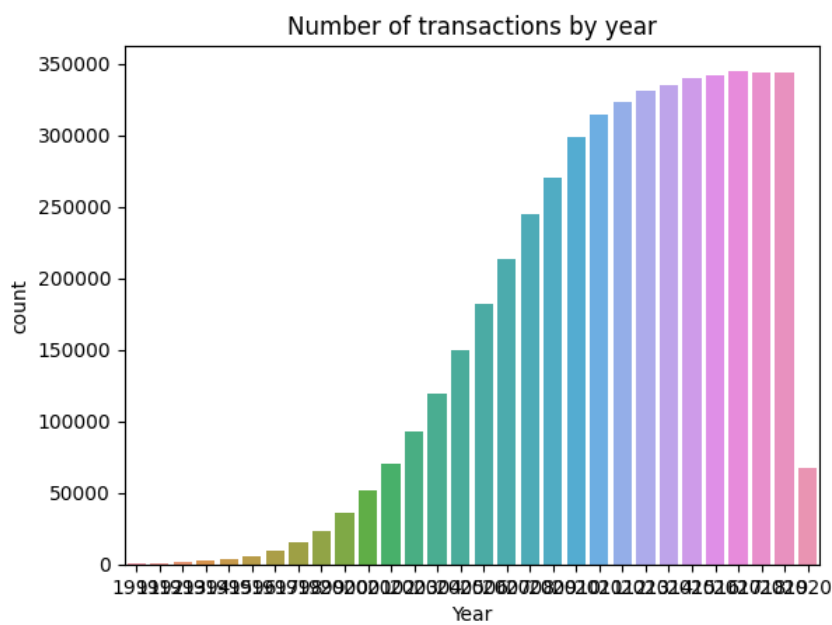
- Counting and amount of transactions.
- Card usage over time.
- Channel of transactions.

In particular, it seems appropriate to look more carefully at the fraud situations.

Feel free to add and/or remove visualizations.

```
In [48]: # Number of transactions by year

df_plot = ( df_clean
            .groupby('Year')
            .count()
            .sort('Year', ascending=True)
            .toPandas()
          )
plotBar(df_plot, 'Year', 'count')
plt.title('Number of transactions by year')
plt.show()
```



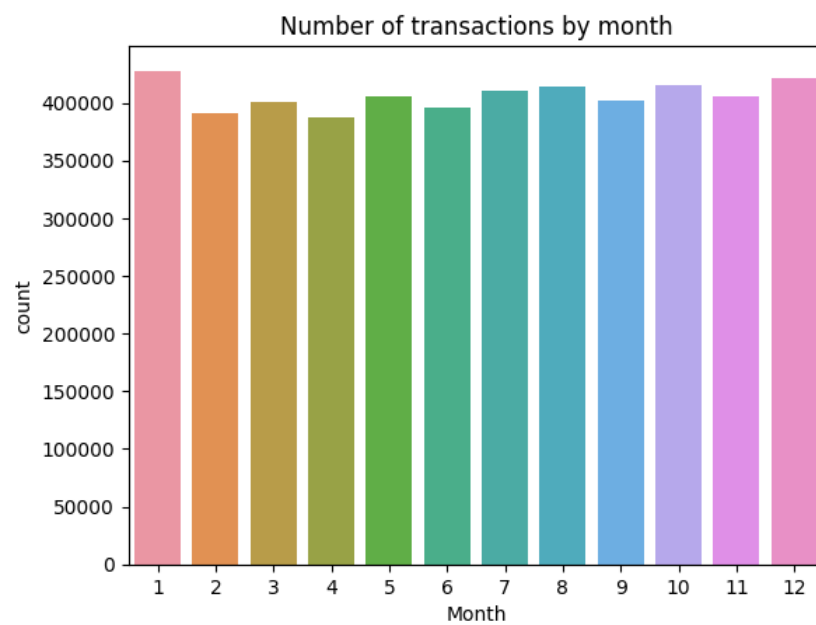
```
In [49]: df_plot.head()
```

```
Out[49]:
```

	Year	count
0	1991	331
1	1992	1005
2	1993	1663
3	1994	2819
4	1995	4052

```
In [50]: # Number of transactions by month

df_plot = ( df_clean
            )
plotBar(df_plot, 'Month', 'count')
plt.title('Number of transactions by month')
plt.show()
```



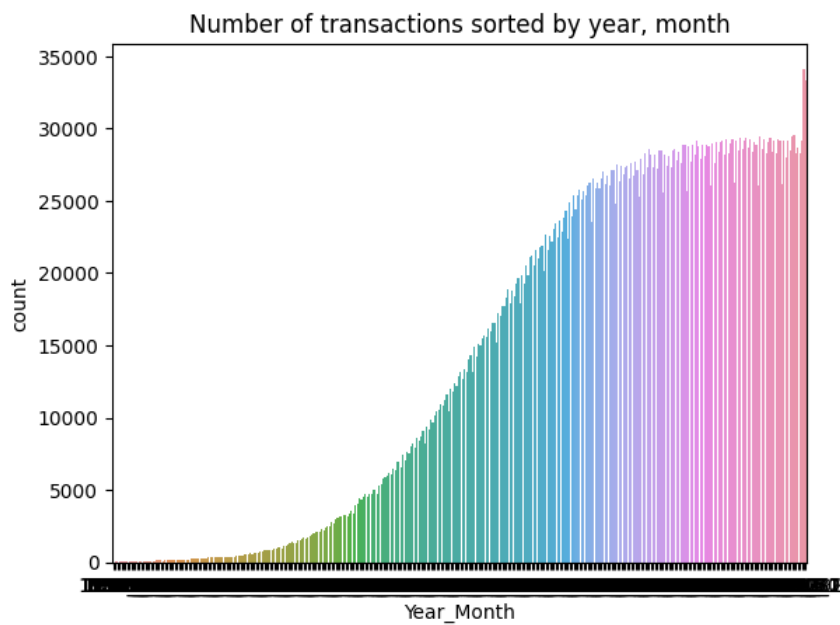
```
In [51]: df_plot.head()
```

```
Out[51]:
```

	Month	count
0	1	427834
1	2	391536
2	3	400966
3	4	387974
4	5	405392

```
In [52]: # Number of transactions by year - month

df_plot = ( df_clean
            .groupby(['Year', 'Month'])
            .count()
            .sort('Year', 'Month', ascending=True)
            .withColumn('Year_Month', F.concat('Year',F.lit('_'),'Month'))
            .toPandas()
            )
plotBar(df_plot, 'Year_Month', 'count')
plt.title('Number of transactions sorted by year, month')
plt.show()
```



```
In [53]: df_plot.head()
```

```
Out[53]:
```

	Year	Month	count	Year_Month
0	1991	1	12	1991_1
1	1991	2	12	1991_2
2	1991	3	9	1991_3
3	1991	4	11	1991_4
4	1991	5	8	1991_5

```
In [54]: # Counting of fraudulent transactions or not
```

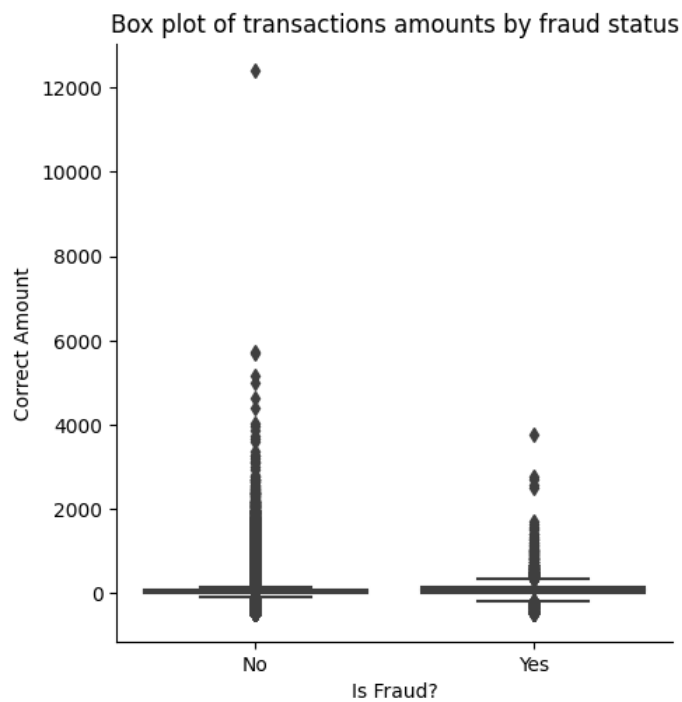
```
df_clean.
```

```
[Stage 532:=====> (17 + 1) / 18]
```

```
+-----+-----+
|Is Fraud?| count|
+-----+-----+
|      No|4872272|
|      Yes|  6004|
+-----+-----+
```

```
In [55]: # Transactions amounts by fraud status
```

```
df_plot = df_clean.select('Correct Amount', 'Is Fraud?').toPandas()
plotBox(df_plot, 'Is Fraud?', 'Correct Amount')
plt.title('Box plot of transactions amounts by fraud status')
plt.show()
```



```
In [56]: df_plot.head()
```


Out [56]:

	Correct Amount	Is Fraud?
0	134.089996	No
1	38.480000	No
2	86.190002	No
3	57.099998	No
4	53.910000	No

```
In [ ]: # Checking fraudulent transactions

df_fraud = df_clean.
df_fraud.show(10)
```

```
In [58]: # Fraudulent transactions by location

( df_fraud

)

[Stage 537:=====> (17 + 1) / 18]
```

Merchant State	count
null	3702
Italy	933
OH	186
CA	143
Algeria	141
TX	68
FL	66
Mexico	62
Haiti	59
Turkey	54

only showing top 10 rows

```
In [59]: # Fraudulent transactions by user

( df_fraud

)

[Stage 540:=====> (17 + 1) / 18]
```

User	sum(Correct Amount)
1	4172.230099260807
1880	3714.309942016378
817	3682.539996881038
629	3388.589950799942
275	3387.1799211502075
1248	3300.0499760191888
1946	3215.8398983478546
1889	3155.9099329710007
580	2989.159905999899
1338	2986.4600098133087

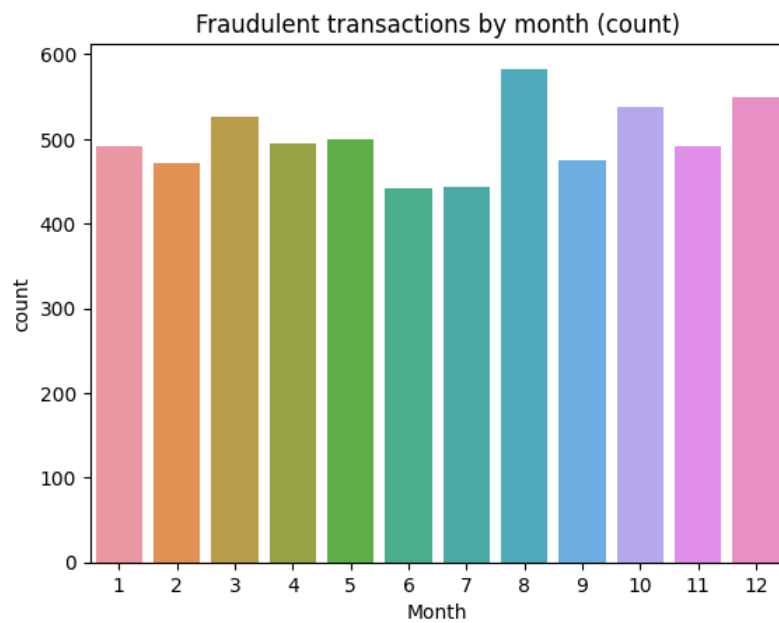
only showing top 10 rows

```
In [60]: # Fraudulent transactions by month (count)

df_plot = ( df_fraud

)

plotBar(df_plot, 'Month', 'count')
plt.title('Fraudulent transactions by month (count)')
plt.show()
```



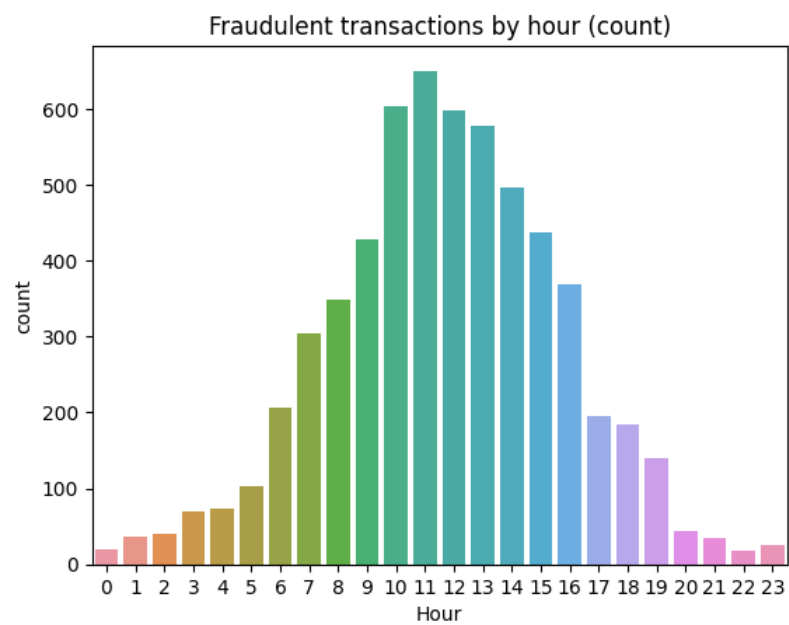
```
In [61]: df_plot.head()
```

```
Out[61]:
```

	Month	count
0	8	583
1	12	550
2	10	537
3	3	526
4	5	499

```
In [62]: # Fraudulent transactions by hour (count)

df_plot = ( df_fraud
            )
plotBar(df_plot, 'Hour', 'count')
plt.title('Fraudulent transactions by hour (count)')
plt.show()
```



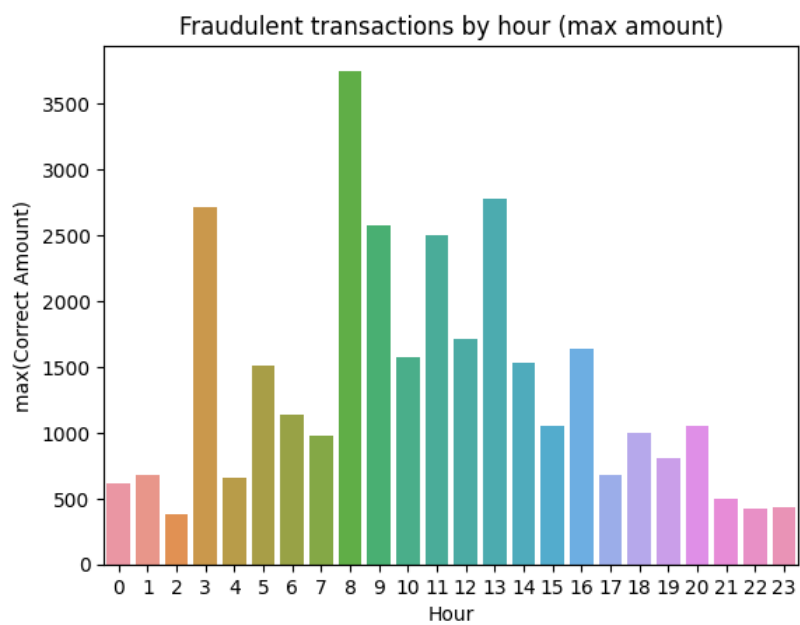
```
In [63]: df_plot.head()
```

```
Out[63]:
```

	Hour	count
0	11	650
1	10	603
2	12	597
3	13	578
4	14	496

```
In [64]: # Fraudulent transactions by hour (max amount)

df_plot = ( df_fraud
            .select('Hour', 'Correct Amount')
            .groupBy('Hour')
            .agg(F.max('Correct Amount'))
            .sort('Hour', ascending=True)
            .toPandas()
            )
plotBar(df_plot, 'Hour', 'max(Correct Amount)')
plt.title('Fraudulent transactions by hour (max amount)')
plt.show()
```



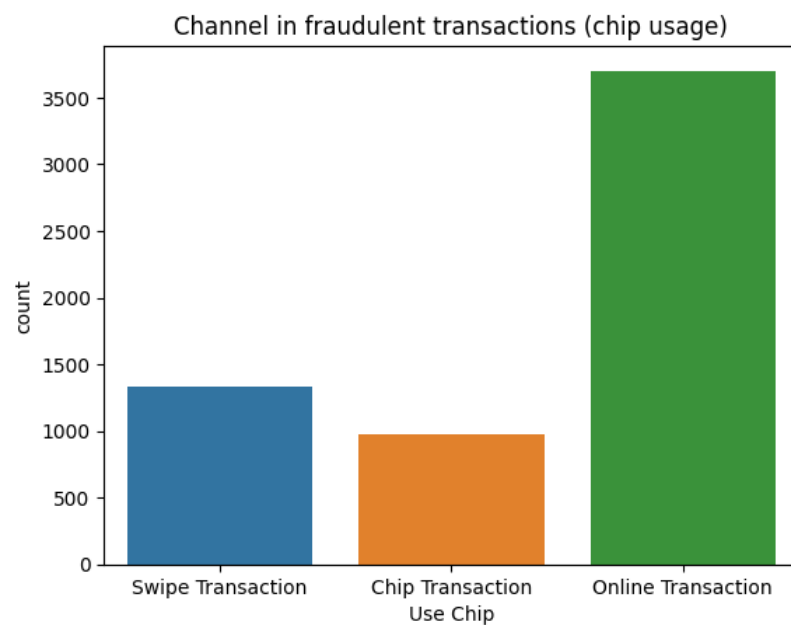
```
In [65]: df_plot.head()
```

```
Out[65]:
```

	Hour	max(Correct Amount)
0	0	609.979980
1	1	684.159973
2	2	385.660004
3	3	2708.899902
4	4	660.760010

```
In [66]: # Channel in fraudulent transactions (chip usage)

df_plot = df_fraud.groupby('Use Chip').count().toPandas()
plotBar(df_plot, 'Use Chip', 'count')
plt.title('Channel in fraudulent transactions (chip usage)')
plt.show()
```



```
In [67]: df_plot.head()
```

```
Out[67]:
```

	Use Chip	count
0	Swipe Transaction	1332
1	Chip Transaction	970
2	Online Transaction	3702

```
In [ ]: # Channel in all transactions (chip usage)

df_plot =

plotBar(df_plot, 'Use Chip', 'count')
plt.title('Channel in all transactions (chip usage)')
plt.show()
```

```
In [69]: df_plot.head()
```

```
Out[69]:
```

	Use Chip	count
0	Swipe Transaction	3078037
1	Chip Transaction	1256053
2	Online Transaction	544186

Columns selection, encoding and vector assembling

It is time to start thinking about which columns to use in the model, whether existing or new derived ones. To do so, the best we understand what the business is all about the better, including in relation to the characteristics of the data we were given. Statistics that we have made, and more we might do, would help to figure out patterns of interest.

Once the columns of interest for the classifier are set out, we have to enter into the specifics of the algorithms.

We are going to use `StringIndexer` and `OneHotEncoder`, as the ML algorithms we are about to use do require processing numbers not text. And because of those algorithms also requiring that all input features are contained within a single vector, we need a transformation. So we use the `VectorAssembler` transformer, already used above.

Also, we have to make sure that the column target (binary label) is of numeric type.

Notes:

- MLlib provides a set of tools to help tackling this issue of features. See <http://spark.apache.org/docs/latest/ml-features.html>.
- Another functionality we could use is Imputer, which completes missing values in a dataset, using the mean, median or mode of the columns in which the missing values are located. The input columns have to be of numeric type.
- There are still nulls or NaN in the columns `Merchant State` and `Zip`. We should sort it out. But such information can be extracted from the column `Merchant City` so we will drop the two columns for the time being.

Column target or label

```
In [70]: df_clean = ( df_clean
                    .withColumn("Fraud", F.when(F.col('Is Fraud?')== 'Yes', 1).otherwise(0))
                    )
```

```
In [71]: df_clean.printSchema()
transactions_cols_interest = df_clean.columns
transactions_cols_interest
```

```

root
|-- User: integer (nullable = true)
|-- Card: integer (nullable = true)
|-- Year: integer (nullable = true)
|-- Month: integer (nullable = true)
|-- Day: integer (nullable = true)
|-- Time: timestamp (nullable = true)
|-- Use Chip: string (nullable = true)
|-- Merchant Name: long (nullable = true)
|-- Merchant City: string (nullable = true)
|-- Merchant State: string (nullable = true)
|-- Zip: double (nullable = true)
|-- MCC: integer (nullable = true)
|-- Is Fraud?: string (nullable = true)
|-- Correct Amount: float (nullable = true)
|-- Hour: integer (nullable = true)
|-- Min: integer (nullable = true)
|-- Fraud: integer (nullable = false)

```

```

Out[71]: ['User',
          'Card',
          'Year',
          'Month',
          'Day',
          'Time',
          'Use Chip',
          'Merchant Name',
          'Merchant City',
          'Merchant State',
          'Zip',
          'MCC',
          'Is Fraud?',
          'Correct Amount',
          'Hour',
          'Min',
          'Fraud']

```

Features to use

In order to select the features to use, one should also take into account the correlations among them.

But as a starting experiment, let us use as many as possible.

```

In [72]: cls_not_features = ['Time', 'Merchant State', 'Zip', 'Is Fraud?', 'Fraud']
         cls_numeric = ['User', 'Card', 'Year', 'Month', 'Day', 'Merchant Name',
                        'Zip', 'MCC', 'Correct Amount', 'Hour', 'Min', 'Fraud']
         cls_non_numeric =
         cls_non_numeric

```

```

Out[72]: ['Time', 'Use Chip', 'Merchant City', 'Merchant State', 'Is Fraud?']

```

```

In [73]: # Encoding columns and vector assembling them
         # See Chapter 10 of the book "Learning Spark – Lightning-Fast Data Analytics"

         categorical_cols = [i for i in cls_non_numeric if i not in cls_not_features]
         non_categorical_cols = [i for i in cls_numeric if i not in cls_not_features]

         index_output_cols = [x + ' Index' for x in categorical_cols]
         ohe_output_cols = [x + ' OHE' for x in categorical_cols]

         string_indexer = StringIndexer(inputCols=categorical_cols, outputCols=index_output_cols, handleInvalid="skip")

         ohe_encoder = OneHotEncoder(inputCols=index_output_cols, outputCols=ohe_output_cols)

         # Put all input features into a single vector, by using a transformer

         assembler_inputs = ohe_output_cols + non_categorical_cols
         vec_assembler = VectorAssembler(inputCols=assembler_inputs, outputCol="features")
         assembler_inputs

```

```
Out[73]: ['Use Chip OHE',
         'Merchant City OHE',
         'User',
         'Card',
         'Year',
         'Month',
         'Day',
         'Merchant Name',
         'MCC',
         'Correct Amount',
         'Hour',
         'Min']
```

```
In [74]: categorical_cols
```

```
Out[74]: ['Use Chip', 'Merchant City']
```

```
In [75]: non_categorical_cols
```

```
Out[75]: ['User',
         'Card',
         'Year',
         'Month',
         'Day',
         'Merchant Name',
         'MCC',
         'Correct Amount',
         'Hour',
         'Min']
```

Select and train model

Now it is time to train and test a model to be used for binary classification, that is, to decide whether there is a fraud or not.

We are going to use a Linear Support Vector Machine algorithm, as presented in <http://spark.apache.org/docs/latest/ml-classification-regression.html#linear-support-vector-machine>.

But at this point in time, probably it is worth considering to look at both the supervised learning and the ML pipeline slides from the lectures.

Train/test split

The step of creating a ML model means we should keep some part of the data in the dark. Basic standard split is 80/20 (or 70/30 if dataset is large), assuming that we opt for a train/test split rather than a train/validation/test split.

Recall that if the test part is relatively too small, then the model will memorize the data so it will reach an overfit situation. That would be bad as it no longer have data to evaluate how well it will generalize to unseen data.

Notice that data for fraudulent cases is less and imbalanced. Ideally, we should carry out better tuning for the train/test split, as it affects the performance of the model as we might conclude later on.

```
In [ ]: # train/test split

df_train, df_test = df_clean.randomSplit([0.8, 0.2], 42)

# Caching data ... just the training part as it is accessed many times by the algorithm
# But, it might not be a good idea if we are using a local computer and large dataset!
# df_train.cache()

# Print the number of rows in each part
print(f"There are {df_train.count()} rows in the training set and {df_test.count()} in the test set.")
```


Notice:

As we did with clean data, we may consider storing the data split into files, should we want to use it elsewhere.

This relates to the need of guaranteeing unicity in a different environment. We leave it as it is now.

Linear SVM model

Once we have a vector assembled with the features in place, then we can use the `Linear SVM` estimator (the algorithm) to learn from the training data and to build the model.

```
In [77]: # Linear SVC algorithm
# default: featuresCol='features', labelCol='label', predictionCol='prediction'

lsvc = LinearSVC(maxIter=10, regParam=0.1, labelCol='Fraud')
```

ML pipeline configuration

```
In [78]: # The pipeline holds four stages as set above:
# 1. string_indexer
# 2. ohe_encoder
# 3. vec_assembler (related to assembling features into vector)
# 4. lsvc (related to ML estimator)

pipeline = Pipeline(stages=[string_indexer, ohe_encoder, vec_assembler, lsvc])
```

Model fitting

Get the model (as transformer) by fitting the pipeline to the training data.

```
In [ ]: pipeline_model = pipeline.fit(df_train)
```

Evaluate model

Let us evaluate the Linear SVM model that has been built.

Testing the model

It is time to apply the model built to test data. Again, we will use the pipeline set above, meaning the stages already specified will be reused. Notice that, since the pipeline model is a transformer, we can easily apply it to test data.

```
In [80]: # Make predictions on test data and show values of columns of interest

df_prediction = pipeline_model.transform(df_test)

# Check its schema

df_prediction.printSchema()
```

```

root
|-- User: integer (nullable = true)
|-- Card: integer (nullable = true)
|-- Year: integer (nullable = true)
|-- Month: integer (nullable = true)
|-- Day: integer (nullable = true)
|-- Time: timestamp (nullable = true)
|-- Use Chip: string (nullable = true)
|-- Merchant Name: long (nullable = true)
|-- Merchant City: string (nullable = true)
|-- Merchant State: string (nullable = true)
|-- Zip: double (nullable = true)
|-- MCC: integer (nullable = true)
|-- Is Fraud?: string (nullable = true)
|-- Correct Amount: float (nullable = true)
|-- Hour: integer (nullable = true)
|-- Min: integer (nullable = true)
|-- Fraud: integer (nullable = false)
|-- Use Chip Index: double (nullable = false)
|-- Merchant City Index: double (nullable = false)
|-- Use Chip OHE: vector (nullable = true)
|-- Merchant City OHE: vector (nullable = true)
|-- features: vector (nullable = true)
|-- rawPrediction: vector (nullable = true)
|-- prediction: double (nullable = false)

```

In [81]: *# Columns to be focus on*

```
df_prediction.
```

23/03/17 20:22:26 WARN DAGScheduler: Broadcasting large task binary with size 1500.6 KiB

[Stage 682:>

(0 + 1) / 1]

features	rawPrediction	prediction	Fraud
(11838, [0, 762, 118...]	[2.00992197805789...	0.0	0
(11838, [0, 529, 118...]	[2.00260482636364...	0.0	0
(11838, [0, 173, 118...]	[1.99734976842966...	0.0	0
(11838, [0, 529, 118...]	[2.01024919177608...	0.0	0
(11838, [0, 762, 118...]	[2.01102023719275...	0.0	0
(11838, [0, 529, 118...]	[2.00373077950577...	0.0	0
(11838, [0, 529, 118...]	[1.99980534341225...	0.0	0
(11838, [0, 529, 118...]	[1.99910034086769...	0.0	0
(11838, [0, 529, 118...]	[2.00663706437133...	0.0	0
(11838, [0, 529, 118...]	[2.01055392530275...	0.0	0
(11838, [0, 762, 118...]	[2.00151796178571...	0.0	0
(11838, [0, 529, 118...]	[2.02055611367043...	0.0	0
(11838, [0, 529, 118...]	[2.00945109951328...	0.0	0
(11838, [0, 173, 118...]	[1.99965286980047...	0.0	0
(11838, [0, 529, 118...]	[2.01694688287628...	0.0	0
(11838, [0, 529, 118...]	[2.01111078369967...	0.0	0
(11838, [0, 762, 118...]	[2.01170878251943...	0.0	0
(11838, [0, 529, 118...]	[2.00010916739202...	0.0	0
(11838, [0, 529, 118...]	[2.00923339940891...	0.0	0
(11838, [0, 529, 118...]	[1.99815681569920...	0.0	0

only showing top 20 rows

Evaluation metrics

How right was the model? Let us figure out using:

1. Specific evaluator
2. Confusion matrix

```
In [82]: # Compute evaluation metrics on test data

prediction_label = df_prediction.select('rawPrediction', 'prediction', 'Fraud')

# supports metricName="areaUnderROC" (default) and "areaUnderPR"
# it relates to sensitivity (TP rate) and specificity (FP rate)

evaluator = BinaryClassificationEvaluator(labelCol='Fraud')

print("areaUnderROC = " + str(evaluator.evaluate(prediction_label)))
# print("areaUnderPR = " + str(evaluator.evaluate(prediction_label, {evaluator.metricName: 'areaUnderPR'})))
```

23/03/17 20:22:29 WARN DAGScheduler: Broadcasting large task binary with size 1498.9 KiB

areaUnderROC = 0.9012415626377711

Recalling the confusion matrix:

- True Positive: the prediction was positive and it is true.
- True Negative: the prediction was negative and it is true.
- False Positive: the prediction was positive and it is false.
- False Negative: the prediction was negative and it is false.

		Actual Values	
		Positive (1)	Negative (0)
Predicted Values	Positive (1)	TP	FP
	Negative (0)	FN	TN

It follows the TP, TN, FP and FN computations.

```
In [ ]: # Counting rows for each case TP, TN, FP and FN respectively

n = df_prediction.count()
tp = df_prediction.filter(F.expr('prediction > 0') & F.expr('Fraud == prediction')).count()
tn = df_prediction.filter
fp = df_prediction.filter
fn = n - tp - tn - fp
[tp, tn, fp, fn, n]
```

Accuracy = $(TP + TN) / (TP + TN + FP + FN)$

How often the classifier is correct? (score)

Metric widely used but not so useful when there are many TN cases.

```
In [84]: accuracy = (tp + tn) / (tp + tn + fp + fn)
```

Precision = $TP / (TP + FP)$

Positive predictive value - proportion of positive results that were correctly identified.

It removes NP and FN from consideration.

```
In [85]: precision = tp / (tp + fp)
```

Recall = $TP / (TP + FN)$

True positive rate. (hit rate, sensitivity)

```
In [86]: recall = tp / (tp + fn)
```

Specificity = $TN / (TN + FP)$

True negative rate. (selectivity)

```
In [87]: specificity = tn / (tn + fp)
```

F1 score = $2 * Recall * Precision / (Recall + Precision)$

Useful metric because it is difficult to compare two models with low precision and high recall or vice versa. Indeed, by combining recall and precision it helps to measure them at once.

```
In [88]: f1_score = 2 * recall * precision / (recall + precision)
```

```
In [89]: # Confusion matrix conclusions
```

```
print("TP = {}, TN = {}, FP = {}, FN = {}, Total = {}".format(tp, tn, fp, fn, n))
print("Accuracy = {}".format(accuracy))
print("Precision = {}".format(precision))
print("Recall = {}".format(recall))
print("Specificity = {}".format(specificity))
print("F1 score = {}".format(f1_score))
```

```
TP = 41, TN = 973414, FP = 15, FN = 1155, Total = 974625
Accuracy = 0.9987995382839554
Precision = 0.7321428571428571
Recall = 0.034280936454849496
Specificity = 0.9999845905556543
F1 score = 0.06549520766773162
```

Questions and/or considerations:

- Which of the above metrics are most relevant for performance analysis in this particular study, considering the dataset that has been used?
- Precision is very low due to the fact that the dataset is imbalanced, with true negatives having a much larger number of instances than true positives. In order to further improve results, it would be nice to train the model on more balanced datasets.

Visual analysis

Plotting `prediction` versus `Fraud` obtained above.

```
In [90]: # Plots
# We leave it as exercise
```

Saving the pipeline

```
In [91]: # We can save the pipeline for further use should it be required

pipeline.save("pipeline-LinearSVM")

# later on, it can be loaded anywhere
```

```
In [92]: # Furthermore, we can save the pipeline after fit, that is, the model

pipeline_model.save("model-LinearSVM")
```

```
In [93]: # ! ls -la
```

```
In [94]: # ! ls -la pipeline-LinearSVM
```

Tune model

We should improve the model. For example, we can think about:

- How can we interpret the scores above?
- How to handle class imbalance, so clear in this dataset?
- Could a model with different set of features and/or target engineering would perform better?
- And what about using real-time data, that is, not training nor testing data?

See the exercises below.

Additional exercises

ML model improvement

Once this exercise has been completed, create one or more notebooks with similar implementation but using the following classifiers instead:

1. Logistic Regression
2. Decision Tree

Also, try to improve the process of feature/target engineering, giving the framework set out. By the way, now you must take into account correlations among features.

See related information in: <http://spark.apache.org/docs/latest/ml-classification-regression.html#logistic-regression>
(<http://spark.apache.org/docs/latest/ml-classification-regression.html#logistic-regression>)

<http://spark.apache.org/docs/latest/ml-classification-regression.html#decision-tree-classifier>
(<http://spark.apache.org/docs/latest/ml-classification-regression.html#decision-tree-classifier>)

Consuming profile

Using also the `User` and `Cards` datasets, create a new notebook to profile the usage of the credit cards. Make sure you have a careful working plan designed in order to reach the goals.

References

- Learning Spark - Lightning-Fast Data Analytics, 2nd Ed. J. Damji, B. Wenig, T. Das, and D. Lee. O'Reilly, 2020
- Spark: The Definitive Guide - Big Data Processing Made Simple, 1st Ed. B. Chambers and M. Zaharia. O'Reilly, 2018
- <http://spark.apache.org/docs/latest/ml-guide.html>
- <https://docs.python.org/3/>
- <https://www.kaggle.com/datasets/ealtman2019/credit-card-transactions>

In []: