

DTSA 5510 Final

June 5, 2025

0.1 Goal of the Project

The goal of this project is to create a product recommender system for Sephora based on customer ratings/reviews. This will be an unsupervised machine learning problem to attempt to predict how customers will like a given product. The approach will be to clean the data and perform some exploratory data analysis to get a high-level understanding of the data elements and the relationships between them. I will then create unsupervised learning models using collaborative filtering and NMF to predict ratings. I will also create an unsupervised model using K-nearest neighbors to provide recommendations to Sephora customers about products they may enjoy based on their highest rated product.

This project has been published to GitHub at <https://github.com/cmisl/MSDS/tree/main/DTSA%205510>. I did not push the data files to the GitHub directory because they are large and also available at <https://www.kaggle.com/datasets/nadyinky/sephora-products-and-skincare-reviews>.

```
[1]: import pandas as pd
import numpy as np
import matplotlib.pyplot as plt
import seaborn as sns
sns.set()
%matplotlib inline

from scipy.sparse import coo_matrix, csr_matrix
from sklearn.decomposition import NMF
from sklearn.metrics import confusion_matrix, ConfusionMatrixDisplay
from sklearn.model_selection import train_test_split
from sklearn.neighbors import NearestNeighbors, KNeighborsRegressor

import warnings
warnings.filterwarnings('ignore')
```

0.2 Data Understanding

The dataset author collected review and product information for Sephora (a beauty and skin care retailer) via a Python scraper in March 2023.

0.2.1 Data Citation in APA Format

Inky, N. (2023). Sephora Products and Skincare Reviews. Version 1. [Data set]. Retrieved from <https://www.kaggle.com/datasets/nadyinky/sephora-products-and-skincare-reviews>.

0.2.2 Data Description

Users The user dataset contains 1,094,411 rows and 18 columns, which I will narrow down to the following columns of interest for this project:

Column	Data Type	Description
author_id	string	Unique identifier for the user
rating	int	1-5 rating for the product
skin_tone	string	User's skin tone (e.g. fair, tan, etc.)
eye_color	string	User's eye color (e.g. brown, green, etc.)
skin_type	string	User's skin type (e.g. combination, oily, etc.)
hair_color	string	User's hair color (e.g. brown, auburn, etc.)
product_id	string	Unique alphanumeric identifier for the product

Products The product dataset contains 8494 rows and 27 columns, which I will narrow down to the following columns of interest for this project:

Column	Data Type	Description
product_id	string	Unique alphanumeric identifier for the product
product_name	string	Full name of the product
brand_name	string	Full name of the brand
price_usd	float	Price of the product in U.S. dollars
limited_edition	int	Indicates whether the product is a limited edition (1=yes, 0=no)
online_only	int	Indicates whether the product only available online (1=yes, 0=no)
sephora_exclusive	int	Indicates whether the product is exclusive to Sephora (1=yes, 0=no)
primary_category	string	First level of product categorization

0.2.3 Load the Data

Users and Ratings I load the reviews data from the multiple CSV files provided by the dataset author and combine them together into a single dataframe. I then separate that dataframe into two dataframes, one for the user's attributes noted above (e.g., eye color) and another for the ratings (i.e., author ID, product ID, and rating).

```
[2]: df1 = pd.read_csv('reviews_0-250.csv', index_col=0)
df2 = pd.read_csv('reviews_250-500.csv', index_col=0)
df3 = pd.read_csv('reviews_500-750.csv', index_col=0)
df4 = pd.read_csv('reviews_750-1250.csv', index_col=0)
```

```
df5 = pd.read_csv('reviews_1250-end.csv', index_col=0)

df_users = pd.concat([df1, df2, df3, df4, df5])
df_users.head()
```

```
[2]:
```

	author_id	rating	is_recommended	helpfulness	total_feedback_count	\
0	1741593524	5	1.0	1.0	2	
1	31423088263	1	0.0	NaN	0	
2	5061282401	5	1.0	NaN	0	
3	6083038851	5	1.0	NaN	0	
4	47056667835	5	1.0	NaN	0	

	total_neg_feedback_count	total_pos_feedback_count	submission_time	\
0	0	2	2023-02-01	
1	0	0	2023-03-21	
2	0	0	2023-03-21	
3	0	0	2023-03-20	
4	0	0	2023-03-20	

	review_text	\
0	I use this with the Nudestix "Citrus Clean Bal...	
1	I bought this lip mask after reading the revie...	
2	My review title says it all! I get so excited ...	
3	I've always loved this formula for a long time...	
4	If you have dry cracked lips, this is a must h...	

	review_title	skin_tone	eye_color	skin_type	\
0	Taught me how to double cleanse!	NaN	brown	dry	
1	Disappointed	NaN	NaN	NaN	
2	New Favorite Routine	light	brown	dry	
3	Can't go wrong with any of them	NaN	brown	combination	
4	A must have !!!	light	hazel	combination	

	hair_color	product_id	product_name	\
0	black	P504322	Gentle Hydra-Gel Face Cleanser	
1	NaN	P420652	Lip Sleeping Mask Intense Hydration with Vitam...	
2	blonde	P420652	Lip Sleeping Mask Intense Hydration with Vitam...	
3	black	P420652	Lip Sleeping Mask Intense Hydration with Vitam...	
4	NaN	P420652	Lip Sleeping Mask Intense Hydration with Vitam...	

	brand_name	price_usd
0	NUDESTIX	19.0
1	LANEIGE	24.0
2	LANEIGE	24.0
3	LANEIGE	24.0
4	LANEIGE	24.0

```
[3]: df_users.info()
```

```
<class 'pandas.core.frame.DataFrame'>
Index: 1094411 entries, 0 to 49976
Data columns (total 18 columns):
#   Column                      Non-Null Count  Dtype
---  -
0   author_id                   1094411 non-null object
1   rating                     1094411 non-null int64
2   is_recommended             926423 non-null float64
3   helpfulness                532819 non-null float64
4   total_feedback_count       1094411 non-null int64
5   total_neg_feedback_count   1094411 non-null int64
6   total_pos_feedback_count   1094411 non-null int64
7   submission_time            1094411 non-null object
8   review_text                 1092967 non-null object
9   review_title               783757 non-null object
10  skin_tone                   923872 non-null object
11  eye_color                   884783 non-null object
12  skin_type                   982854 non-null object
13  hair_color                  867643 non-null object
14  product_id                  1094411 non-null object
15  product_name                1094411 non-null object
16  brand_name                  1094411 non-null object
17  price_usd                   1094411 non-null float64
dtypes: float64(3), int64(4), object(11)
memory usage: 158.6+ MB
```

```
[4]: df_ratings = df_users[['author_id', 'product_id', 'rating']]
df_users = df_users[['author_id', 'skin_tone', 'eye_color', 'skin_type', '
↳ 'hair_color']]
df_users.info()
```

```
<class 'pandas.core.frame.DataFrame'>
Index: 1094411 entries, 0 to 49976
Data columns (total 5 columns):
#   Column      Non-Null Count  Dtype
---  -
0   author_id   1094411 non-null object
1   skin_tone   923872 non-null object
2   eye_color   884783 non-null object
3   skin_type   982854 non-null object
4   hair_color  867643 non-null object
dtypes: object(5)
memory usage: 50.1+ MB
```

```
[5]: df_users.head()
```

```
[5]:      author_id skin_tone eye_color    skin_type hair_color
0    1741593524      NaN    brown         dry    black
1    31423088263      NaN      NaN         NaN      NaN
2    5061282401    light    brown         dry    blonde
3    6083038851      NaN    brown combination    black
4    47056667835    light    hazel combination      NaN
```

```
[6]: df_ratings.head()
```

```
[6]:      author_id product_id  rating
0    1741593524    P504322        5
1    31423088263    P420652        1
2    5061282401    P420652        5
3    6083038851    P420652        5
4    47056667835    P420652        5
```

Products I now load the product dataset and filter to the columns of interest listed above.

```
[7]: df_products = pd.read_csv('product_info.csv')
df_products.head()
```

```
[7]:      product_id      product_name  brand_id brand_name  loves_count  \
0    P473671  Fragrance Discovery Set    6342    19-69        6320
1    P473668    La Habana Eau de Parfum    6342    19-69        3827
2    P473662  Rainbow Bar Eau de Parfum    6342    19-69        3253
3    P473660      Kasbah Eau de Parfum    6342    19-69        3018
4    P473658  Purple Haze Eau de Parfum    6342    19-69        2691

      rating  reviews      size      variation_type  \
0    3.6364     11.0      NaN      NaN
1    4.1538     13.0  3.4 oz/ 100 mL  Size + Concentration + Formulation
2    4.2500     16.0  3.4 oz/ 100 mL  Size + Concentration + Formulation
3    4.4762     21.0  3.4 oz/ 100 mL  Size + Concentration + Formulation
4    3.2308     13.0  3.4 oz/ 100 mL  Size + Concentration + Formulation

      variation_value  ...  online_only  out_of_stock  sephora_exclusive  \
0      NaN  ...      1      0      0
1  3.4 oz/ 100 mL  ...      1      0      0
2  3.4 oz/ 100 mL  ...      1      0      0
3  3.4 oz/ 100 mL  ...      1      0      0
4  3.4 oz/ 100 mL  ...      1      0      0

      highlights  primary_category  \
0  ['Unisex/ Genderless Scent', 'Warm &Spicy Scen...  Fragrance
1  ['Unisex/ Genderless Scent', 'Layerable Scent'...  Fragrance
2  ['Unisex/ Genderless Scent', 'Layerable Scent'...  Fragrance
3  ['Unisex/ Genderless Scent', 'Layerable Scent'...  Fragrance
```

```

4  ['Unisex/ Genderless Scent', 'Layerable Scent'...      Fragrance

      secondary_category  tertiary_category  child_count  child_max_price  \
0  Value & Gift Sets  Perfume Gift Sets          0           NaN
1           Women      Perfume                2           85.0
2           Women      Perfume                2           75.0
3           Women      Perfume                2           75.0
4           Women      Perfume                2           75.0

      child_min_price
0           NaN
1           30.0
2           30.0
3           30.0
4           30.0

```

[5 rows x 27 columns]

```
[8]: df_products.info()
```

```

<class 'pandas.core.frame.DataFrame'>
RangeIndex: 8494 entries, 0 to 8493
Data columns (total 27 columns):
#   Column                Non-Null Count  Dtype
---  -
0   product_id            8494 non-null  object
1   product_name          8494 non-null  object
2   brand_id              8494 non-null  int64
3   brand_name            8494 non-null  object
4   loves_count           8494 non-null  int64
5   rating                8216 non-null  float64
6   reviews               8216 non-null  float64
7   size                  6863 non-null  object
8   variation_type         7050 non-null  object
9   variation_value        6896 non-null  object
10  variation_desc         1250 non-null  object
11  ingredients            7549 non-null  object
12  price_usd             8494 non-null  float64
13  value_price_usd        451 non-null   float64
14  sale_price_usd         270 non-null   float64
15  limited_edition        8494 non-null  int64
16  new                    8494 non-null  int64
17  online_only            8494 non-null  int64
18  out_of_stock           8494 non-null  int64
19  sephora_exclusive      8494 non-null  int64
20  highlights             6287 non-null  object
21  primary_category       8494 non-null  object
22  secondary_category     8486 non-null  object

```

```

23  tertiary_category    7504 non-null    object
24  child_count         8494 non-null    int64
25  child_max_price     2754 non-null    float64
26  child_min_price     2754 non-null    float64
dtypes: float64(7), int64(8), object(12)
memory usage: 1.7+ MB

```

```

[9]: df_products = df_products[['product_id', 'product_name',
                                'brand_name', 'price_usd',
                                'limited_edition', 'online_only',
                                'sephora_exclusive', 'primary_category']]

```

```

[10]: df_products.info()

<class 'pandas.core.frame.DataFrame'>
RangeIndex: 8494 entries, 0 to 8493
Data columns (total 8 columns):
#   Column                Non-Null Count  Dtype
---  -
0   product_id            8494 non-null   object
1   product_name          8494 non-null   object
2   brand_name            8494 non-null   object
3   price_usd             8494 non-null   float64
4   limited_edition       8494 non-null   int64
5   online_only           8494 non-null   int64
6   sephora_exclusive     8494 non-null   int64
7   primary_category      8494 non-null   object
dtypes: float64(1), int64(3), object(4)
memory usage: 531.0+ KB

```

0.3 Data cleaning

0.3.1 Data Types

The author id had some dummy values that were not numeric. Casting the column to a number replaces the invalid values with NaNs.

```

[11]: df_ratings['author_id'] = pd.to_numeric(df_ratings['author_id'],
      ↪errors='coerce')
df_users['author_id'] = pd.to_numeric(df_users['author_id'], errors='coerce')

```

0.3.2 Handle missing values

Ratings I removed the 60 rows with missing IDs (i.e., the author_ids that had invalid values when converting the column to an integer).

```

[12]: print(df_ratings.isna().sum())
max_na = max(df_ratings.isna().sum())
print(f"{max_na*100/len(df_ratings):.2f}% of rows have missing value")

```

```
print(df_ratings.shape)
```

```
author_id      64
product_id      0
rating          0
dtype: int64
0.01% of rows have missing value
(1094411, 3)
```

```
[13]: df_ratings = df_ratings.dropna()
print(df_ratings.isna().sum())
print(df_ratings.shape)
```

```
author_id      0
product_id      0
rating          0
dtype: int64
(1094347, 3)
```

Users The user information has missing values in at least 20% of the rows. However, each user can submit multiple reviews which may allow me to copy any missing values from another review submitted by that same user.

```
[14]: print(df_users.isna().sum())
max_na = max(df_users.isna().sum())
print(f"At least {max_na*100/len(df_users):.2f}% of rows have missing value")
print(df_users.shape)
```

```
author_id      64
skin_tone      170539
eye_color      209628
skin_type      111557
hair_color     226768
dtype: int64
At least 20.72% of rows have missing value
(1094411, 5)
```

```
[15]: ''' Create a dictionary for each of the columns with missing values using the_
    ↪author_id as the key
        and the first value for the column in question (e.g., skin_tone) as the_
    ↪value in the dictionary.
        Then map the values from the dictionary into the rows missing those values.
    '''

skin_tone_dict = df_users.dropna(subset=['skin_tone']).
    ↪groupby('author_id')['skin_tone'].first().to_dict()
df_users['skin_tone'] = df_users['author_id'].map(skin_tone_dict).
    ↪fillna(df_users['skin_tone'])
```



```

eye_color_dict = df_users.dropna(subset=['eye_color']).
    ↳groupby('author_id')['eye_color'].first().to_dict()
df_users['eye_color'] = df_users['author_id'].map(eye_color_dict).
    ↳fillna(df_users['eye_color'])

skin_type_dict = df_users.dropna(subset=['skin_type']).
    ↳groupby('author_id')['skin_type'].first().to_dict()
df_users['skin_type'] = df_users['author_id'].map(skin_type_dict).
    ↳fillna(df_users['skin_type'])

hair_color_dict = df_users.dropna(subset=['hair_color']).
    ↳groupby('author_id')['hair_color'].first().to_dict()
df_users['hair_color'] = df_users['author_id'].map(hair_color_dict).
    ↳fillna(df_users['hair_color'])

```

I cut the percentage of rows with missing values almost in half. Given the data set contains over one million users, I am just going to drop the rows that contain a missing value. This left 969,071 rows in the dataset.

```

[16]: print(df_users.isna().sum())
max_na = max(df_users.isna().sum())
print(f"At least {max_na*100/len(df_users):.2f}% of rows have missing value")
print(df_users.shape)

```

```

author_id      64
skin_tone     116184
eye_color      108376
skin_type       76126
hair_color     111621
dtype: int64
At least 10.62% of rows have missing value
(1094411, 5)

```

```

[17]: df_users = df_users.dropna()
print(df_users.isna().sum())
print(df_users.shape)

```

```

author_id      0
skin_tone      0
eye_color      0
skin_type      0
hair_color     0
dtype: int64
(978178, 5)

```

The users dataframe contains duplicate rows now that I populated the missing values, so I removed the duplicates. This left over 400,000 unique users with no missing attributes.

```
[18]: df_users = df_users.drop_duplicates()
      print(df_users.shape)
```

```
(419679, 5)
```

Products There are no missing values in the products dataset, which contains over 8,000 records.

```
[19]: print(df_products.isna().sum())
      max_na = max(df_products.isna().sum())
      print(f"{max_na*100/len(df_products):.2f}% of rows have missing value")
      print(df_products.shape)
```

```
product_id          0
product_name        0
brand_name          0
price_usd           0
limited_edition      0
online_only         0
sephora_exclusive   0
primary_category    0
dtype: int64
0.00% of rows have missing value
(8494, 8)
```

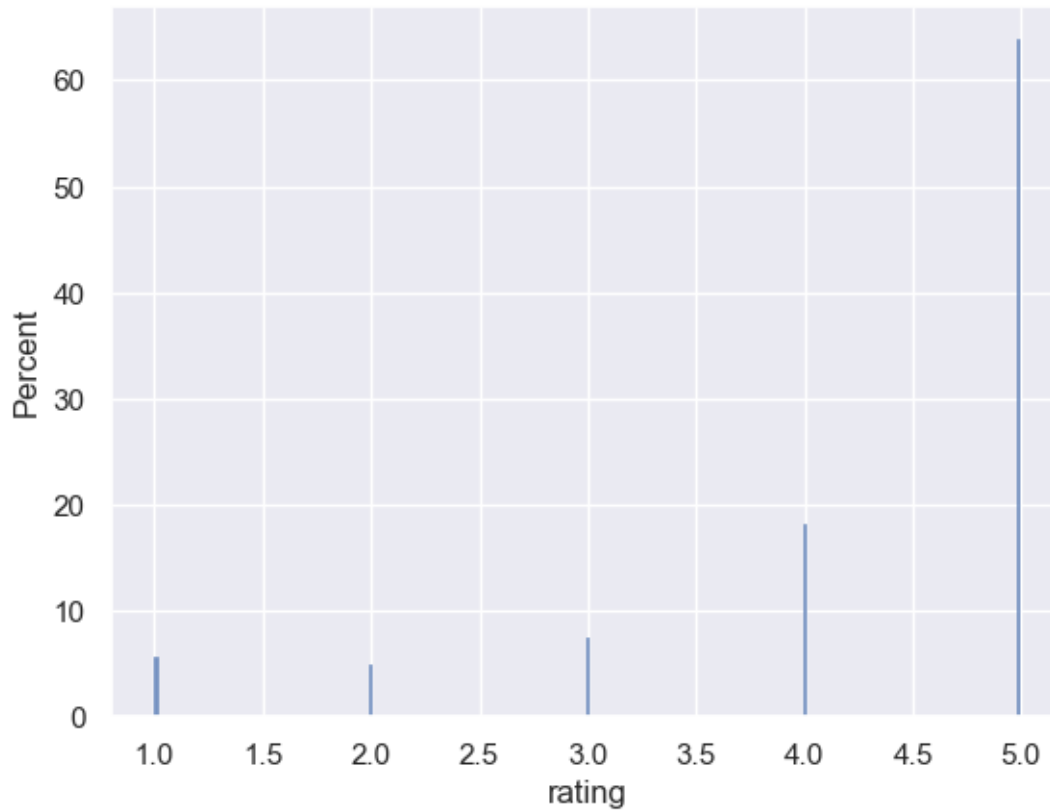
0.4 EDA

0.4.1 Distribution of Data

Ratings The ratings are on a 1-5 scale and contains a majority of 5 ratings.

```
[20]: sns.histplot(data=df_ratings, x="rating", stat="percent")
```

```
[20]: <Axes: xlabel='rating', ylabel='Percent'>
```



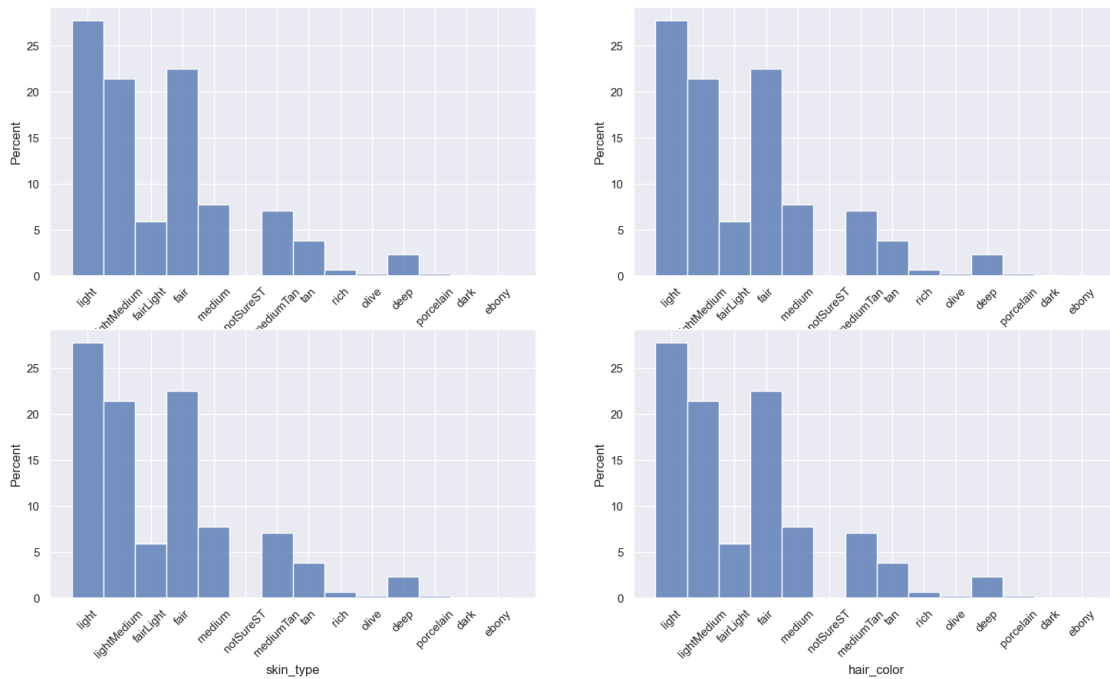
Users The users dataset is skewed toward users with lighter skin, eyes, and hair, so the model will likely have difficulty predicting for users with darker features.

```
[21]: fig, axes = plt.subplots(2, 2, figsize=(18, 10))
fig.suptitle('Frequency Distribution for each Variable')
axes[0,0].tick_params(axis='x', labelrotation=45)
axes[0,1].tick_params(axis='x', labelrotation=45)
axes[1,0].tick_params(axis='x', labelrotation=45)
axes[1,1].tick_params(axis='x', labelrotation=45)

sns.histplot(ax=axes[0, 0], data=df_users, x='skin_tone', stat="percent")
sns.histplot(ax=axes[0, 1], data=df_users, x='eye_color', stat="percent")
sns.histplot(ax=axes[1, 0], data=df_users, x='skin_type', stat="percent")
sns.histplot(ax=axes[1, 1], data=df_users, x='hair_color', stat="percent")
```

```
[21]: <Axes: xlabel='hair_color', ylabel='Percent'>
```

Frequency Distribution for each Variable



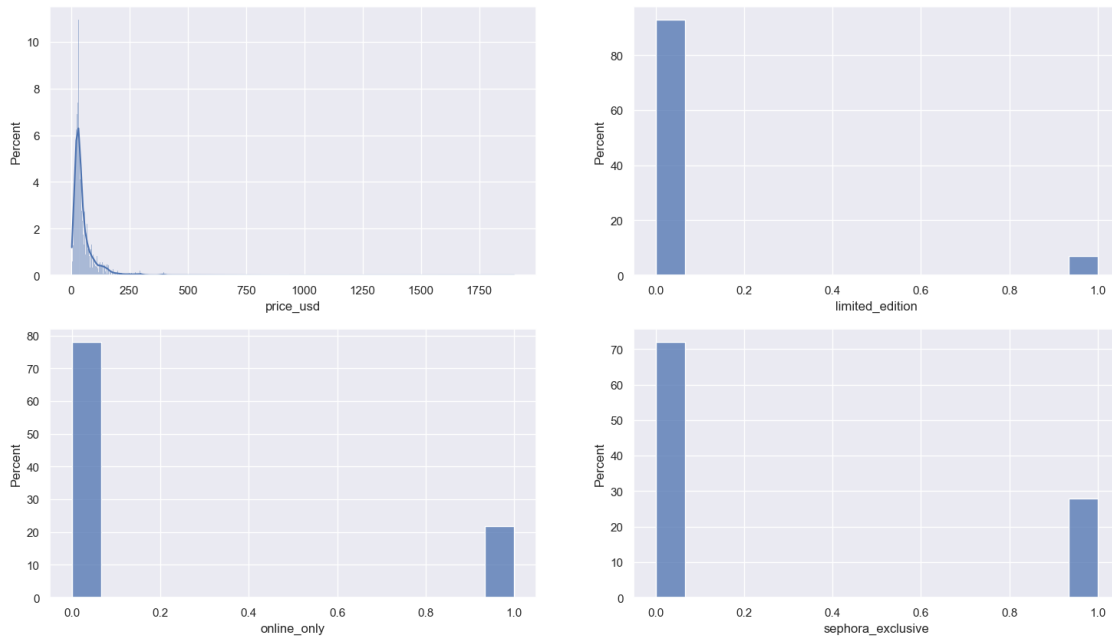
Products The binary factors (limited edition, online only, and sephora exclusive) have values of 0 and 1 and are heavily skewed toward the 0 (not) value.

```
[22]: fig, axes = plt.subplots(2, 2, figsize=(18, 10))
fig.suptitle('Frequency Distribution for each Variable')

sns.histplot(ax=axes[0, 0], data=df_products, x='price_usd', kde=True,
             stat="percent")
sns.histplot(ax=axes[0, 1], data=df_products, x='limited_edition',
             stat="percent")
sns.histplot(ax=axes[1, 0], data=df_products, x='online_only', stat="percent")
sns.histplot(ax=axes[1, 1], data=df_products, x='sephora_exclusive',
             stat="percent")
```

```
[22]: <Axes: xlabel='sephora_exclusive', ylabel='Percent'>
```

Frequency Distribution for each Variable

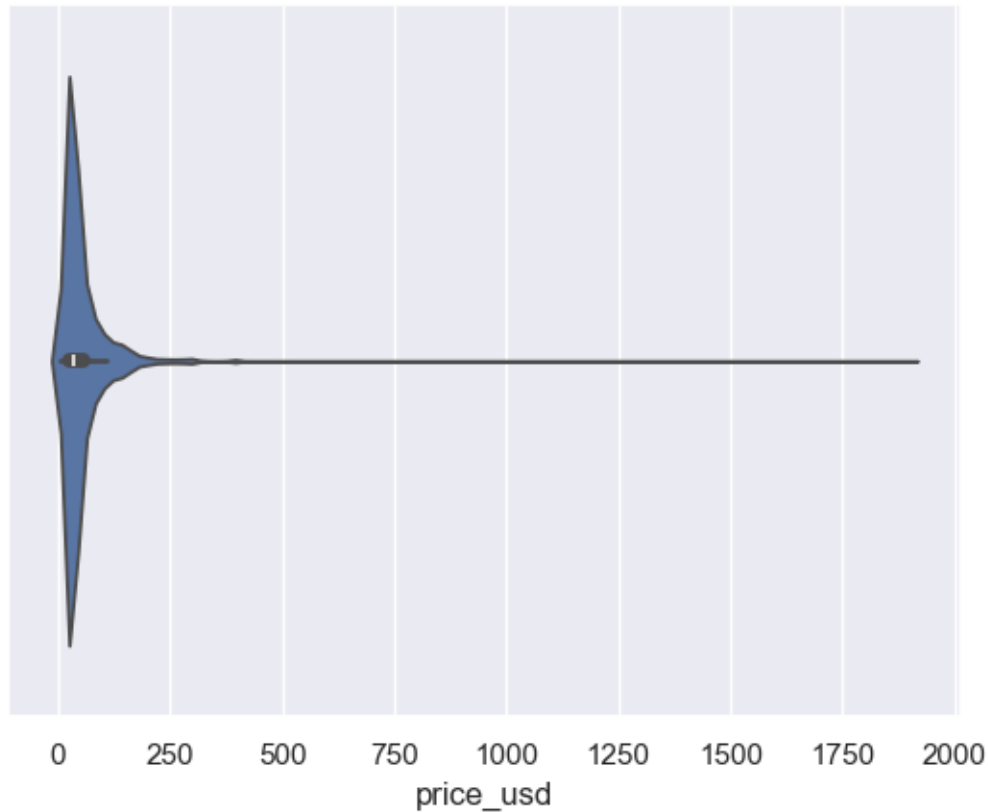


0.4.2 Outliers in Price

Price has some significant outliers given the third quartile at \\$58 and a max value of \\$1900. Removing outliers outside of 4 standard deviations will eliminate the significant outliers and leave 8113 rows in the dataset that follow a roughly normal distribution with a right skew.

```
[23]: sns.violinplot(data=df_products, x='price_usd')
```

```
[23]: <Axes: xlabel='price_usd'>
```



```
[24]: df_products['price_usd'].describe()
```

```
[24]: count      8494.000000
      mean        51.655595
      std        53.669234
      min         3.000000
      25%        25.000000
      50%        35.000000
      75%        58.000000
      max       1900.000000
      Name: price_usd, dtype: float64
```

```
[25]: total = len(df_products['price_usd'])
      z_scores = np.abs((df_products['price_usd'] - df_products['price_usd'].mean()) /
      ↪ df_products['price_usd'].std())

      for i in range(3,7):
          count = len(df_products['price_usd'][z_scores > i])
          print(f"Outliers outside {i} standard deviations: {count} ({count*100/total:
          ↪ .2f}% of dataset)")
```

Outliers outside 3 standard deviations: 163 (1.92% of dataset)
Outliers outside 4 standard deviations: 98 (1.15% of dataset)
Outliers outside 5 standard deviations: 37 (0.44% of dataset)
Outliers outside 6 standard deviations: 31 (0.36% of dataset)

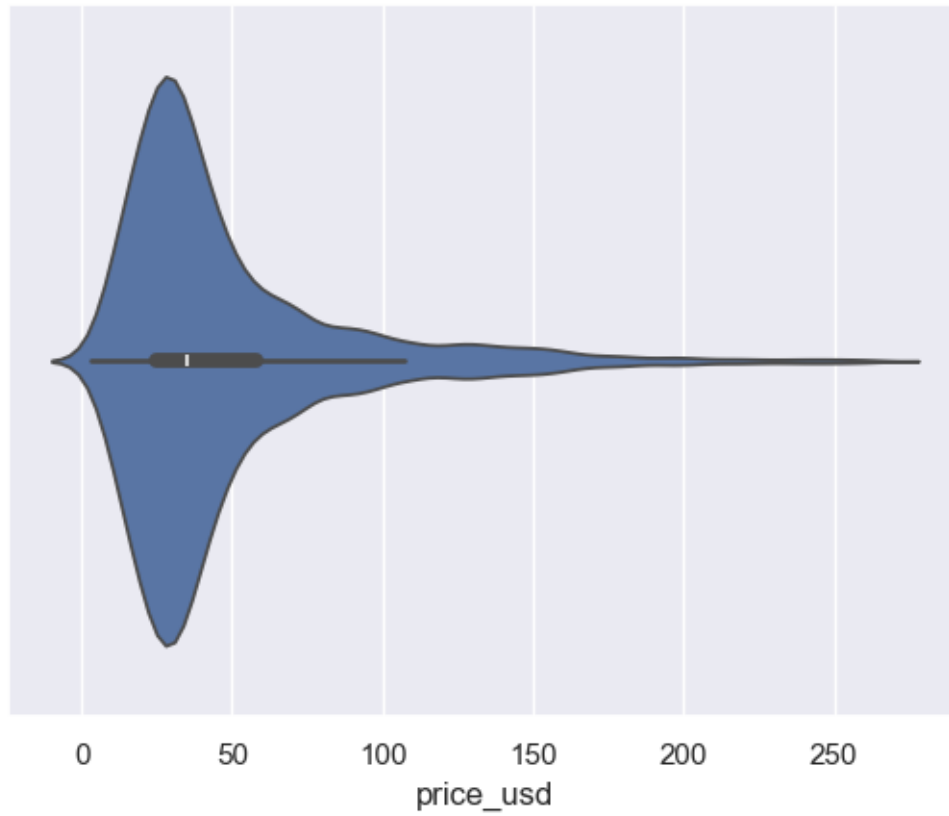
```
[26]: #Filter out rows with prices outside of 4 standard deviations from the mean
df_products = df_products[z_scores <= 4]
df_products['price_usd'].describe()
```

```
[26]: count      8396.000000
      mean       48.209578
      std       39.456292
      min        3.000000
      25%       25.000000
      50%       35.000000
      75%       58.000000
      max      265.000000
      Name: price_usd, dtype: float64
```

After removing the significant outliers, the price still has a right skew. However, the remaining outliers are less severe.

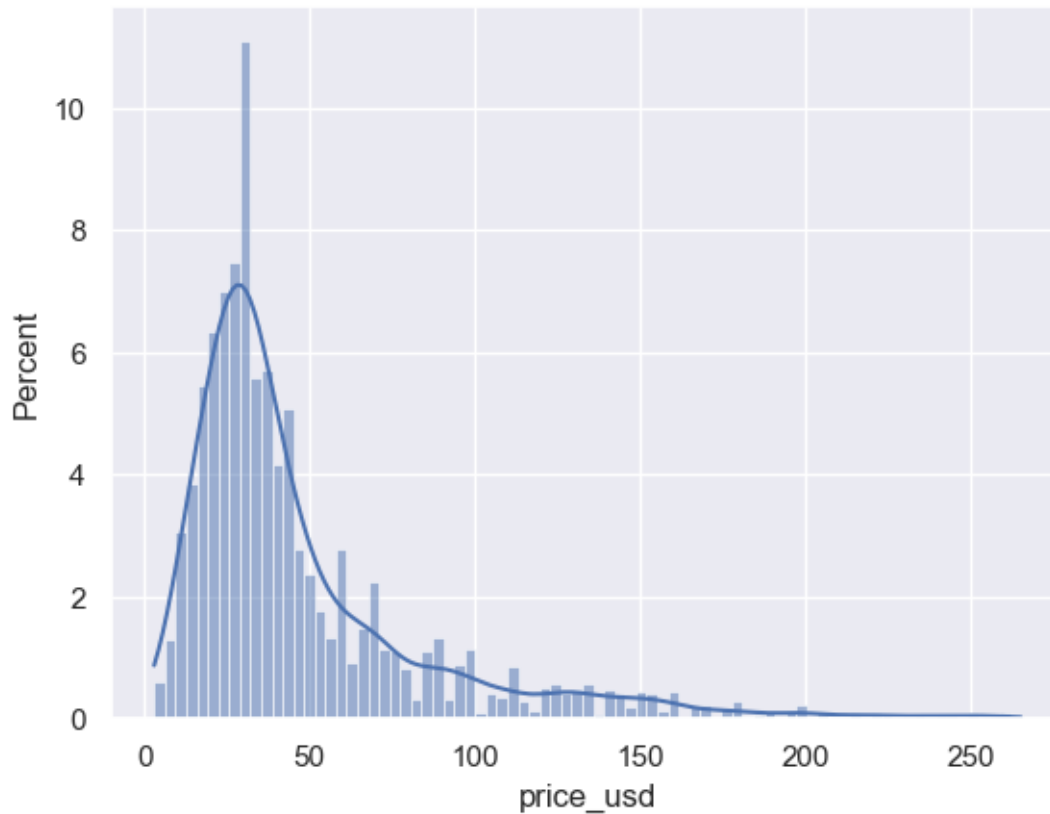
```
[27]: sns.violinplot(data=df_products, x='price_usd')
```

```
[27]: <Axes: xlabel='price_usd'>
```



```
[28]: sns.histplot(data=df_products, x="price_usd", kde=True, stat="percent")
```

```
[28]: <Axes: xlabel='price_usd', ylabel='Percent'>
```

0.4.3 Correlation Analysis

Correlation analysis of the numerical columns shows little to no correlation between the factors. The strongest correlation is between the price and Sephora exclusive factors at a -0.14, which is still a weak correlation.

```
[29]: df_corr = df_products[['price_usd', 'limited_edition', 'online_only',
    ↪ 'sephora_exclusive']]
```

```
[30]: df_corr.corr()
```

```
[30]:
```

	price_usd	limited_edition	online_only	sephora_exclusive
price_usd	1.000000	0.055505	0.084031	-0.163157
limited_edition	0.055505	1.000000	0.060368	0.065669
online_only	0.084031	0.060368	1.000000	-0.101281
sephora_exclusive	-0.163157	0.065669	-0.101281	1.000000

```
[31]: fig, ax = plt.subplots(figsize=(7, 4))
    #Plot a heatmap using correlation matrix
    sns.heatmap(df_corr.corr(), annot=True, fmt=".2f", linewidth=.1, cmap="RdBu_r",
    ↪ ax=ax)
```

```
plt.show()
```



0.4.4 Sync up Rating, User, and Product Datasets

I removed a number of rows from the user and product datasets, so I need to ensure that any rows remaining in the rating dataset have `author_id` and `product_id` values that exist in the user and product datasets, respectively.

```
[32]: df_ratings = df_ratings[df_ratings['author_id'].isin(df_users['author_id']) &
      ↪ df_ratings['product_id'].isin(df_products['product_id'])]
```

0.5 Modeling

I first split the rating data into a training and test set. I filtered the test set to ensure that the users and products were in the training set, which left me with I then create a sparse matrices to hold the ratings for all users and products. This left a training set of 778,457 rows and a test set of 140,659 rows.

```
[33]: x_train, x_test = train_test_split(df_ratings, test_size=.2, random_state=42)
      x_train.shape
```

```
[33]: (778457, 3)
```

```
[34]: x_test.shape
```

```
[34]: (194615, 3)
```

```
[35]: x_test = x_test[x_test['author_id'].isin(x_train['author_id'])]
x_test.shape
```

```
[35]: (140664, 3)
```

```
[36]: x_test = x_test[x_test['product_id'].isin(x_train['product_id'])]
x_test.shape
```

```
[36]: (140659, 3)
```

```
[37]: df_ratings.head()
```

```
[37]:
```

	author_id	product_id	rating
2	5.061282e+09	P420652	5
3	6.083039e+09	P420652	5
4	4.705667e+10	P420652	5
5	4.280257e+10	P420652	4
6	6.941884e+09	P420652	2

0.5.1 Create Sparse Rating Matrices

```
[38]: user_count = len(df_ratings['author_id'].unique())
prod_count = len(df_ratings['product_id'].unique())

# Map Ids to indices
user_id_to_idx = dict(zip(np.unique(df_ratings["author_id"]),
    ↳list(range(user_count))))
prod_id_to_idx = dict(zip(np.unique(df_ratings["product_id"]),
    ↳list(range(prod_count))))

# Map indices to IDs
prod_idx_to_id = dict(zip(list(range(prod_count)), np.
    ↳unique(df_ratings["product_id"])))

user_index = [user_id_to_idx[i] for i in x_train['author_id']]
prod_index = [prod_id_to_idx[i] for i in x_train['product_id']]

rating_matrix_csr = csr_matrix((x_train["rating"], (prod_index, user_index)),
    ↳shape=(prod_count, user_count))
rating_matrix_coo = np.array(coo_matrix((list(x_train['rating']), (user_index,
    ↳prod_index)), shape=(user_count, prod_count)).toarray())
```

0.5.2 Predict Ratings Using Collaborative Similarity

I created an unsupervised learning model to predict user-product ratings. The model used both cosine and jaccard similarity measures.

```

[39]: def predict_from_sim(userID, prodID, sim_matrix, rat_matrix):
    #1. Get index of the provided user id
    index_userID = user_id_to_idx[userID]

    #2. Get all the user ratings for the user using index_userID
    ratings_index_userID = rat_matrix[index_userID]

    #3. Get index of the provided product id
    index_prodID = prod_id_to_idx[prodID]

    #4. Get all the similarity scores using index_prodID
    prod_sims = sim_matrix[index_prodID]

    #5. Take the averaged dot product.
    valid_ratings = (ratings_index_userID != 0)

    num = np.dot(ratings_index_userID, prod_sims)
    den = np.dot(prod_sims, valid_ratings)
    return num / den

def predict(sim_matrix, rat_matrix):
    test_preds = []
    for i in range(len(x_test)):
        userID = x_test.iloc[i]['author_id']
        prodID = x_test.iloc[i]['product_id']
        test_preds.append(predict_from_sim(userID, prodID, sim_matrix,
↪rat_matrix))
    return np.array(test_preds)

def cossim(xr):
    #Algorithm:
    #1. Compute averaged product ratings for all users
    ↪(prod_ratings_allUsers)
    #Calcs mean of each row
    prod_ratings_allUsers = xr.sum(axis=1) / np.count_nonzero(xr, axis=1)

    #2. Create a sparse matrix for operating cosine on its values:
    prod_ratings_array = np.repeat(np.expand_dims(prod_ratings_allUsers,
↪axis=1), xr.shape[1], axis=1)

    #3. Take care of all the zero ratings (missing value/intentionally we don't
    ↪know):
    prod_ratings_array_adjusted = xr + (xr==0)*prod_ratings_array -
    ↪prod_ratings_array

    #4. Average all the ratings: divide by its magnitude!

```

```

    rating_avg = prod_ratings_array_adjusted/np.
    ↪sqrt((prod_ratings_array_adjusted**2).sum(axis=0))

    #5. Put a Boundary check # 1: since dividing by magnitude may produce inf,
    ↪zeros, etc. Set nans to 0.
    rating_avg = np.nan_to_num(rating_avg, 0)

    #6. Perform an item-item cosine similarity using: np.dot(matrix.T, matrix)
    similarity = np.dot(rating_avg.T, rating_avg)

    #7. Put a Boundary check # 2: Covariance/correlation values for np.dot([M.
    ↪T, M]) matrix should have
    #    diagonal set to 1.
    np.fill_diagonal(similarity, 1)

    #8. Normalized Cosine Formula:
    similarity = np.multiply(similarity, 0.5) + 0.5

    return similarity

def jacsim(Xr):
    # Return a sim matrix by calculating item-item similarity for all pairs of
    ↪items using Jaccard similarity
    # Jaccard Similarity:  $J(A, B) = |A \cap B| / |A \cup B|$ 
    n = Xr.shape[1]
    maxr = int(Xr.max())

    #This is only used for the non-transformed case
    if maxr>1:
        nz_inter = np.zeros((n,n)).astype(int)
        for i in range(1, maxr+1):
            csr = csr_matrix((Xr==i).astype(int))
            nz_inter = nz_inter + np.array(csr.T.dot(csr).toarray()).astype(int)
    else:
        # Convert Xr into a CSR format
        csr0 = csr_matrix((Xr>0).astype(int))

        # Take the dot product
        nz_inter = np.array(csr0.T.dot(csr0).toarray()).astype(int)

    # Formula JS:
    A = (Xr>0).astype(bool)
    rowsum = A.sum(axis=0)
    rsumtile = np.repeat(rowsum.reshape((n,1)),n,axis=1)
    union = rsumtile.T + rsumtile - nz_inter

    # Perform the two boundary checks:-

```

```

# - since dividing by magnitude may produce inf, zeros, etc. Set nans to 0.
# - Covariance/correlation values for np.dot([M.T, M]) matrix should have
#   diagonal set to 1.

union = np.nan_to_num(union, 0)
intersection = np.nan_to_num(nz_inter, 0)

similarity = np.divide(intersection, union, out=np.zeros_like(intersection,
dtype=float), where=union!=0)
np.fill_diagonal(similarity, 1)
return similarity

def rmse(yp):
    yp[np.isnan(yp)]=3 #In case there is nan values in prediction, it will
    impute to 3.
    yt=np.array(x_test['rating'])
    return np.sqrt(((yt-yp)**2).mean())

```

```
[40]: sim_matrix = cossim(rating_matrix_coo)
```

```
[41]: yp = predict(sim_matrix, rating_matrix_coo)
print(rmse(yp))
```

```
1.0881795275262927
```

```
[42]: jacsim_matrix = jacsim(rating_matrix_coo)
```

```
[43]: yp = predict(jacsim_matrix, rating_matrix_coo)
print(rmse(yp))
```

```
1.1191216782108373
```

0.5.3 Predict Using Non-Negative Matrix Factorization (NMF)

I created an unsupervised model to predict user-product ratings using Non-Negative Matrix Factorization (NMF).

```

[44]: def predict_nmf(all_preds):
    """
    Predict ratings in the test data. Returns predicted rating in a numpy array
    of size (# of rows in testdata,)
    """
    test_preds = []
    for i, row in x_test.iterrows():
        index_userID = user_id_to_idx[row['author_id']]
        index_prodID = prod_id_to_idx[row['product_id']]
        rating = all_preds[index_prodID][index_userID]
        test_preds.append(rating)

```

```
return np.array(test_preds)
```

```
[45]: model = NMF(n_components=5)
W = model.fit_transform(rating_matrix_csr)
H = model.components_
pred_ratings = np.dot(W, H)

y_pred = predict_nmf(pred_ratings)
rmse(y_pred)
```

```
[45]: 4.328119322146862
```

0.5.4 Recommendation System Using K-Nearest Neighbors

Now that I've implemented rating prediction, I enhanced the solution by building a recommender system. I used k-nearest neighbors to return the recommendations for a given user. The recommendations are centered around the user's favorite (highest-rated) product. Using two different distance metrics for the neighbor calculations provided different recommendations for the same user, as shown below.

```
[46]: def find_similar_products(target_prod_id, rating_matrix, k, metric='cosine'):
    neighbor_ids = []

    product_to_match = prod_id_to_idx[target_prod_id]
    prod_vector = rating_matrix[product_to_match]
    k += 1 #Increase by one because the target product will be included by
↪NearestNeighbors

    kNN = NearestNeighbors(n_neighbors=k, metric=metric)
    kNN.fit(rating_matrix)
    neighbor = kNN.kneighbors(prod_vector, return_distance=False)

    for i in range(0, k):
        n = neighbor.item(i)
        neighbor_ids.append(prod_idx_to_id[n])

    neighbor_ids.pop(0) # Remove the target product from the final list
    return neighbor_ids
```

```
[47]: def recommend_prods_for_user(user_id, rating_matrix, user_id_to_idx,
    ↪prod_id_to_idx, prod_idx_to_id, metric, k=5):
    df = df_ratings[df_ratings['author_id'] == user_id]

    # Find the user's highest-rated product and k-nearest neighbors
    fav_prod_id = df[df['rating'] == max(df['rating'])]['product_id'].iloc[0]
    similar_ids = find_similar_products(fav_prod_id, rating_matrix, k,
    ↪metric=metric)
```

```

# Map product IDs to product names
prod_names = dict(zip(df_products['product_id'],
↪df_products['product_name']))

print(f"Since you liked {prod_names[fav_prod_id]}, you might also like:")

for i in similar_ids:
    if i in prod_names:
        print(f"* {prod_names[i]}")

```

```

[48]: user_id = 6047267707
recommend_prods_for_user(user_id, rating_matrix_csr, user_id_to_idx,
↪prod_id_to_idx, prod_idx_to_id, metric='cosine')

```

Since you liked Greek Yoghurt Foaming Cream Cleanser, you might also like:

- * Extra Illuminating Moisture Balm
- * Greek Yoghurt Nourishing Probiotic Gel-Cream
- * POWER Recharging Night Pressed Serum
- * Pep-Start Eye Cream
- * Advanced Night Repair Synchronized Multi-Recovery Complex Duo

```

[49]: user_id = 6047267707
recommend_prods_for_user(user_id, rating_matrix_csr, user_id_to_idx,
↪prod_id_to_idx, prod_idx_to_id, metric='euclidean')

```

Since you liked Greek Yoghurt Foaming Cream Cleanser, you might also like:

- * ExfoliKate All Over Glow Kit
- * Big Break Soap Set
- * 3 Step Intro Kit Type II
- * Break from the Burnout Skin Wellness Set
- * Glow Facial Set

0.6 Results and Analysis

0.6.1 Model Comparison

The cosine similarity model performed better than the jaccard similarity and NMF models based on root mean squared error. The NMF likely did not perform well because of the sparsity of the training data (i.e., the training data was missing ratings for most user-product combinations). Using a zero for the missing data would skew the predictions because the 0 value falls outside of the valid range of 1-5.

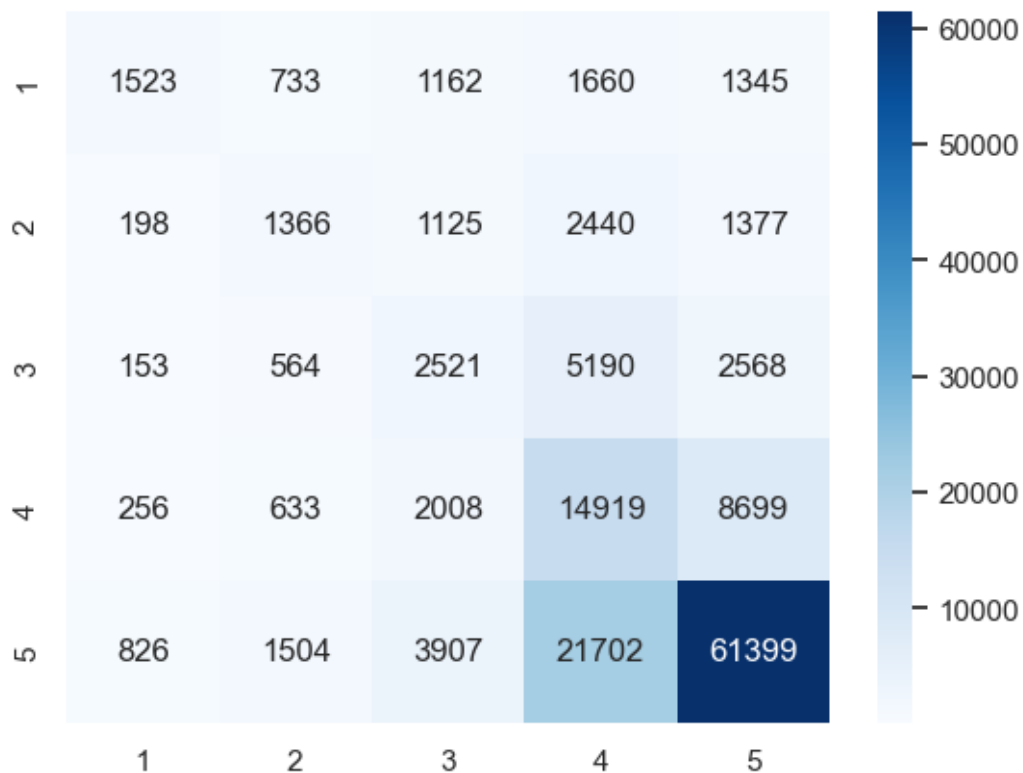
Method	RMSE
Collaborative, cosine	1.088
Collaborative, jaccard	1.119
NMF	4.328

I plotted the confusion matrix of the cosine similarity model, which had the lowest RMSE of the models I built. The training data was heavily skewed toward high ratings, which also show up in the predicted test ratings in terms of both accurate and inaccurate predictions.

```
[50]: y_pred = predict(sim_matrix, rating_matrix_coo)
      y_pred_rounded = np.round(y_pred, decimals=0, out=None)

[51]: cm = confusion_matrix(x_test['rating'], y_pred_rounded, labels=[1,2,3,4,5])
      sns.heatmap(cm, annot=True, cmap='Blues', fmt='g', xticklabels=[1,2,3,4,5],
      ↪ yticklabels=[1,2,3,4,5])
```

[51]: <Axes: >



0.6.2 Improving Performance Through Hypertuning Parameters

I adjusted the number of components to see if I could improve the performance of the NMF model. The RMSE improved as the number of components increased, but the RMSE was still significantly above that of the collaborative similarity models.

```
[52]: components = [5, 15, 25, 50]
      for n in components:
          model = NMF(n_components=n)
          W = model.fit_transform(rating_matrix_csr)
```

```
H = model.components_  
pred_ratings = np.dot(W, H)  
y_pred = predict_nmf(pred_ratings)  
error = rmse(y_pred)  
print(f"{n} components RMSE: {error:.2f}")
```

```
5 components RMSE: 4.33  
15 components RMSE: 4.23  
25 components RMSE: 4.15  
50 components RMSE: 4.07
```

0.7 Discussion and Conclusion

0.7.1 Learnings and Takeaways

Understanding and cleaning the data is incredibly important to creating a useful and accurate model. There is a delicate balance between eliminating noise in the data and inadvertently skewing the data, so it is important to repeatedly inspect the data for bias.

0.7.2 Things that Did Not Go as Planned

The NMF prediction did not perform as well as collaborative models. This could be due to the sparseness of the ratings in the training set (i.e., users did not rate all movies). Increasing the number of components or imputing missing values to make the matrix less sparse could improve the RMSE. Note that when imputing missing values, it would be better to use something other than zero (e.g., use the user's average rating) because filling in missing values as zero falls outside of the "valid" ratings of 1-5.

0.7.3 Ways to Improve

Ideally, the dataset would be more balanced between user and product features. This would allow for a more accurate model with less bias. The models would also have benefitted from more user-product ratings to make the rating matrix less sparse.

0.8 References

1. <https://scikit-learn.org/stable/modules/neighbors.html>
2. <https://scikit-learn.org/stable/modules/generated/sklearn.decomposition.NMF.html>
3. <https://www.geeksforgeeks.org/recommendation-system-in-python/>

[]: