

mega_mart

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1 MegaMart Customer Segmentation Analysis

1.0.1 TEAM 10

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1.1 Section 1: Project Setup & Data Loading

```
[274]: import pandas as pd
import numpy as np
from sklearn import datasets
from scipy import stats
import seaborn as sns
import matplotlib.pyplot as plt
from sklearn.preprocessing import StandardScaler
from scipy.cluster.hierarchy import linkage, dendrogram
from scipy.cluster.hierarchy import fcluster
from sklearn.metrics import silhouette_score
from sklearn.cluster import KMeans
import matplotlib.cm as cm
from sklearn.metrics import silhouette_samples
from sklearn.decomposition import PCA
```

```
[275]: df = pd.read_csv("retail_customer_data-1.csv")
df.head()
```

```
[275]:   customer_id  monthly_transactions  avg_basket_size  total_spend \
0    CUST_0001                  1.8            3.0      527.04
1    CUST_0002                  5.4            4.5     1137.72
2    CUST_0003                  2.9            4.4      670.28
3    CUST_0004                 12.0            22.8     6359.35
4    CUST_0005                  2.2            17.6     4058.48

          avg_session_duration  email_open_rate  product_views_per_visit \
0                      38.1           0.95                  17.3
1                      20.0           0.00                  16.1
```

2	64.3	0.52	36.9
3	37.9	0.17	42.2
4	22.5	0.53	18.4
	return_rate	customer_tenure_months	recency_days
0	0.00	23	33
1	0.41	1	8
2	0.11	32	39
3	0.00	21	5
4	0.15	20	18

```
[276]: df.info()
df.describe()
```

```
<class 'pandas.core.frame.DataFrame'>
RangeIndex: 3000 entries, 0 to 2999
Data columns (total 10 columns):
 #   Column           Non-Null Count  Dtype  
 ---  --  
 0   customer_id      3000 non-null   object 
 1   monthly_transactions 3000 non-null   float64
 2   avg_basket_size    3000 non-null   float64
 3   total_spend        3000 non-null   float64
 4   avg_session_duration 3000 non-null   float64
 5   email_open_rate    3000 non-null   float64
 6   product_views_per_visit 3000 non-null   float64
 7   return_rate         3000 non-null   float64
 8   customer_tenure_months 3000 non-null   int64  
 9   recency_days        3000 non-null   int64  
dtypes: float64(7), int64(2), object(1)
memory usage: 234.5+ KB
```

```
[276]: monthly_transactions  avg_basket_size  total_spend  \
count          3000.000000     3000.000000  3000.000000
mean           6.011300      9.485133   2367.375387
std            4.776564      7.961280   2248.271454
min           0.200000      1.000000   50.000000
25%           2.100000      3.300000   511.115000
50%           5.000000      5.600000  1456.105000
75%           8.800000     17.325000  3772.227500
max          22.300000     31.600000  8746.290000

avg_session_duration  email_open_rate  product_views_per_visit  \
count          3000.000000     3000.000000  3000.000000
mean           38.441533      0.443720   31.359467
std            14.334159      0.427384   9.964088
min           3.400000      0.000000   3.000000
25%           27.000000      0.000000  24.900000
```

50%	36.550000	0.340000	31.600000
75%	49.400000	0.950000	37.800000
max	87.300000	0.950000	62.400000

	return_rate	customer_tenure_months	recency_days
count	3000.000000	3000.000000	3000.000000
mean	0.185890	17.912667	20.680667
std	0.162283	11.242294	12.055419
min	0.000000	1.000000	1.000000
25%	0.040000	9.000000	11.000000
50%	0.150000	18.000000	18.000000
75%	0.290000	26.000000	29.250000
max	0.500000	59.000000	67.000000

Initial Findings The dataset contains 3,000 records of active customers. There are no null values in any variable, indicating that the dataset is complete and clean.

Out of the 10 columns, 9 are numerical behavioral variables and 1 is an identifier (`customer_id`). The key behavioral metrics include: `monthly_transactions`, `avg_basket_size`, `total_spend`, `avg_session_duration`, `email_open_rate`, `product_views_per_visit`, `return_rate`, `customer_tenure_months`, and `recency_days`.

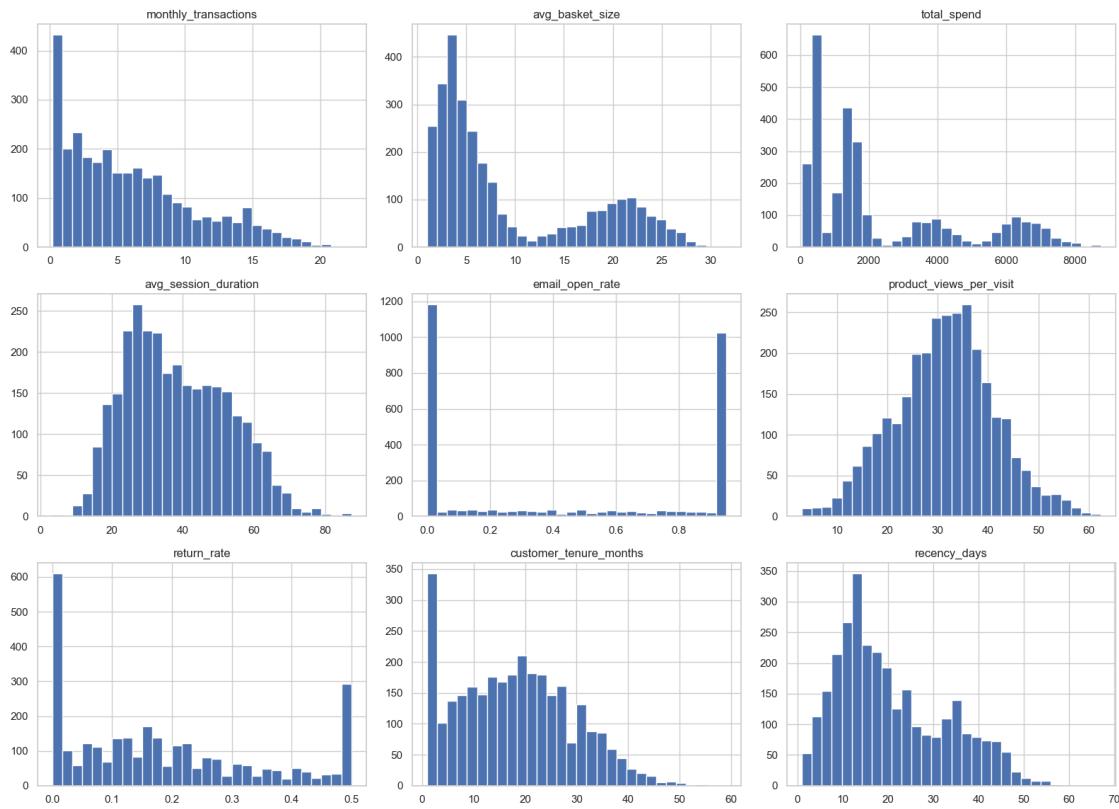
There is high variability in customer behavior. For instance, total annual spending (`total_spend`) ranges from as low as \$50 to over \$8,700; email open rates (`email_open_rate`) vary from 0.00 to 0.95; and customer tenure (`customer_tenure_months`) spans from 1 to 59 months. Additionally, the data shows significant differences in scale between variables (`return_rate` ranges from 0.00 to 0.50, while `total_spend` reaches up to 8,700).

1.2 Section 2: Exploratory Data Analysis (EDA)

1.2.1 2.1-Variable Distributions:

```
[277]: df_numeric = df.drop(columns=["customer_id"])
sns.set(style="whitegrid")
df_numeric.hist(bins=30, figsize=(16, 12), layout=(3, 3))
plt.suptitle("Variable Distributions (Histograms)", fontsize=18, y=1.02)
plt.tight_layout()
plt.show()
```

Variable Distributions (Histograms)



1.2.2 2.2-Correlation Analysis

```
[278]: correlation_matrix = df_numeric.corr()
plt.figure(figsize=(10, 8))
sns.heatmap(correlation_matrix, annot=True, cmap="Blues", fmt=".2f")
plt.title("Correlation Matrix Heatmap", fontsize=16)
plt.show()
```



1.2.3 Highly correlated variables

The correlation matrix reveals several strong relationships between variables:

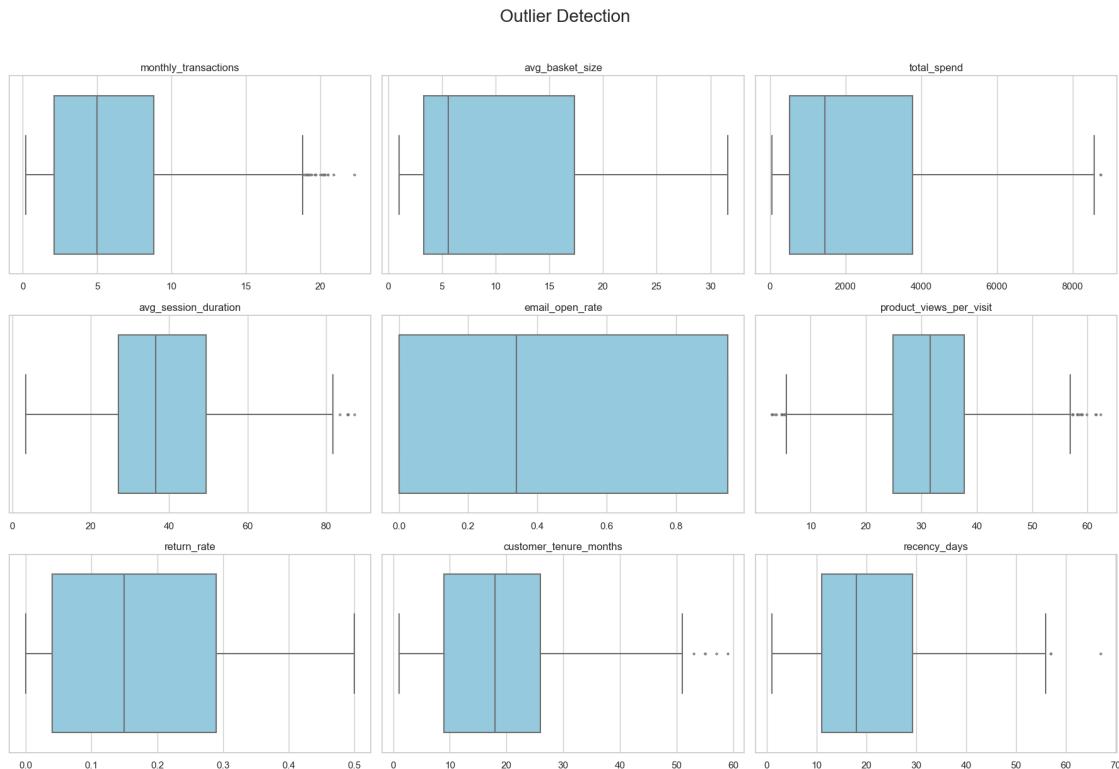
- **avg_basket_size** and **total_spend** show a very strong positive correlation (**0.94**), suggesting that customers who spend more typically have larger baskets.
- **monthly_transactions** and **total_spend** are also highly correlated (**0.76**), indicating that more frequent shoppers tend to spend more overall.
- **monthly_transactions** and **avg_basket_size** have a moderate positive correlation (**0.69**), which reinforces the pattern of more active customers also having higher basket values.
- **avg_session_duration** and **product_views_per_visit** are moderately correlated (**0.50**), hinting that longer sessions lead to more product exploration.
- **recency_days** is **negatively correlated** with both **monthly_transactions** (**-0.63**) and **total_spend** (**-0.61**), suggesting that more recent activity is associated with higher engagement and spending.

1.2.4 2.3-Outlier Detection:

```
[279]: fig, axes = plt.subplots(3, 3, figsize=(18, 12))
fig.suptitle(" Outlier Detection ", fontsize=20, y=1.02)

for ax, col in zip(axes.flatten(), df_numeric.columns):
    sns.boxplot(x=df_numeric[col],
                 ax=ax,
                 color="skyblue",
                 fliersize=2,
                 linewidth=1.5)
    ax.set_title(col, fontsize=12)
    ax.set_xlabel("")

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



1.2.5 2.4-Scatter Plots:

```
[280]: sns.set(style="whitegrid")
df_numeric = df.drop(columns=["customer_id"])

fig, axes = plt.subplots(3, 1, figsize=(10, 18))
```

```

fig.suptitle(" Key Variable Relationships ", fontsize=22, y=1.02)

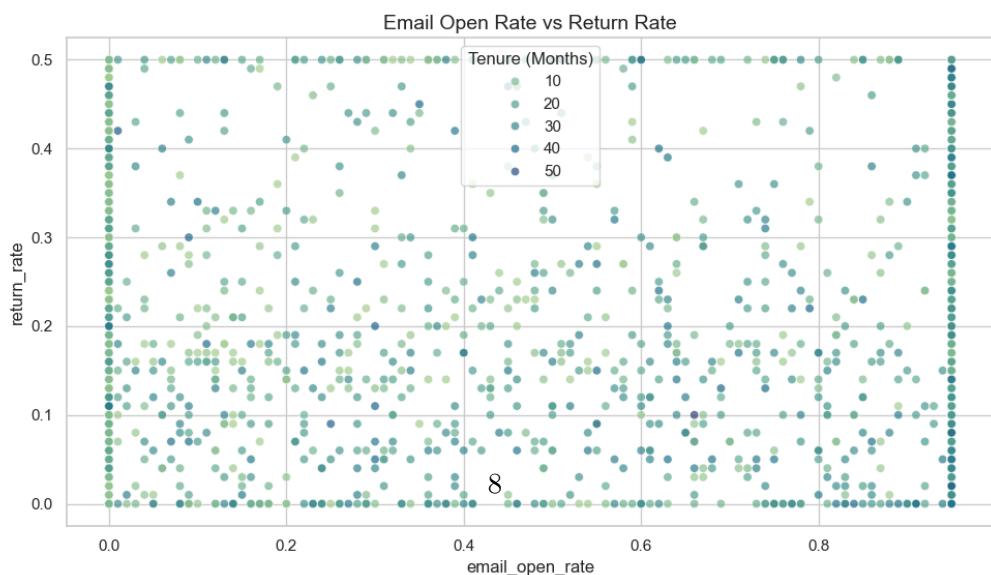
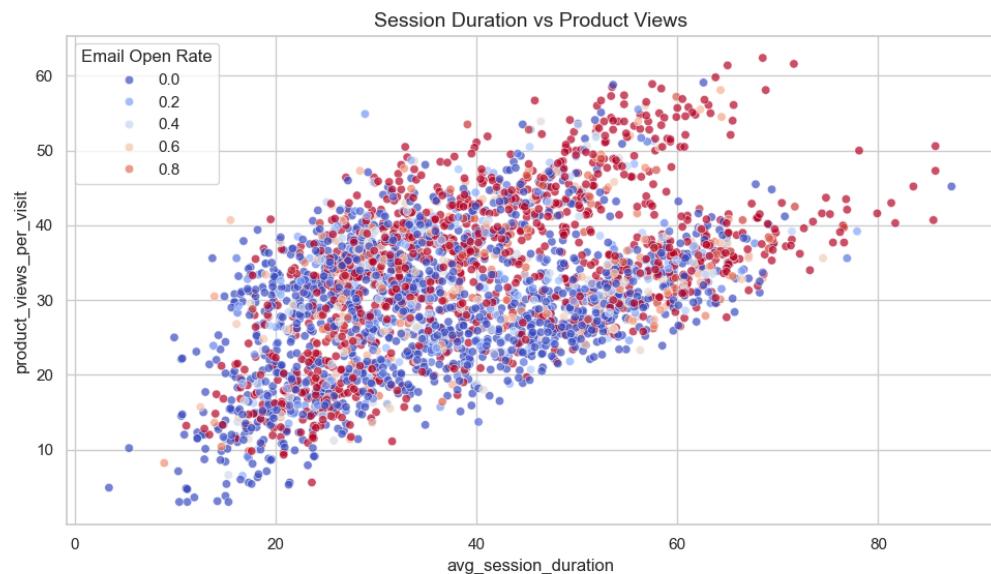
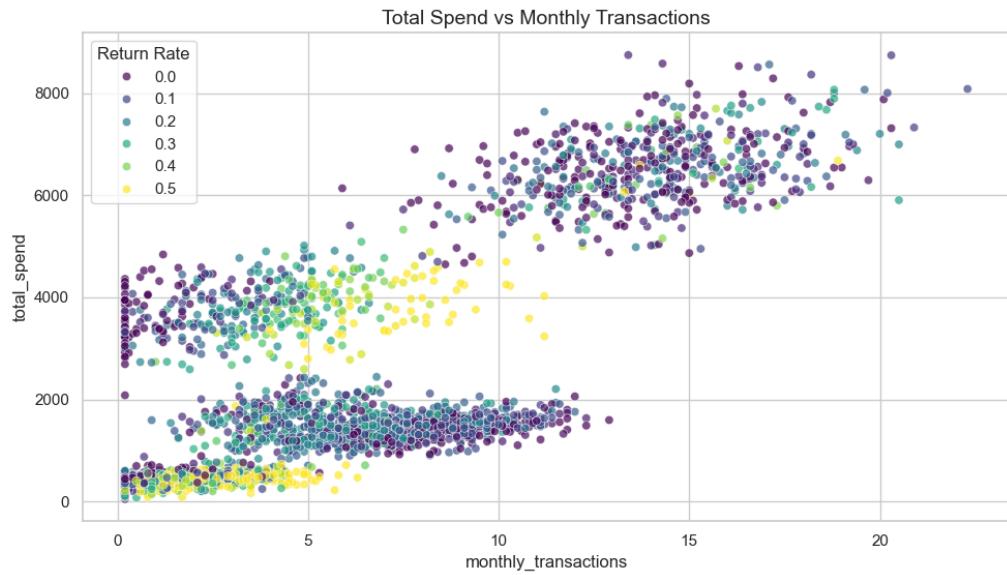
sns.scatterplot(data=df_numeric,
                 x="monthly_transactions", y="total_spend",
                 hue="return_rate", palette="viridis", alpha=0.7,
                 ax=axes[0])
axes[0].set_title("Total Spend vs Monthly Transactions", fontsize=14)
axes[0].legend(title="Return Rate", loc="best")

sns.scatterplot(data=df_numeric,
                 x="avg_session_duration", y="product_views_per_visit",
                 hue="email_open_rate", palette="coolwarm", alpha=0.7,
                 ax=axes[1])
axes[1].set_title("Session Duration vs Product Views", fontsize=14)
axes[1].legend(title="Email Open Rate", loc="best")

sns.scatterplot(data=df_numeric,
                 x="email_open_rate", y="return_rate",
                 hue="customer_tenure_months", palette="crest", alpha=0.7,
                 ax=axes[2])
axes[2].set_title("Email Open Rate vs Return Rate", fontsize=14)
axes[2].legend(title="Tenure (Months)", loc="best")
plt.tight_layout(rect=[0, 0, 1, 0.97])
plt.show()

```

Key Variable Relationships



1.3 Section 3: Data Preprocessing

1.3.1 3.1-Check for Missing Data:

```
[281]: missing_values = df.isnull().sum()
if missing_values.sum() == 0:
    print(" No missing values.")
```

No missing values.

1.3.2 3.2-Standardization

```
[282]: scaler = StandardScaler()
scaled_array = scaler.fit_transform(df_numeric)
df_scaled = pd.DataFrame(scaled_array, columns=df_numeric.columns)
df_scaled.head()
```

```
[282]:   monthly_transactions  avg_basket_size  total_spend  avg_session_duration \
0           -0.881806        -0.814720      -0.818692       -0.023831
1           -0.128000        -0.626277      -0.547025       -1.286759
2           -0.651476        -0.638840      -0.754970       1.804276
3            1.253976        1.672732       1.775871      -0.037786
4           -0.798050        1.019462       0.752305      -1.112321

   email_open_rate  product_views_per_visit  return_rate \
0          1.184799        -1.411249      -1.145657
1         -1.038395        -1.531702      1.381211
2          0.178511         0.556143      -0.467717
3         -0.640561         1.088142      -1.145657
4          0.201913        -1.300834      -0.221193

  customer_tenure_months  recency_days
0             0.452593      1.022062
1            -1.504629     -1.052040
2             1.253275      1.519847
3             0.274664     -1.300932
4             0.185699     -0.222399
```

```
[283]: df_scaled.describe()
```

```
[283]:   monthly_transactions  avg_basket_size  total_spend \
count      3.000000e+03      3.000000e+03  3.000000e+03
mean       1.290819e-16     -4.263256e-17  2.842171e-17
std        1.000167e+00      1.000167e+00  1.000167e+00
min        -1.216830e+00     -1.065978e+00 -1.030908e+00
25%       -8.189887e-01     -7.770313e-01 -8.257765e-01
```

```

50%           -2.117565e-01   -4.880849e-01  -4.053880e-01
75%            5.839270e-01   9.849136e-01   6.249629e-01
max            3.410697e+00   2.778266e+00   2.837726e+00

      avg_session_duration  email_open_rate  product_views_per_visit \
count      3.000000e+03      3.000000e+03      3.000000e+03
mean       7.460699e-17     -8.526513e-17     4.973799e-17
std        1.000167e+00     1.000167e+00     1.000167e+00
min        -2.445025e+00    -1.038395e+00    -2.846642e+00
25%        -7.983336e-01    -1.038395e+00    -6.483828e-01
50%        -1.319818e-01    -2.427260e-01     2.414405e-02
75%         7.646276e-01     1.184799e+00     6.464824e-01
max         3.409102e+00     1.184799e+00     3.115760e+00

      return_rate  customer_tenure_months  recency_days
count  3.000000e+03      3.000000e+03      3.000000e+03
mean   -1.539509e-16     2.368476e-18     -4.263256e-17
std     1.000167e+00     1.000167e+00     1.000167e+00
min    -1.145657e+00    -1.504629e+00    -1.632788e+00
25%    -8.991336e-01    -7.929123e-01    -8.031475e-01
50%    -2.211934e-01     7.769579e-03    -2.223990e-01
75%     6.416396e-01     7.194868e-01     7.109468e-01
max     1.935889e+00     3.655320e+00     3.842841e+00

```

1.3.3 3.3-Explain your choice

1.3.4 Standardization in Clustering

Standardization is essential before applying clustering algorithms because most clustering methods rely on distance based calculations. Without standardizing, variables with larger numerical ranges would disproportionately influence the results. In the original dataset, the `total_spend` variable ranges from **\$50 to over \$8,700**, while `return_rate` ranges only from **0.00 to 0.50**. If we don't scale the data, `total_spend` will dominate the distance metric simply due to its magnitude, even if `return_rate` is more informative. With standardization we bring all variables to a common scale, ensuring that each variable contributes equally to the clustering.

You can clearly see the difference by comparing the `.describe()` output of both DataFrames:

- Before standardization, variables had different means and wildly varying ranges.
- After standardization, all variables have similar ranges (mostly between -2 and +3) and standard deviations around 1.

1.4 Section 4: Hierarchical Clustering Analysis

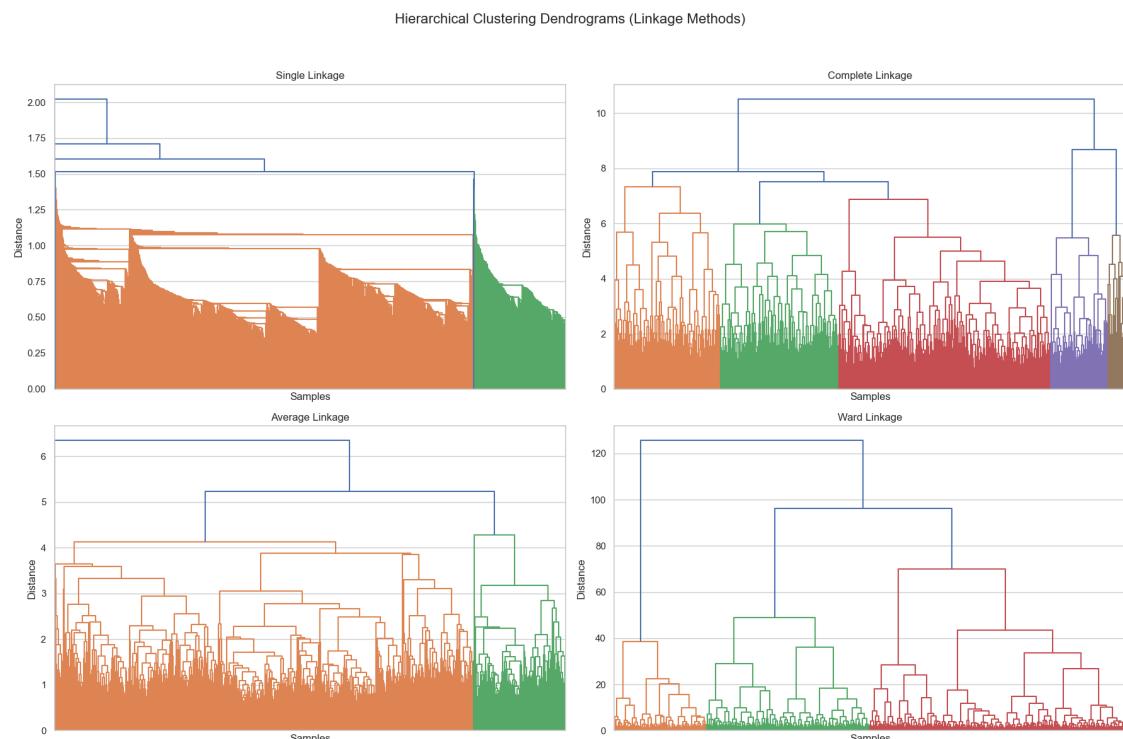
1.4.1 4.1-Compute Linkage Matrices

```
[284]: linkage_single = linkage(df_scaled, method='single')
linkage_complete = linkage(df_scaled, method='complete')
linkage_average = linkage(df_scaled, method='average')
linkage_ward = linkage(df_scaled, method='ward')
```

1.4.2 4.2-Create Dendrograms

```
[285]: fig, axes = plt.subplots(2, 2, figsize=(18, 12))
fig.suptitle('Hierarchical Clustering Dendrograms (Linkage Methods)', fontweight='bold', fontstyle='italic', fontsize=16)
dendrogram(linkage_single, ax=axes[0, 0], no_labels=True)
axes[0, 0].set_title("Single Linkage")
dendrogram(linkage_complete, ax=axes[0, 1], no_labels=True)
axes[0, 1].set_title("Complete Linkage")
dendrogram(linkage_average, ax=axes[1, 0], no_labels=True)
axes[1, 0].set_title("Average Linkage")
dendrogram(linkage_ward, ax=axes[1, 1], no_labels=True)
axes[1, 1].set_title("Ward Linkage")
for ax in axes.flat:
    ax.set_xlabel("Samples")
    ax.set_ylabel("Distance")

plt.tight_layout(rect=[0, 0, 1, 0.95])
plt.show()
```



1.4.3 4.3-Interpret Dendrograms

How do the linkage methods work?

- Single Linkage: Merges clusters based on the minimum distance between any pair of points from each group.
- Complete Linkage: Uses the maximum distance between points from different groups.
- Average Linkage: Calculates the average distance between all pairs of points across clusters.
- Ward Linkage: Merges clusters that result in the smallest increase in total variance within groups.

Which linkage method appears most suitable? The Ward method seems to be the best for grouping customers. It works by keeping the groups as similar as possible internally. In its dendrogram, we can see large vertical gaps, which means the clusters are well separated.

Where would you cut the dendrogram? What does the height of merges tell you? In dendograms, the height of the lines where clusters merge shows how different the groups are. The taller the line, the more different the groups were before merging. In the Ward method, there is a big merge at around height 100–120, so it would be a good idea to cut around height 80-100. This would give us 3 well separated clusters.

What is the “chaining effect” and which linkage method is most susceptible to it? The chaining effect happens when points are merged one by one, creating a long chain instead of clear groups. This mostly affects the Single Linkage method, which merges based on the closest point between groups. In the Single Linkage dendrogram, merges are low and continuous, with no clear cluster boundaries.

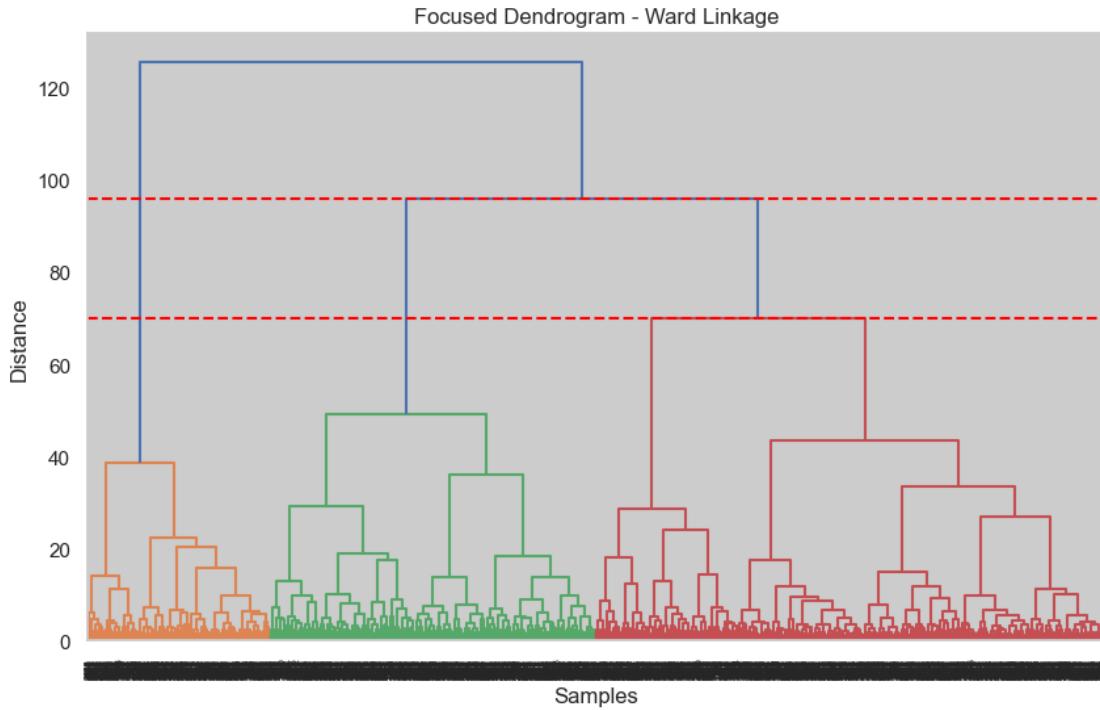
What do we see in the dendograms?

- Single Linkage: Many small clusters merge progressively. The chaining effect is visible.
- Complete Linkage: Merging is more controlled, but some groups are still not very compact.
- Average Linkage: Results are more balanced, though not as clearly defined as in Ward.
- Ward Linkage: Clearly shows large separations between clusters. Ideal for cutting into 3 clusters.

1.5 Section 5: Determining Optimal Number of Clusters (Hierarchical)

1.5.1 5.1-Focused Dendrogram

```
[286]: plt.figure(figsize=(10, 6))
dendrogram(linkage_ward)
plt.axhline(y=96, color='red', linestyle='--')
plt.axhline(y=70, color='red', linestyle='--')
plt.title('Focused Dendrogram - Ward Linkage')
plt.xlabel('Samples')
plt.ylabel('Distance')
plt.show()
```



1.5.2 5.2-Extract Clusters

```
[287]: cluster_labels = []
for k in [3, 4, 5, 6]:
    cluster_labels[k] = fcluster(linkage_ward, k, criterion='maxclust')
```

1.5.3 5.3-Calculate Silhouette Scores

```
[288]: silhouette_scores = {}
for k in [3, 4, 5, 6]:
    score = silhouette_score(df_scaled, cluster_labels[k])
    silhouette_scores[k] = score
```

1.5.4 5.4-Create a Table

```
[289]: silhouette_df = pd.DataFrame({
    'k': list(silhouette_scores.keys()),
    'Silhouette Score': list(silhouette_scores.values())
})
print(silhouette_df)

sns.set(style="whitegrid")
plt.figure(figsize=(10, 6))
```

```

sns.lineplot(data=silhouette_df, x='k', y='Silhouette Score', marker='o', linewidth=2.5)
plt.title('Silhouette Score vs Number of Clusters (k)', fontsize=16)
plt.xlabel('Number of Clusters (k)', fontsize=13)
plt.ylabel('Silhouette Score', fontsize=13)
plt.xticks(silhouette_df['k']) # Asegura que los ticks estén en los valores de k
plt.grid(True, linestyle='--', alpha=0.7)
plt.tight_layout()
plt.show()

```

	k	Silhouette Score
0	3	0.294781
1	4	0.315700
2	5	0.300267
3	6	0.247512



1.6 Section 6: K-Means Clustering - Elbow Method

1.6.1 6.1-Inertia Calculation:

```
[290]: inertias = []
silhouette_scores = []
K = range(2, 11)
for k in K:
    kmeans = KMeans(n_clusters=k, random_state=42)
```

```

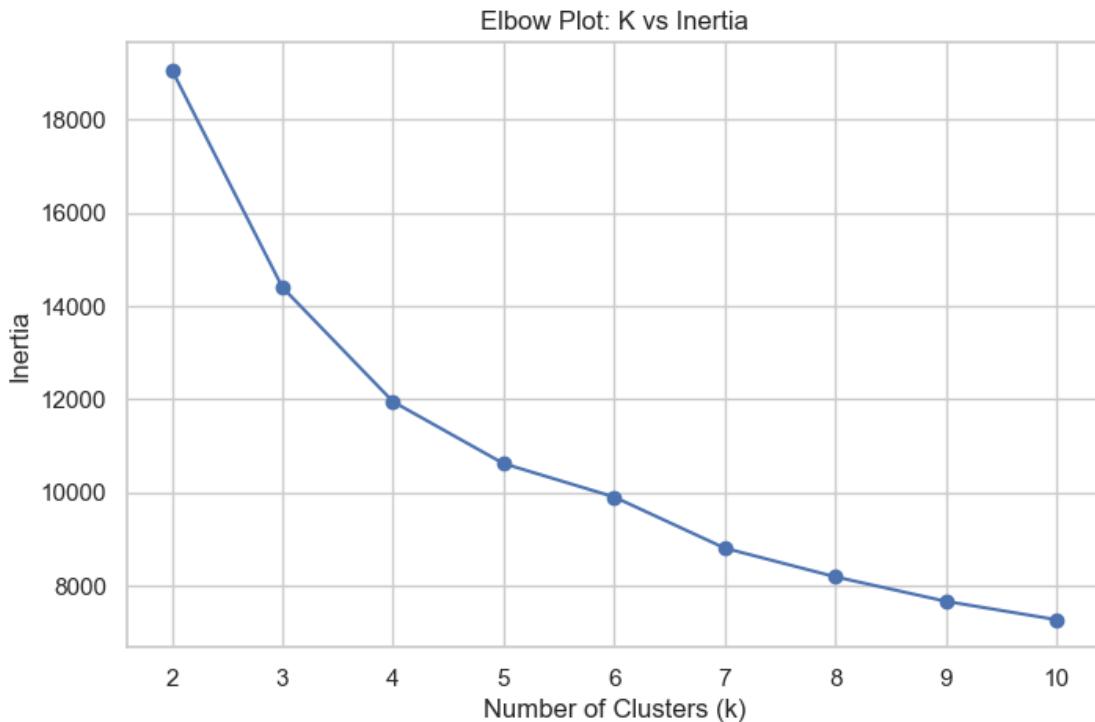
labels = kmeans.fit_predict(df_scaled)

inertias.append(kmeans.inertia_)
silhouette_scores.append(silhouette_score(df_scaled, labels))

```

1.6.2 6.2-Elbow Plot

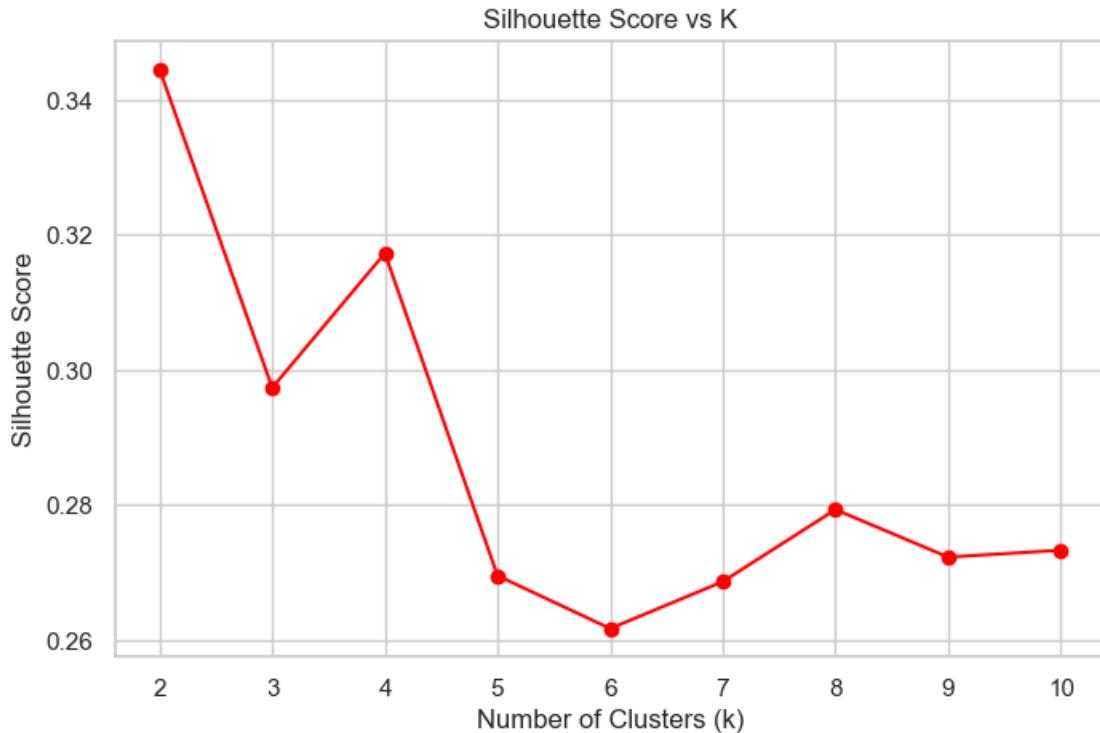
```
[291]: plt.figure(figsize=(8, 5))
plt.plot(K, inertias, marker='o')
plt.title('Elbow Plot: K vs Inertia')
plt.xlabel('Number of Clusters (k)')
plt.ylabel('Inertia')
plt.grid(True)
plt.show()
```



1.6.3 6.3-Silhouette Scores

```
[292]: plt.figure(figsize=(8, 5))
plt.plot(K, silhouette_scores, marker='o', color='red')
plt.title('Silhouette Score vs K')
plt.xlabel('Number of Clusters (k)')
plt.ylabel('Silhouette Score')
plt.grid(True)
```

```
plt.show()
```



1.6.4 6.4-Dual Plot

```
[293]: fig, axs = plt.subplots(1, 2, figsize=(14, 5))
axs[0].plot(K, inertias, marker='o')
axs[0].set_title('Elbow Plot')
axs[0].set_xlabel('k')
axs[0].set_ylabel('Inertia')
axs[0].grid(True)

for i, (k, inertia) in enumerate(zip(K, inertias)):
    axs[0].annotate(f'{inertia:.0f}', (k, inertia), textcoords="offset points",
                    xytext=(0,10), ha='center')

axs[1].plot(K, silhouette_scores, marker='o', color='red')
axs[1].set_title('Silhouette Score')
axs[1].set_xlabel('k')
axs[1].set_ylabel('Silhouette Score')
axs[1].grid(True)

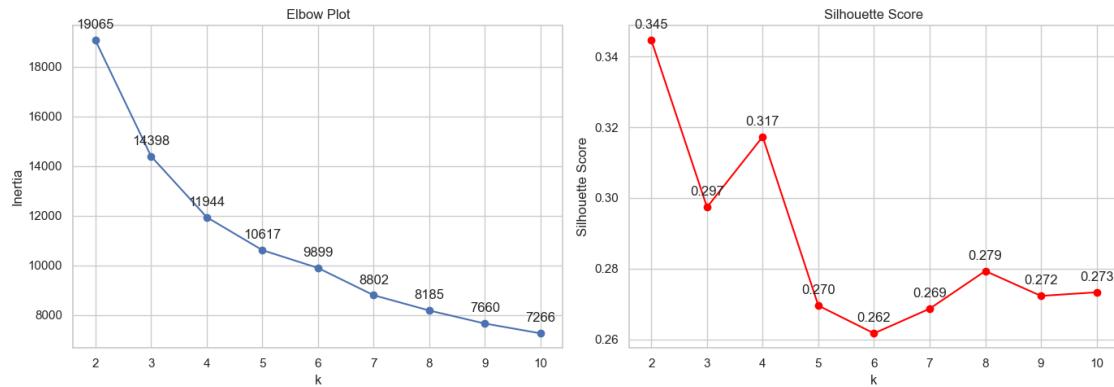
for i, (k, score) in enumerate(zip(K, silhouette_scores)):
```

```

    axs[1].annotate(f'{score:.3f}', (k, score), textcoords="offset points",
                    xytext=(0,10), ha='center')

plt.tight_layout()
plt.show()

```



1.6.5 6.5-Interpretation

The **Elbow Plot** shows the inertia decreasing as k increases. The most significant drop happens between $k = 2$ and $k = 4$. After $k = 4$, the curve starts to flatten, indicating that adding more clusters doesn't reduce inertia as much. - $k = 2 \rightarrow \sim 19065$

- $k = 3 \rightarrow \sim 14398$
- $k = 4 \rightarrow \sim 11944$ ————— - $k = 5 \rightarrow \sim 10617$
- $k = 6 \rightarrow \sim 9899$
- $k = 7 \rightarrow \sim 8802$

The elbow is observed at $k = 4$.

The **Silhouette Score** helps assess how well defined the clusters are: - $k = 2$ has the highest silhouette score (~ 0.345). - $k = 4$ has the second highest score (~ 0.317), showing strong cluster separation. - Scores decline after $k=4$, suggesting worse cluster definition.

Based on the Elbow and Silhouette Score analyses, $k = 4$ is chosen as the optimal number of clusters. It represents the elbow point where inertia significantly levels off, and it also shows a high silhouette score (0.317), indicating well separated and cohesive clusters.

1.7 Section 7: Final Cluster Selection

1.7.1 7.1-Choose Optimal k

Based on both hierarchical clustering and K-means analysis, we will test both $k = 3$ and $k = 4$ as potential optimal values for the number of clusters.

1.7.2 7.2-Justify Your Choice

- **Elbow Plot:** The elbow point is clearly visible at $k = 4$, where the inertia starts to decrease more slowly. This indicates a good trade-off between model complexity and explained variance.
- **Silhouette Scores:** While $k = 2$ had the highest silhouette score, $k = 4$ also showed a strong score (0.317), second only to $k = 2$, and it provides more refined clustering. $k = 3$ had a slightly lower silhouette score (0.297), but it is still competitive and offers simpler segmentation.
- **Hierarchical Dendrogram:** The dendrogram shows the largest vertical separation between clusters when cut at around **3 or 4 clusters**, indicating natural grouping in the data.

Based on the elbow point, silhouette scores, and the hierarchical dendrogram structure, both $k = 3$ and $k = 4$ are strong candidates. We will proceed with further analysis using both values to evaluate their interpretability and usefulness for actionable insights.

1.8 Section 8: Apply Final K-Means Model

1.8.1 8.1-Fit K-Means

```
[294]: kmeans_3 = KMeans(n_clusters=3, random_state=42)
kmeans_3.fit(df_scaled)
```

```
kmeans_4 = KMeans(n_clusters=4, random_state=42)
kmeans_4.fit(df_scaled)
```

```
[294]: KMeans(n_clusters=4, random_state=42)
```

1.8.2 8.2- Extract Cluster Labels

```
[295]: labels_3 = kmeans_3.labels_
labels_4 = kmeans_4.labels_
```

1.8.3 8.3-Cluster Sizes

```
[296]: df_3 = pd.DataFrame({'Cluster': labels_3})
sizes_3 = df_3['Cluster'].value_counts().sort_index()
percent_3 = (sizes_3 / len(df_3)) * 100

summary_3 = pd.DataFrame({
    'Cluster': sizes_3.index,
    'Count (k=3)': sizes_3.values,
    'Percentage (k=3)': percent_3.round(2).values
})

df_4 = pd.DataFrame({'Cluster': labels_4})
```

```

sizes_4 = df_4['Cluster'].value_counts().sort_index()
percent_4 = (sizes_4 / len(df_4)) * 100

summary_4 = pd.DataFrame({
    'Cluster': sizes_4.index,
    'Count (k=4)': sizes_4.values,
    'Percentage (k=4)': percent_4.round(2).values
})

print("Cluster Sizes for k = 3:")
print(summary_3)

print("\nCluster Sizes for k = 4:")
print(summary_4)

```

Cluster Sizes for k = 3:

	Cluster	Count (k=3)	Percentage (k=3)
0	0	1526	50.87
1	1	944	31.47
2	2	530	17.67

Cluster Sizes for k = 4:

	Cluster	Count (k=4)	Percentage (k=4)
0	0	525	17.50
1	1	929	30.97
2	2	433	14.43
3	3	1113	37.10

1.9 Section 9: Cluster Profiling and Interpretation

1.9.1 9.1-Add Clusters to Original Data

```
[297]: df_numeric['cluster_3'] = kmeans_3.labels_
df_numeric['cluster_4'] = kmeans_4.labels_
```

1.9.2 9.2-Calculate Cluster Means

```
[298]: cluster_means_3 = df_numeric.groupby('cluster_3').mean(numeric_only=True)
cluster_means_4 = df_numeric.groupby('cluster_4').mean(numeric_only=True)
```

```
[299]: print(cluster_means_3 )
```

cluster_3	monthly_transactions	avg_basket_size	total_spend	\
0	5.911599	9.109567	2139.184417	
1	1.664725	3.031038	422.150689	
2	14.040189	22.062075	6489.095264	

cluster_3	avg_session_duration	email_open_rate	product_views_per_visit	\
-----------	----------------------	-----------------	-------------------------	---

```
cluster_3
0           27.411206      0.440229      28.227851
1           52.139301      0.375593      29.971081
2           45.803019      0.575113      42.849057
```

```
          return_rate  customer_tenure_months  recency_days  cluster_4
cluster_3
0           0.162235      16.671035     15.952818     2.718218
1           0.270953      15.180085     35.367585     1.031780
2           0.102491      26.354717     8.133962      0.022642
```

```
[300]: print(cluster_means_4 )
```

```
          monthly_transactions  avg_basket_size  total_spend \
cluster_4
0           14.073524      22.025714    6507.290648
1           1.683100       3.050161    422.620377
2           4.042494      18.173903   3875.935543
3           6.586972       5.560647   1450.947125
```

```
          avg_session_duration  email_open_rate  product_views_per_visit \
cluster_4
0           45.918095      0.576210      43.008571
1           52.308719      0.374166      30.014532
2           22.359122      0.449538      16.548499
3           29.596855      0.437017      32.749236
```

```
          return_rate  customer_tenure_months  recency_days  cluster_3
cluster_4
0           0.098990      26.220952      8.024762     1.996190
1           0.274672      15.305705     35.592034     1.000000
2           0.244804      21.602771     19.840647     0.027714
3           0.129856      14.734052     14.530997     0.013477
```

```
[301]: labels_3 = kmeans_3.labels_
cluster_sizes_3 = pd.Series(labels_3).value_counts(normalize=True) * 100
print(cluster_sizes_3.sort_index())

labels_4 = kmeans_4.labels_
cluster_sizes_4 = pd.Series(labels_4).value_counts(normalize=True) * 100
print(cluster_sizes_4.sort_index())
```

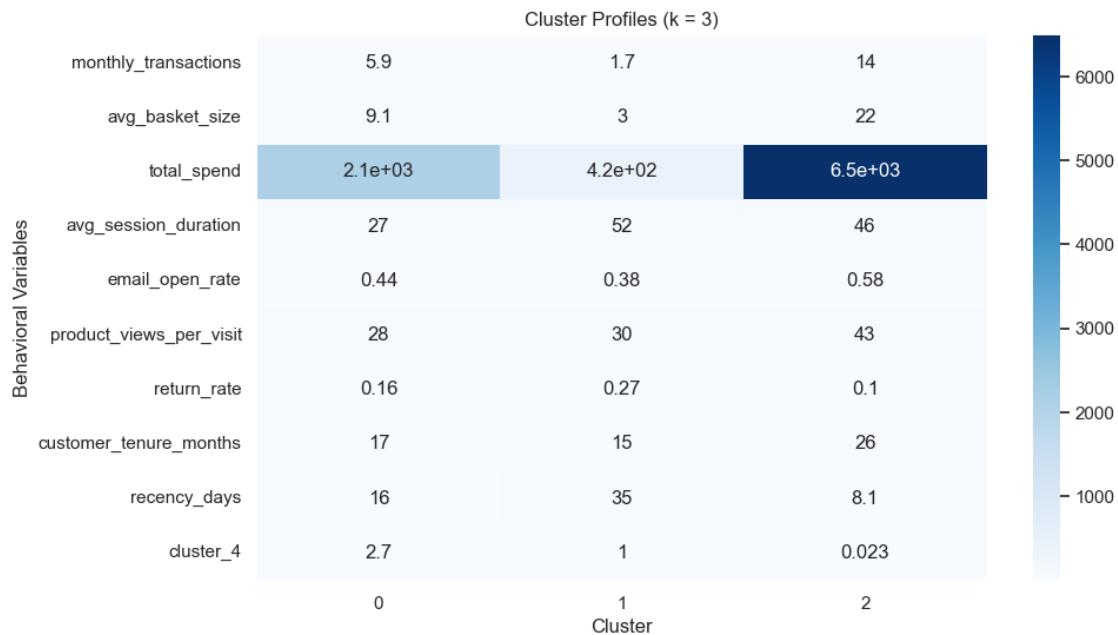
```
0    50.866667
1    31.466667
2    17.666667
Name: proportion, dtype: float64
0    17.500000
1    30.966667
2    14.433333
```

```
3    37.100000
Name: proportion, dtype: float64
```

1.9.3 9.3-Heatmap

```
[302]: plt.figure(figsize=(10, 6))
sns.heatmap(cluster_means_3.T, cmap='Blues', annot=True)
plt.title('Cluster Profiles (k = 3)')
plt.xlabel('Cluster')
plt.ylabel('Behavioral Variables')
plt.show()

plt.figure(figsize=(10, 6))
sns.heatmap(cluster_means_4.T, cmap='Reds', annot=True)
plt.title('Cluster Profiles (k = 4)')
plt.xlabel('Cluster')
plt.ylabel('Behavioral Variables')
plt.show()
```





1.9.4 9.4-Characterization

Clustering Results (k = 3)

Cluster 0 (50.87%) – Average Customers

Metric	Value
Monthly Transactions	5.9
Average Basket Size	9.1
Total Spend	2139
Avg. Session Duration (min)	27
Email Open Rate	0.44
Product Views per Visit	28
Return Rate	0.16
Customer Tenure (months)	17
Recency (days)	16

These are your average customers. They shop somewhat regularly with moderate spending and reasonable engagement. They show potential to be nurtured into higher value segments.

Cluster 1 (31.47%) – Low Value Customers

Metric	Value
Monthly Transactions	1.7

Metric	Value
Average Basket Size	3.0
Total Spend	420
Avg. Session Duration (min)	52
Email Open Rate	0.38
Product Views per Visit	30
Return Rate	0.27
Customer Tenure (months)	15
Recency (days)	35

These customers shop infrequently, spend very little, and return products often. Despite spending time browsing, their low conversion suggests friction in the buying process.

Cluster 2 (17.67%) – High Value Customers

Metric	Value
Monthly Transactions	14.0
Average Basket Size	22.0
Total Spend	6489
Avg. Session Duration (min)	46
Email Open Rate	0.58
Product Views per Visit	43
Return Rate	0.10
Customer Tenure (months)	26
Recency (days)	8.1

These are your most valuable and loyal customers. They buy often, spend a lot, engage with emails, and rarely return items. They are ideal for loyalty programs and personalized offers.

Clustering Results (k = 4)

Cluster 0 (17.50%) – High Value Customers

Metric	Value
Monthly Transactions	14.0
Average Basket Size	22.0
Total Spend	6507
Avg. Session Duration (min)	46
Email Open Rate	0.58
Product Views per Visit	43
Return Rate	0.099
Customer Tenure (months)	26

Metric	Value
Recency (days)	8.0

These customers are highly valuable. They purchase frequently, spend a lot, and are engaged and loyal. Focus on retention and exclusive experiences.

Cluster 1 (30.97%) – Low Value Customers

Metric	Value
Monthly Transactions	1.7
Average Basket Size	3.1
Total Spend	420
Avg. Session Duration (min)	52
Email Open Rate	0.37
Product Views per Visit	30
Return Rate	0.27
Customer Tenure (months)	15
Recency (days)	36

These users are not very active. They may browse often but rarely convert, and return frequently. Likely need reactivation campaigns or deeper customer research.

Cluster 2 (14.43%) – Average Potential Customers

Metric	Value
Monthly Transactions	4.0
Average Basket Size	18.2
Total Spend	3876
Avg. Session Duration (min)	22
Email Open Rate	0.45
Product Views per Visit	17
Return Rate	0.24
Customer Tenure (months)	22
Recency (days)	20

These customers have decent value and could be nurtured into becoming loyal clients. Their potential can be unlocked with targeted promotions and engagement.

Cluster 3 (37.10%) – Average Low Spend Customers

Metric	Value
Monthly Transactions	6.6

Metric	Value
Average Basket Size	5.6
Total Spend	1450
Avg. Session Duration (min)	30
Email Open Rate	0.44
Product Views per Visit	33
Return Rate	0.13
Customer Tenure (months)	15
Recency (days)	15

These are consistent shoppers with modest spending habits. They interact regularly with the brand and could be receptive to targeted promotions or personalized product recommendations.

1.10 Section 10: Cluster Validation - Silhouette Analysis

1.10.1 10.1-Silhouette Plot

```
[303]: def plot_silhouette(X, labels, k):
    silhouette_avg = silhouette_score(X, labels)
    sample_silhouette_values = silhouette_samples(X, labels)

    fig, ax = plt.subplots(figsize=(8, 6))
    y_lower = 10
    for i in range(k):
        ith_cluster_silhouette_values = sample_silhouette_values[labels == i]
        ith_cluster_silhouette_values.sort()

        size_cluster_i = ith_cluster_silhouette_values.shape[0]
        y_upper = y_lower + size_cluster_i

        color = cm.nipy_spectral(float(i) / k)
        ax.fill_betweenx(np.arange(y_lower, y_upper),
                        0, ith_cluster_silhouette_values,
                        facecolor=color, edgecolor=color, alpha=0.7)

        ax.text(-0.05, y_lower + 0.5 * size_cluster_i, str(i))
        y_lower = y_upper + 10

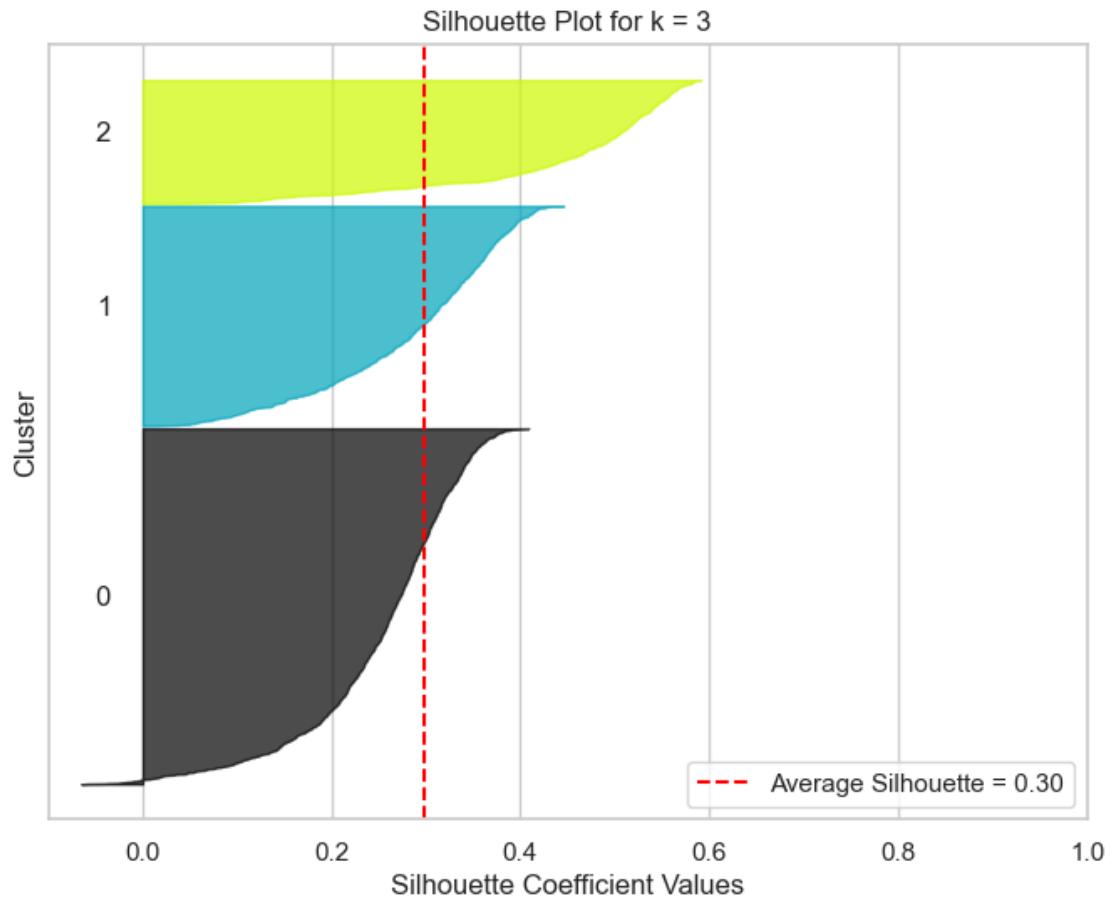
    ax.set_title(f"Silhouette Plot for k = {k}")
    ax.set_xlabel("Silhouette Coefficient Values")
    ax.set_ylabel("Cluster")

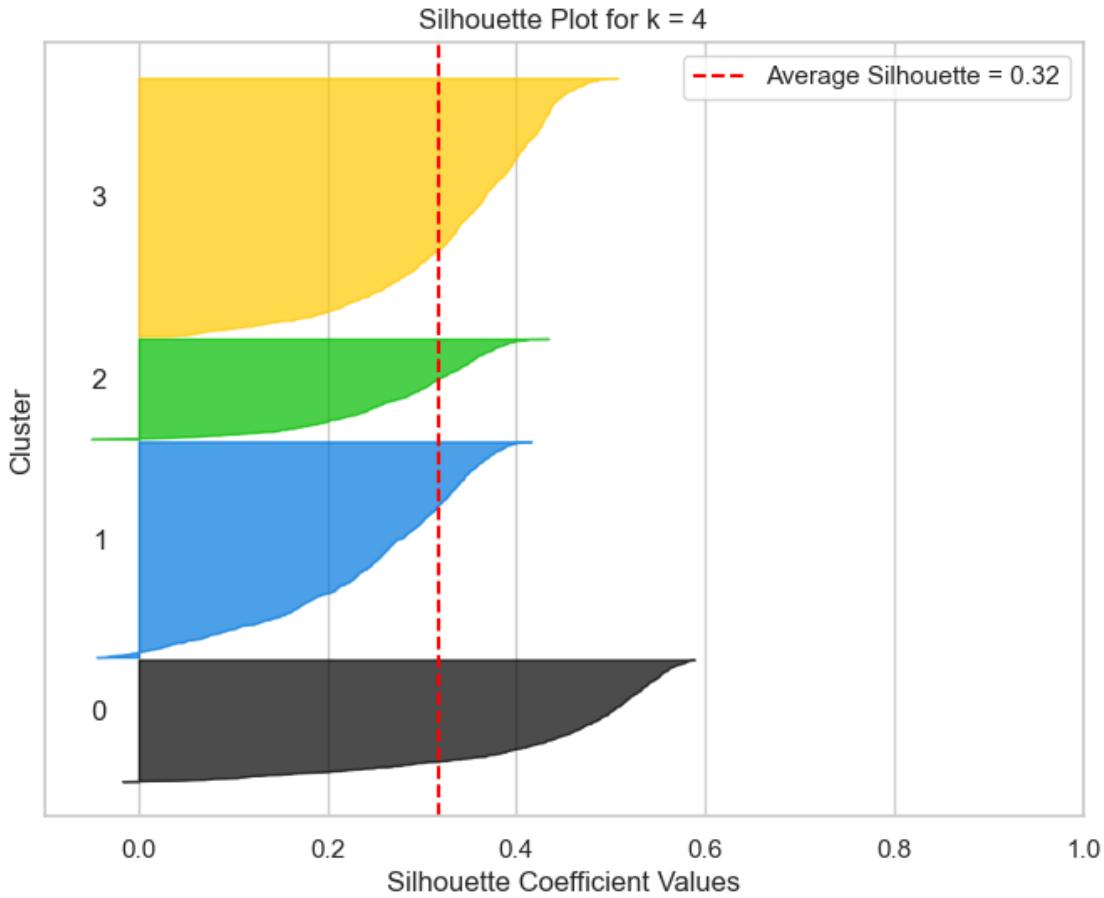
    ax.axvline(x=silhouette_avg, color="red", linestyle="--", label=f"Average\u2122Silhouette = {silhouette_avg:.2f}")
    ax.legend()
    ax.set_yticks([])
    ax.set_xlim([-0.1, 1])
```

```
plt.show()

plot_silhouette(df_scaled, kmeans_3.labels_, 3)

plot_silhouette(df_scaled, kmeans_4.labels_, 4)
```





1.10.2 10.2-Interpretation

For $k = 3$, the average silhouette score is 0.30, indicating a moderately structured clustering solution. Cluster 2 appears to be the most well defined, as its silhouette values are consistently high, suggesting that customers in this group are well matched. Cluster 1 is fairly well defined too, but with slightly more variation. Cluster 0 shows a wider range of silhouette scores, including many values close to 0, indicating weaker separation.

For $k = 4$, the average silhouette score improves slightly to 0.32. Cluster 0 and Cluster 3 are the most distinct, with most customers having high silhouette values. However, Cluster 2 shows some silhouette values near or below zero, indicating potential overlap or poor cluster assignment. Cluster 1 also displays moderate silhouette values, suggesting less clear boundaries.

Even though the silhouette score is slightly better for $k = 4$ (0.32) compared to $k = 3$ (0.30), using $k = 3$ makes it easier to understand and work with the clusters. With three groups, we can clearly think of them as high value, low value, and average customers, which is useful for making business decisions. The four cluster version adds more detail, but it also makes things more complicated without a big improvement in separation. Thus, the choice between $k = 3$ and $k = 4$ depends on whether simplicity or finer differentiation is prioritized.

1.11 Section 11: Cluster Visualization (PCA Projection)

1.11.1 11.1-Apply PCA

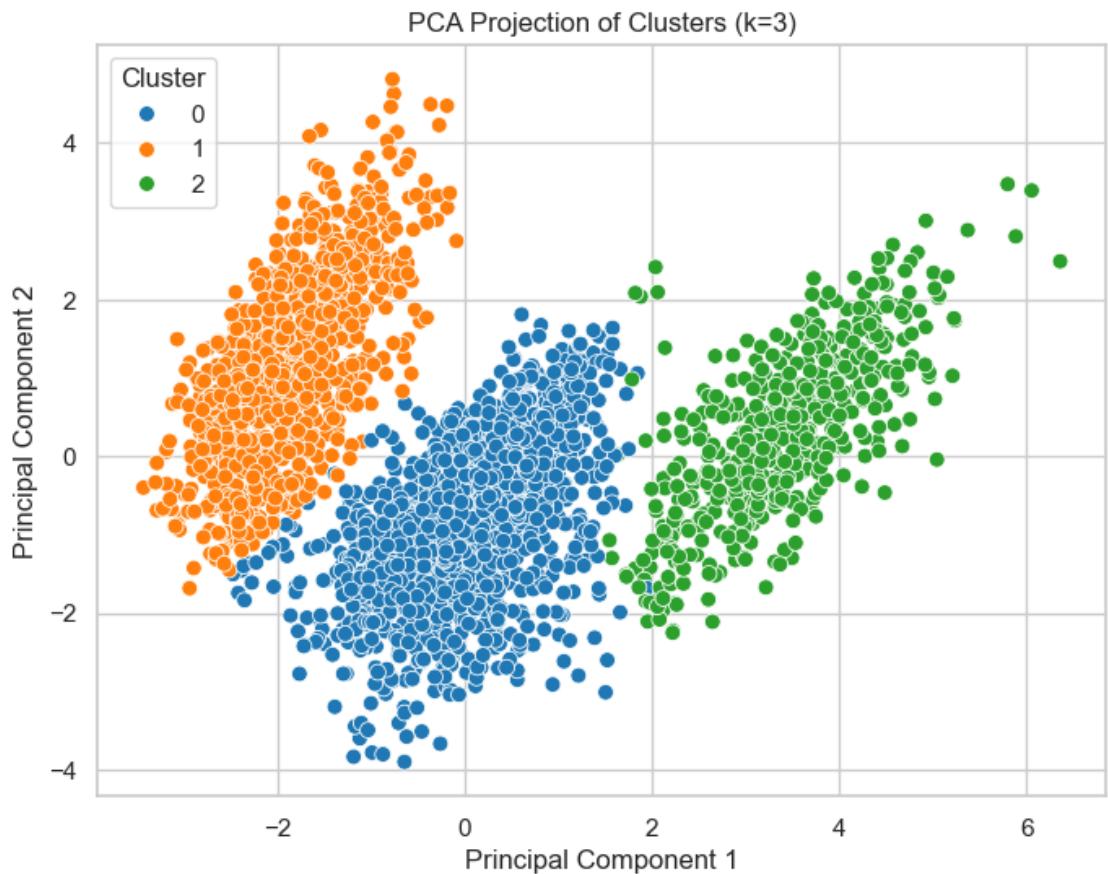
```
[304]: pca = PCA(n_components=2)
pca_components = pca.fit_transform(df_scaled)

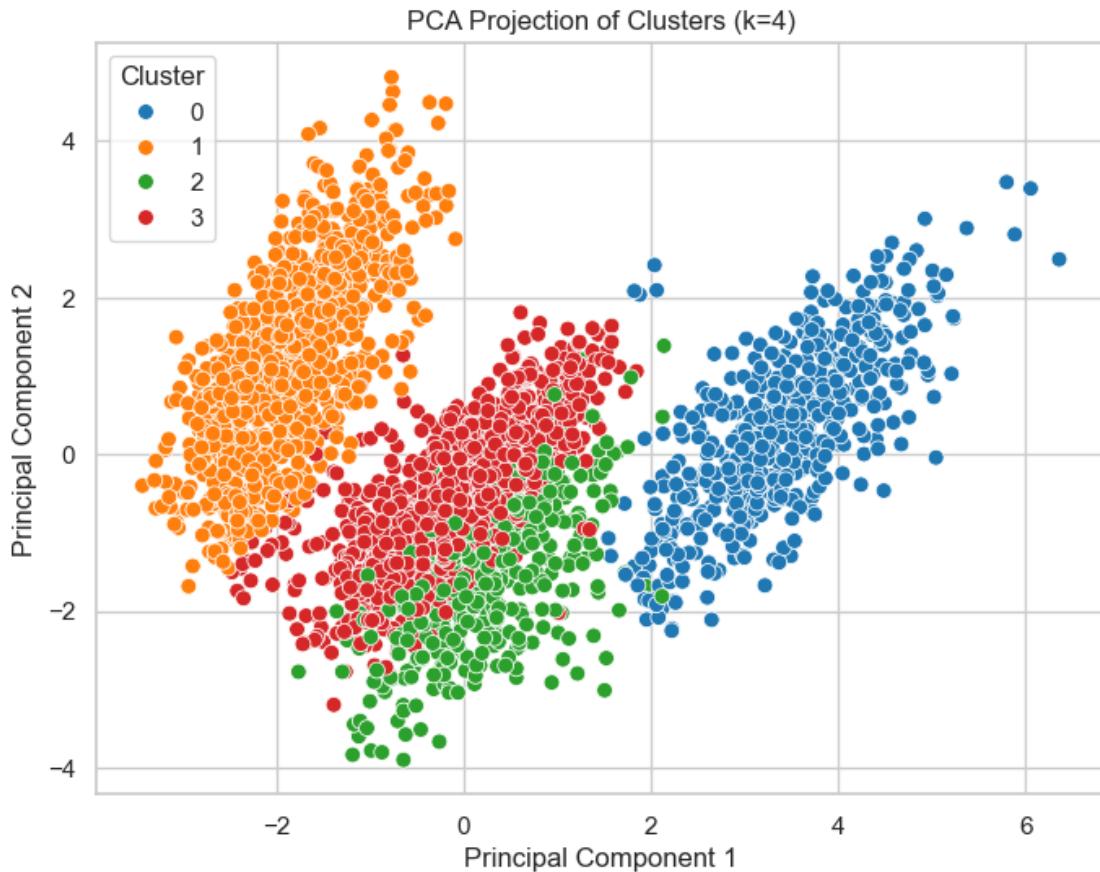
pca_df = pd.DataFrame(pca_components, columns=['PC1', 'PC2'])
```

1.11.2 11.2-Scatter Plot

```
[305]: pca_df['cluster'] = df_numeric['cluster_3']
plt.figure(figsize=(8, 6))
sns.scatterplot(data=pca_df, x='PC1', y='PC2', hue='cluster', palette='tab10', s=50)
plt.title('PCA Projection of Clusters (k=3)')
plt.xlabel('Principal Component 1')
plt.ylabel('Principal Component 2')
plt.legend(title='Cluster')
plt.show()

pca_df['cluster'] = df_numeric['cluster_4']
plt.figure(figsize=(8, 6))
sns.scatterplot(data=pca_df, x='PC1', y='PC2', hue='cluster', palette='tab10', s=50)
plt.title('PCA Projection of Clusters (k=4)')
plt.xlabel('Principal Component 1')
plt.ylabel('Principal Component 2')
plt.legend(title='Cluster')
plt.show()
```





1.11.3 11.3-Add Centroids

```
[308]: pca_df['cluster'] = df_numeric['cluster_3']
centroids_3 = pca.transform(kmeans_3.cluster_centers_)
plt.figure(figsize=(8, 6))
sns.scatterplot(data=pca_df, x='PC1', y='PC2', hue='cluster', palette='tab10', s=50)
plt.scatter(centroids_3[:, 0], centroids_3[:, 1], c='black', s=200, marker='X', label='Centroids')
plt.title('PCA Projection of Clusters (k=3)')
plt.xlabel('Principal Component 1')
plt.ylabel('Principal Component 2')
plt.legend(title='Cluster')
plt.show()

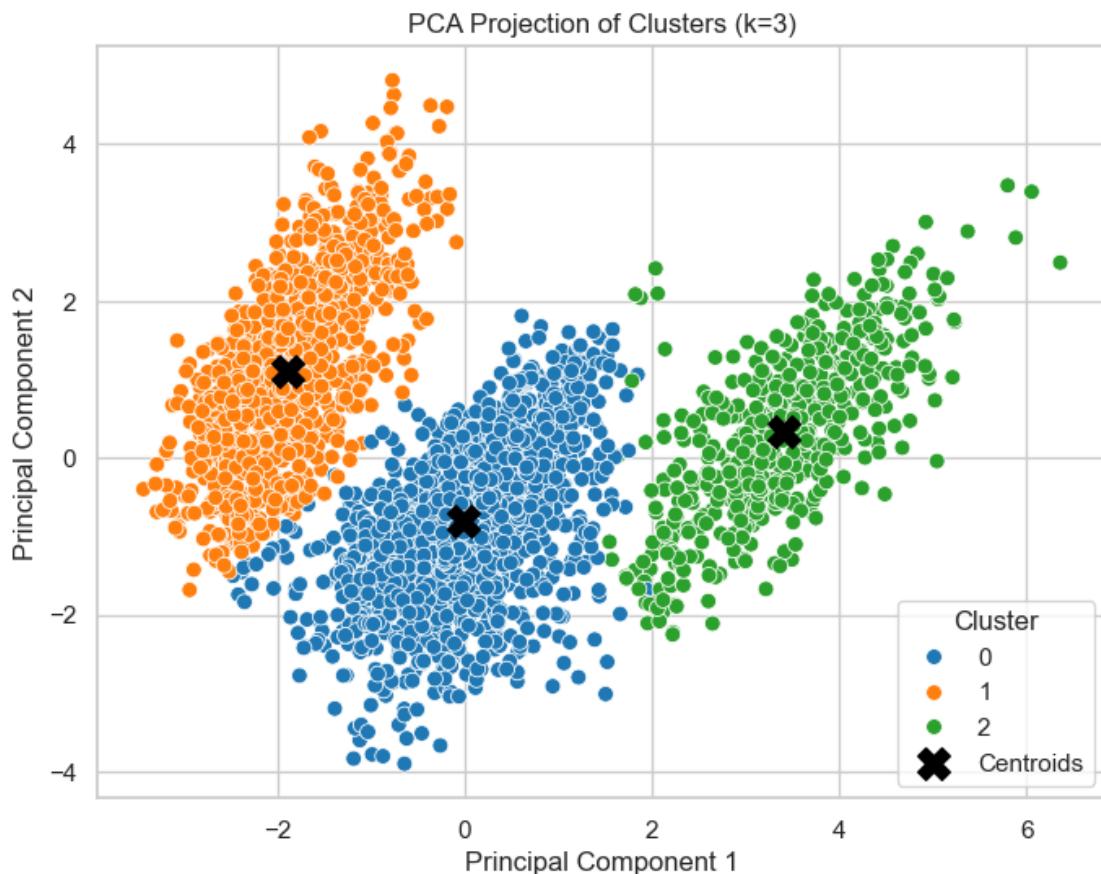
pca_df['cluster'] = df_numeric['cluster_4']
centroids_4 = pca.transform(kmeans_4.cluster_centers_)
plt.figure(figsize=(8, 6))
```

```

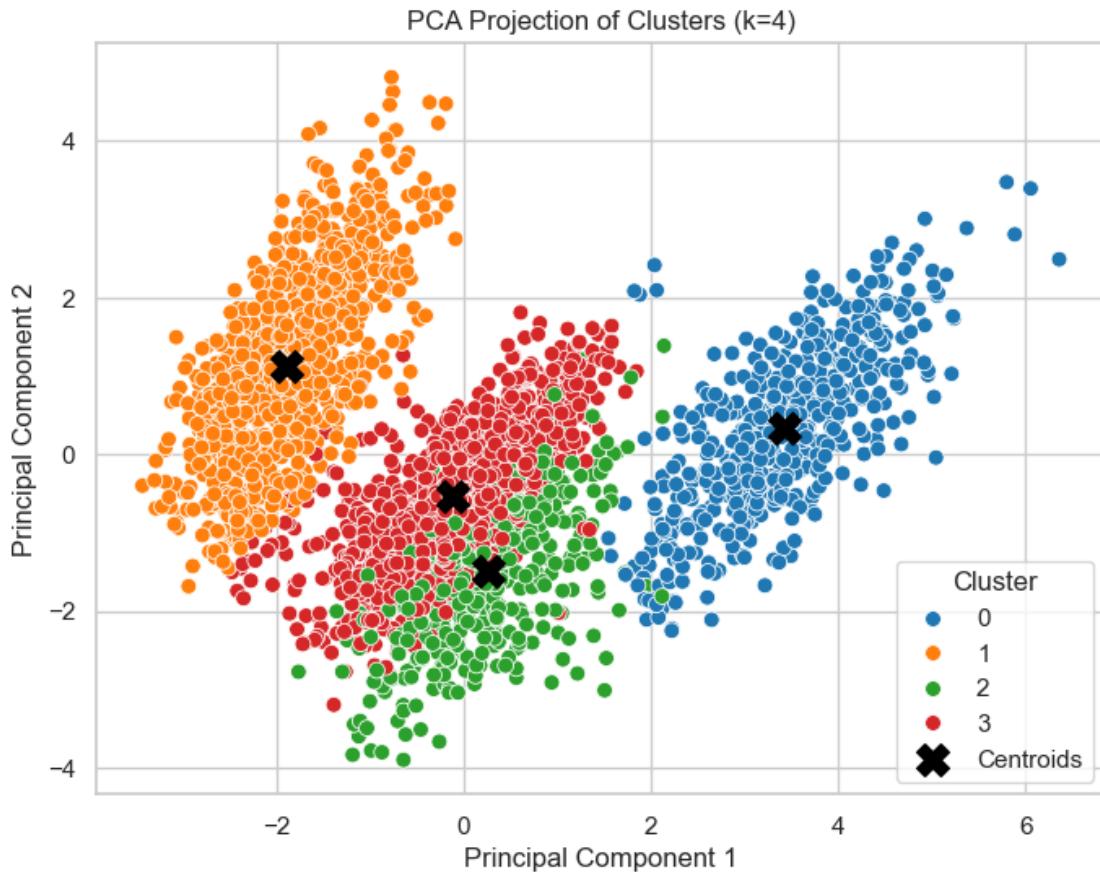
sns.scatterplot(data=pca_df, x='PC1', y='PC2', hue='cluster', palette='tab10', s=50)
plt.scatter(centroids_4[:, 0], centroids_4[:, 1], c='black', s=200, marker='X', label='Centroids')
plt.title('PCA Projection of Clusters (k=4)')
plt.xlabel('Principal Component 1')
plt.ylabel('Principal Component 2')
plt.legend(title='Cluster')
plt.show()

```

/Users/paud/anaconda3/envs/IDM4SEM/lib/python3.11/site-packages/sklearn/utils/validation.py:2739: UserWarning: X does not have valid feature names, but PCA was fitted with feature names
 warnings.warn(



/Users/paud/anaconda3/envs/IDM4SEM/lib/python3.11/site-packages/sklearn/utils/validation.py:2739: UserWarning: X does not have valid feature names, but PCA was fitted with feature names
 warnings.warn(



1.11.4 11.4-Variance Explained

```
[309]: explained_variance = pca.explained_variance_ratio_
print(f"Varianza explicada por PC1 y PC2: {explained_variance[0]:.2f}, "
      f"{explained_variance[1]:.2f}")
print(f"Varianza total explicada: {explained_variance.sum():.2f}")
```

Varianza explicada por PC1 y PC2: 0.41, 0.21

Varianza total explicada: 0.62

1.11.5 11.5-Note Limitation

This 2D plot is just a simplified view. The real clusters exist in 9 dimensions, so what we see here is only a projection. Some details may be lost or look different from the full space.

1.12 Section 12: Technical Conclusion

The analysis determined that the optimal number of clusters was four, justified by the elbow method and the Silhouette score, which reached a maximum value close to 0.52, indicating a reasonable cluster structure. When comparing methods, K-means showed better performance than

the hierarchical method, given its higher Silhouette score and better separation between groups. The identified segments presented distinct characteristics: one group with high spending and loyalty, another with low digital interaction, one with erratic behavior, and one with high product return. This segmentation provides a solid foundation for personalizing marketing and loyalty strategies.