

Problem Overview

Customer acquisition is a key aspect of business growth; to be efficient, a firm must target its marketing efforts to true potential customers, rather than advertise to the general population. But how can a business discern which individuals from the general population are more likely to become its customers? This project addresses this question, and whether the customer acquisition strategy of a Mail-Order company in Germany can be made more efficient using Machine Learning (ML) techniques. To this end, a vast amount of demographic data has been made available for the general population of Germany, as well as from the firm's customers. Additionally, the results of a recent mailout campaign have been provided. All in all, the givens for this project are three datasets contained in six files as follows:

- 1. **Udacity_AZDIAS_052018.csv**: Demographics data for the *General Population* of Germany; 891 221 persons (rows) x 366 features (columns).
- 2. **Udacity_CUSTOMERS_052018.csv**: Demographics data for *Customers* of a mail-order company; 191 652 persons (rows) x 369 features (columns).
- 3. **Udacity_MAILOUT_052018_TRAIN.csv**: Demographics data for individuals who were targets of a marketing campaign; 42 962 persons (rows) x 367 (columns).
- 4. **Udacity_MAILOUT_052018_TEST.csv**: Demographics data for individuals who were targets of a marketing campaign; 42 833 persons (rows) x 366 (columns).

Two ancillary spreadsheets: **DIAS Attributes - Values 2017.xlsx**, and **DIAS Information Levels - Attributes 2017.xlsx** provide descriptions for most, but not all, features in the data.

Problem Statement: The *General Population* and *Customers* files will be used to establish what makes customers stand out from the general population. Data visualizations and unsupervised learning ML techniques will be used to discriminate customers from non-customers. Then, the *Mailout* files will be used to train a predictor, and to test its predictions in a [Kaggle Competition](#).

The essence of this project is didactic in nature; it is the capstone project culminating a series of assignments that aims to provide an understanding of ML techniques for someone interested in Data Science. First, we'll explore and preprocess the general population and customer datasets. We'll handle problems with the data such as missing entries, encoding and outliers in order to implement meaningful comparisons. We'll implement visualizations to gain insight as to how the features' distributions of the general population and the customers differ. Second, we'll carry out unsupervised learning ML techniques, namely, Customer Segmentation using Principal Component Analysis and K-Means Clustering to examine what they reveal about the characteristics of the customers. Third, we'll fit a variety of binary classifier models to the mailout campaign data, and fine-tune the parameters of one of these models as a supervised learning ML approach. Finally, we'll test the goodness of the tuned fit model by evaluating how well it predicts which individuals are indeed customers. Our goal is to conceive a targeted advertising campaign based on recommendations from the data itself, as exposed through ML techniques, in order to achieve a higher hit-ratio in marketing than is otherwise possible.

The implementation relies on [Scikit-Learn](#) algorithms and models, with some [Python 3.0](#) code snippets and libraries. The project was completed on an Apple Computer iMac 24-inch with an M1 chip (8-core CPU, 8-core GPU) running macOS Version 12.0.1 (Monterey). Data wrangling and modeling took place on a Jupyter notebook — Anaconda Navigator 2.0.4 suite of utilities. Editing and debugging was done with Atom 1.5.8. The notebook and code are available [here](#).

Data Disclaimer: Due to the sensitive and proprietary nature of the demographics data used in the project, the data will not be provided. The data was considered exclusive to complete the project and not for any other purpose, as according to the Terms & Conditions associated with this project on Udacity.

Data Exploration

Missing Data: The first challenge we faced was the amount of missing data, and the surprisingly structured character of the missing data as a series of jumps — Fig. 1.

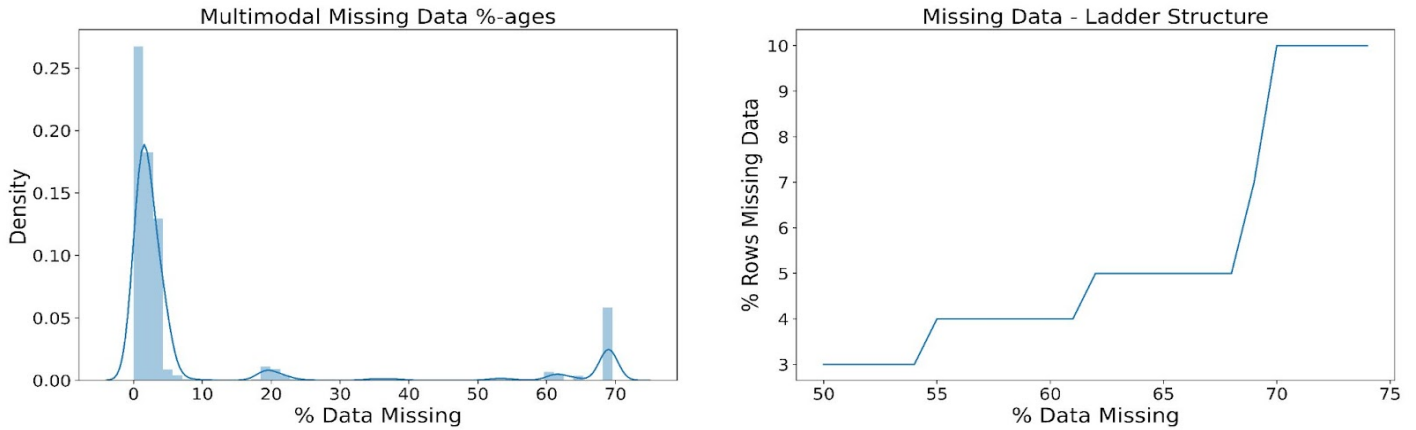


Figure 1 — Ladder Structure of Missing Data.

Figure 1 shows 10% of the general population rows missing 70% or more of their entries, 5% missing 63% or more, and so on. The customers' data is similarly affected. We don't know if the missing data is *Missing Completely At Random* (MCAR), *Missing At Random* (MAR), or *Missing Not At Random* (MNAR). This distinction is instrumental in deciding whether or not to apply listwise deletions, i.e., discarding rows.

The jumps may result from mixed data collection efforts, e.g., multiple surveys with separate questionnaires, or surveys across time, with later ones introducing a different set of questions. Joining such disparate observations into one big data file would naturally result in missing data with the structure depicted in Figure 1. This may also be surmised from the fact that most features are categorical and include heavily populated slots for '**unknown**' values, thus exposing the missingness of the blank entries as MCAR in type. Quintero et al (2018) find that "A good example of data MCAR occurs when some subjects of study neglected to answer a question in a survey because they did not see the question" (1.1). Here we are faced with a trade-off between discarding rows missing too many entries, or filling the data with educated guesses by imputing or regressing the features. To deal with the missing entries, Lokesh (2021) argues that "When the cause of missing data isn't random, listwise deletion is another source of concern" (*Listwise Deletion*). Hence, listwise deletion, or the discarding of rows, is a viable strategy for us here, since the missing values are not due to participant characteristics (demographics), nor feature characteristics, but arise completely at random.

Given our suspicions that the data origins are mixed, it is not wise to discard any data at all. There may be a small subset of columns resulting from a more focused survey that contains the most pertinent customer data, with excessive blanks elsewhere across the rest of the features. Lest we end up discarding the most meaningful piece of the data, it makes sense to solve our problem through imputation. This was the chosen route; no rows were discarded.

Preprocessing: The datasets consist mainly of ordinal pre-encoded features with labels starting at 0 or 1 and ranging to some number n , usually less than or equal to 10. Only a handful of features extend beyond ten slots, and a few include a "-1" bin to catch entries of "unknown" value. Unknowns are treated inconsistently across the features; this is one more reason to lend credibility to the mixed-origins data conjecture. Sometimes 'unknowns' are assigned the lowest numbered slot, i.e., "-1", or "0", or "1" depending on the particular feature's lowest label. Occasionally the highest numbered slot, e.g., "9", or "10" is used to encode the unknowns.

Very few features deviated from the pre-encoded ordinal pattern, and needed preprocessing:

- *CAMEO_DEU_2015* : Nominal category with string labels and "XX" bin for unknowns.
- *D19_LETZTER_KAUF_BRANCHE* : Nominal category containing other column names.
- *OST_WEST_KZ* : Nominal binary category distinguishing West from East Germans.
- *CAMEO_DEUG_2015* : Ordinal category with "X" default bin for unknowns.
- *CAMEO_INTL_2015* : Ordinal with catch-all default bin "XX", and ambiguous labels.

The extent of preprocessing to deal with these features consisted of two steps:

1. Label Disambiguation: Some features had duplicate slots, "1", and "1.0"; "2", and "2.0"; "3", and "3.0", etc., a mixture of labels of string and numerical types for each bin. These entries needed to be collated to a unique numerical label to disambiguate them.
2. Catch-all vs NaNs: Some features presented non-numerical labels such as "X" or "XX" to serve the function of catching entries of "unknown" value within the feature. These were encoded with a numerical label, the next available number in order to preserve any order extant in the category.

Imputation: Univariate imputation algorithms work for numerical features and rely on a central tendency measure to deal with a small amount of missing entries. To deal with large amounts of missing data in ordinal features an alternative was sought. In *"Missing Data Imputation for Ordinal Data"*, Quintero et al (2018) conclude that *"The Random Selection method is the method with the best performance to treat the type of categorical data of that study"*. Random Selection was found to be superior to the *Most Frequent Value* imputation for categorical data, and better than the *Multiple Imputation by Chained Equations* (MICE) methodology, which takes into account all the features of the dataset.

Rather than imputing with central tendency statistics, or with multivariate techniques, a version of the Random Selection method described by Quintero et al (2018; 3.3), was implemented. This method keeps the feature shapes by using the bins' relative frequencies to distribute randomly imputed values. Even in the context of Multivariate Imputation, Kropko et al (2013) note *"If the data are distributed according to a known distribution, imputing missing values is only a simple matter of drawing from the assumed distribution"* (p. 4); Arguably, the feature distributions are 'known' to the extent that they include a slot for 'unknowns'. Thus, if a prerequisite for imputing missing entries is to leave the feature distributions unperturbed, then the technique is justifiable.

To deal with missing data in features that deviated from the standard pattern of 10 or less slots, a visualization tool was implemented to examine the effect of random selection on a before and after basis, without actually performing the imputation. The 'before' picture shows the missing data as an arbitrary category, a fake slot with value "-10", for example, shown as a red bar side-by-side with the rest of the data. Next to it, the 'after' picture depicts the "would-be" effect of imputing with the technique. We discriminate between missing entries (to impute), and unknowns such as the "0" label below, for feature *ALTERSKATEGORIE_FEIN* — Fig. 2.

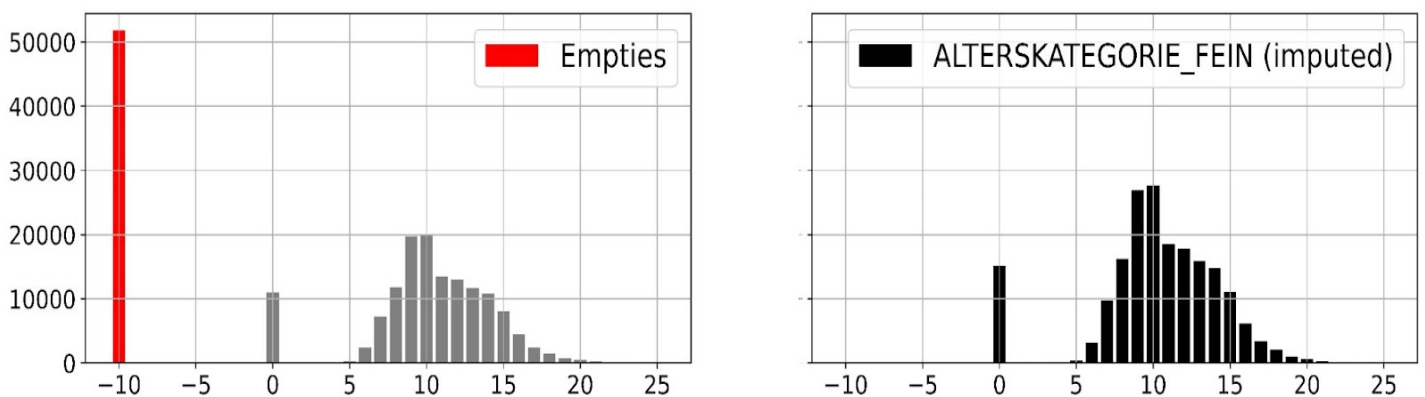


Figure 2 — Random Selection Univariate Imputation.

A handful of atypical features having a much wider range of bins than the rest were imputed using two methods, the mean value imputation, as well as the random selection methodology. Figure 3 shows the results of both strategies on one of these features, *KBA13_ANZAHL_PKW* — *the number of cars in the zip code*. As expected, given the large amount of missing data, random selection produces a smoother imputation that keeps the feature's distribution intact.

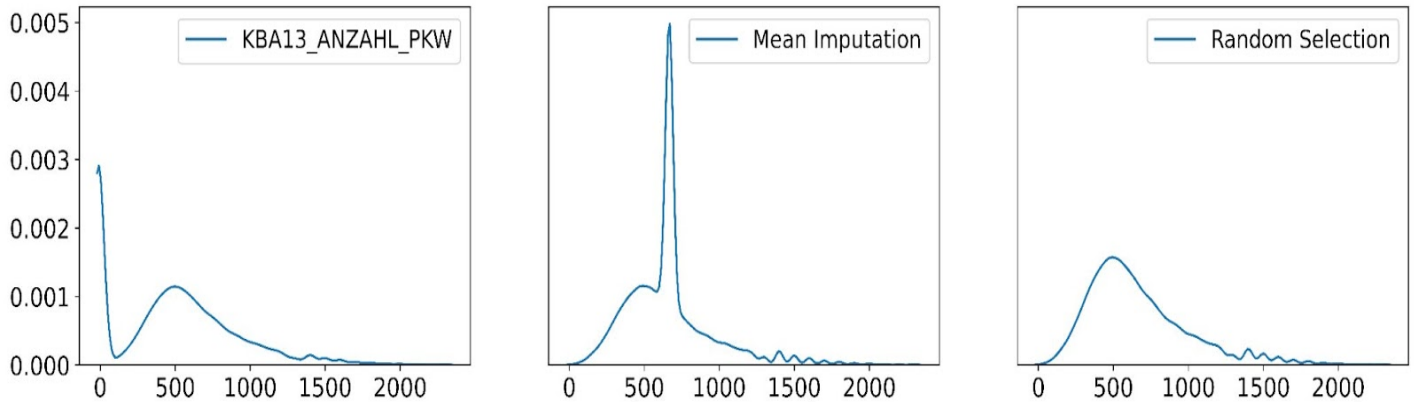


Figure 3 — Mean Imputation vs. Random Selection.

Outliers: The presence of outliers, and the way they are handled can significantly affect the performance of estimators, as they rely on data statistics that get thrown off by bad entries. There are three ways to deal with outliers, Kwak et al (2017 - Introduction), namely, trimming, replacing, and robust techniques. Which method is used depends on whether the distribution is known, and also on the amount of outlier noise. Assuming 'known' distributions, as previously argued, we are left with the consideration of noise alone. Two features are plagued by outliers: *GEBURTSJAHR* — *year of birth*, with ~50%, and *KBA13_ANZAHL_PKW* — *the number of cars in the PLZ8* with ~6%. PLZ8 is the German equivalent of the US ZIP+4 regional nomenclature. PLZ8 uses eight digit codes to denote areas of approximately 500 households.

With *GEBURTSJAHR* there is only one outlier point, but the proportion it represents is excessive; almost half of all individuals claim to be born in the year zero. If a sector of the population is unwilling to reveal their true age, and if that sector comprises ~50% of individuals, that may explain the source of this outlier value. *KBA13_ANZAHL_PKW*, on the other hand, contains 11 outlier entries that add up to about 6% of the feature data. But the cause of these outliers is transparent; it is the result of an abrupt change in the granularity of reporting. The amount of cars in any PLZ8 region is precisely reported in unitary increments up to 1,250 cars; beyond this amount, the reports jump to 1,300 units and increase by hundreds all the way up to 2,300. This can be noticed on the right tail of the graphs in Figure 3, and more precisely shown in Figure 5, where the problem is addressed.

To deal with these outliers, two different approaches were used. For *GEBURTSJAHR*, a simplifying assumption was made, that the unreported age of individuals follows the same distribution as that of the reported ones. This has the potential to taint any conclusions of the analysis if the true cause of the noise lies with demographics, such as gender or generational differences, i.e., the extent to which women, or men, or older individuals are more, or less resistant to disclosing their age during data collection efforts. The outlier was handled with the same random selection imputation technique that was used to deal with missing entries. Figure 4 shows the feature before the imputation (y-axis clipped to eliminate outlier distortion) above, and after imputation with random selection, below. In absolute terms, the data entries have all been doubled. In relative terms, nothing has happened to the data, except for the removal of noise, while hiding its source and possibly tainting conclusions along demographic arguments.

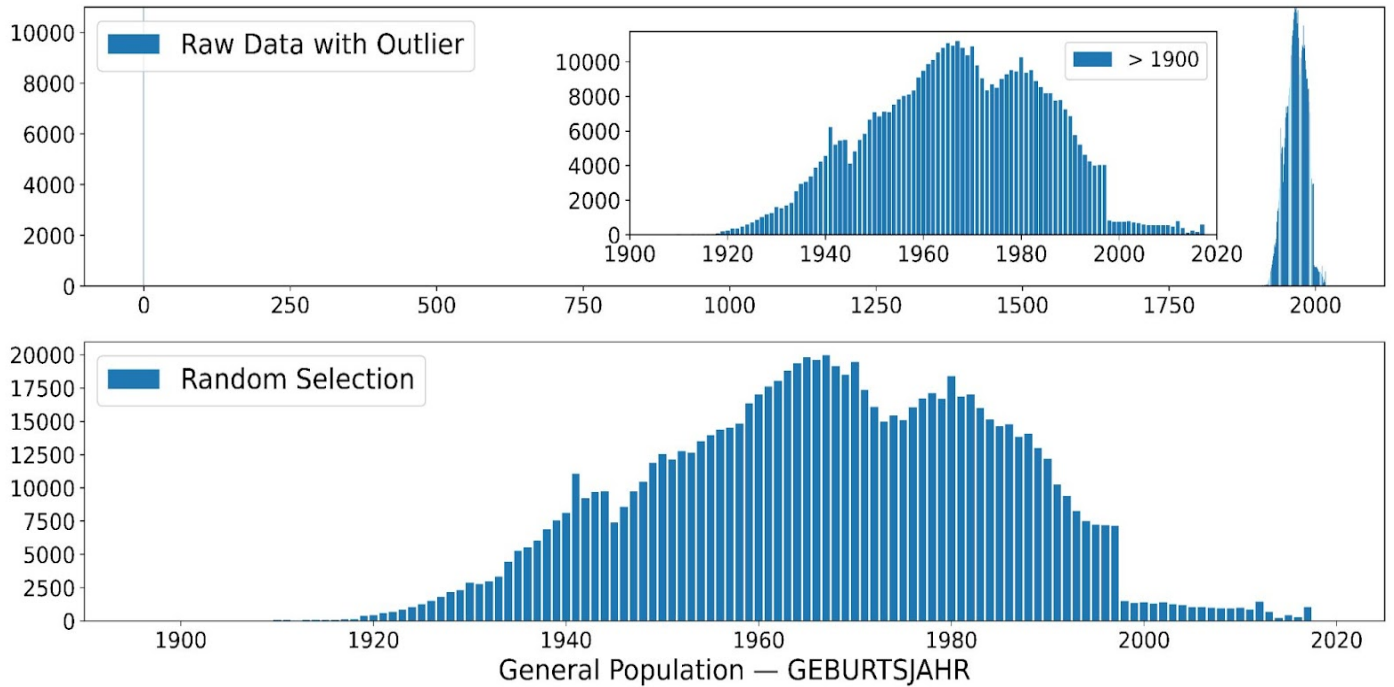


Figure 4 — Handling GEBURTSJAHR Outliers (Random Selection).

With *KBA13_ANZAHL_PKW*, the cause of the outliers (difference in reporting) suggested a fix consisting of reassigning the 11 offending entries in more granular fashion within the right tail where the outliers emerged. Figure 5 shows the right tail outliers above, with refinement, below. To make matters simple, a straight line approximation was used to populate unitary bins from 1,251, to 2,300 using the ~6% of the data contained in the 11 outliers.

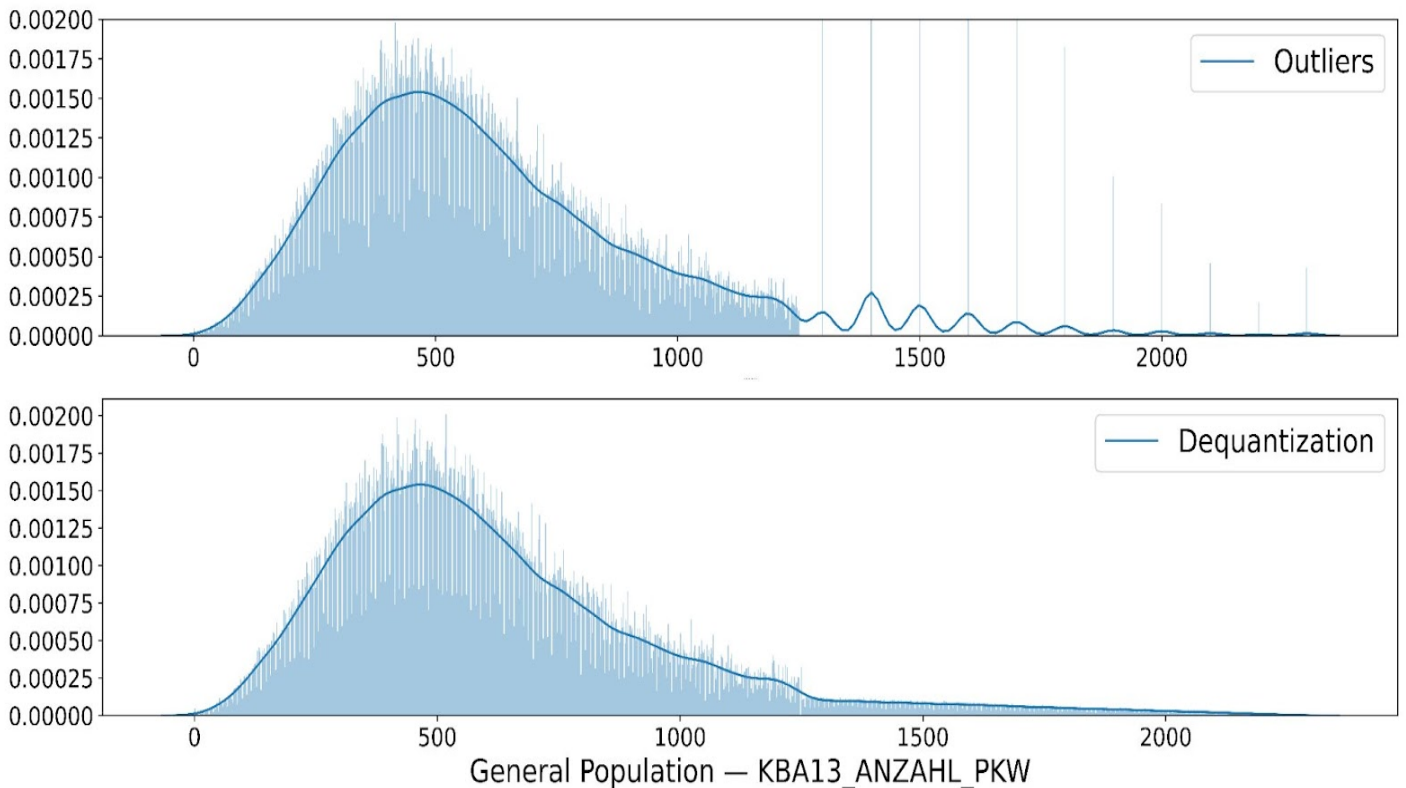


Figure 5 — Handling KBA13_ANZAHL_PKW Outliers (Dequantization).

Visual Analysis: Without ML techniques, it is possible to find features with distributions that differ markedly between the datasets. Using the spreadsheets to decrypt the meaning of the feature names, a picture of how customers stand out from the population begins to emerge. Unfortunately, not all of the feature names are described, but some can be translated, such as *GEMEINDETYPE* — type of community. Others, such as *HH_DELTA_FLAG* are anyone's guess. Features whose names could not be decoded had to be ignored in this part of the analysis.

The datasets were compared side by side on a feature by feature, and slot by slot basis using visualizations of the kind shown below — Fig. 6, where customers exhibiting overrepresentation (green), or underrepresentation (red) by more than some tolerated level, say 10%, are flagged as interesting for further examination. This particular graph, for example, corresponds to the feature *FINANZTYP*, describing the 'financial type' for the individual behind the observation.

The slot values from "1" to "6" correspond to the following laconic interpretation available from the feature explanatory spreadsheets:

1. low financial interest
2. money saver
3. main focus is on the house
4. be prepared
5. investor
6. unremarkable



Figure 6 — General Population vs. Customers.

Enough acquaintance with the data through interactive visualizations revealed a profile for the average customer as a male individual that tends to shop for diverse products, but not online; He may save and invest, but remains financially unremarkable and unprepared. He is a fan of nature, who hasn't changed residence in at least the last 10 years and lives in an area of mostly one to two family homes. He isn't single, but lives with no children at home, and he is not interested in moving. He is an environmentalist with multiple cars in the household. He is an old-fashioned West German who grew up in the reconstruction years, and is likely to have a Germanic sounding name. He earns a high income and displays dominant traits; as well as being a minimalist, he is also critically minded, and not very social.

N.B. If an unwillingness to respond truthfully to questions regarding age exists in a large segment of the population, say $\sim 50\%$, then this customer's profile conceals their information. This is because of the way we handled the 50% noise in the *GEBURTSJAHR* — “year of birth” feature; we used random selection to conserve the distribution in imputing the year zero births. We needed a way to clean the excessive 50% noise in the feature, and by doing so, we created a situation that both conceals some information, at the same time as it amplifies some other.

Information pertaining to ‘reserved’ individuals who, other things being equal, are less likely to disclose their age, is blended with the rest of the data. And this is fine as long as all segments of the population at large exhibit some degree of unwillingness to reveal such private information. The problem arises when the ‘reserved’ individuals account for almost half of the observations. For example, if only men, or if only individuals older than the median age refuse to divulge their year of birth, while their counterparts, i.e., women or younger persons are ‘open’ to answer, then the data gets tainted. Features containing information pertinent to reserved individuals would flow to those who are open and either amplify or curtail the information therein. This would happen more, or less, depending on the extent to which those features are positively or negatively correlated, and our ability to detect significant relations to those variables would be limited accordingly.

Further, a quick look at the *GEBURTSJAHR* feature histogram — Fig. 4, shows two peaks, one in 1965, and another in 1980. Thus, our imputation of the outlier biases the customers’ profile towards the predilections of individuals in their late 50’s and early 40’s who happen to be open about answering such questions. This, of course, is nothing to worry about, if the source of the outlier is not demographic, i.e., as long as there is no segment of the population who are unwilling to reveal their age and represent roughly half of all individuals.

Unsupervised Learning — Customer Segmentation

Keeping in mind our ultimate goal of improving customer acquisition using targeted marketing, we now turn to unsupervised learning ML techniques; Chinedu et al (2015) remark “*The importance of customer segmentation include, inter alia, the ability of a business to customize market programs that will be suitable for each of its customer segments*” (p.40). Customer Segmentation aims at recasting the customers observations into a few segments. “*Each segment comprises customers who share similar market characteristics*” (Abstract). Chinedu et al (2015).

Principal Component Analysis: It is easier to form clusters if we start with fewer dimensions. In high dimensionality cases, such as ours, with 366 features, a reduction step takes place before clustering. Principal Component Analysis (PCA) is a dimensionality reduction technique that projects the original data features onto a space of uncorrelated new features (components) that successively maximize retained variance at the cost of dropping a number of features. Holland (2019) notes *"several criteria have been proposed for determining how many PCs should be investigated and how many should be ignored. One common criteria is to ignore principal components at the point at which the next PC offers little increase in the total variance explained. A second criteria is to include all those PCs up to a predetermined total percent variance explained, such as 90%"* (p. 3).

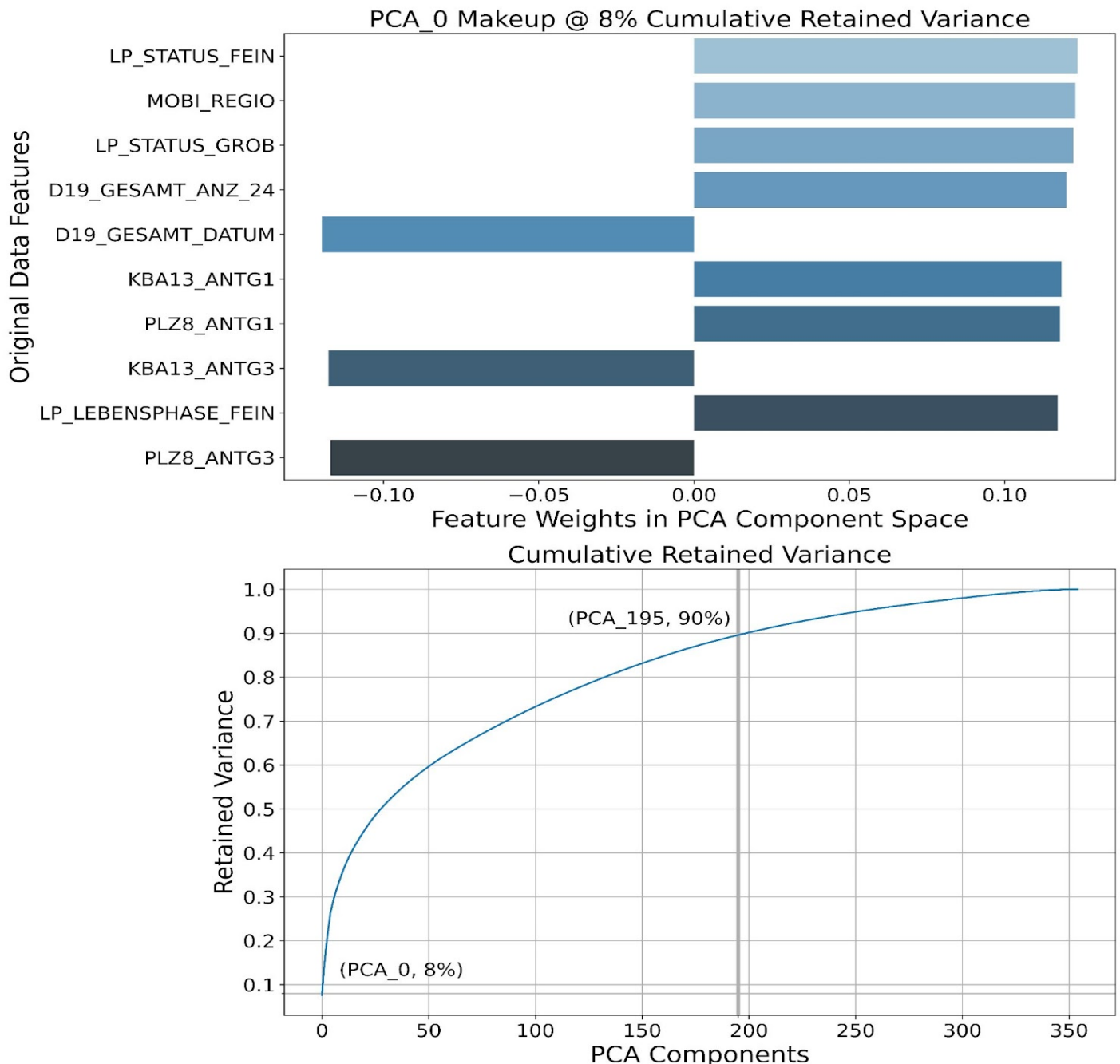


Figure 7 — PCA Component Features and Retained Variance.

Using PCA, the features were projected onto a 90% retained variance space, using 195 principal components instead of the original 366 columns; thus trading off 10% of the information contained in the original variables to attain $\sim 50\%$ reduction in dimensionality. The linear combination of features making up each principal component as well as the cumulative amount of variance retained by it, were made visible interactively. Figure 7 (top) shows *PCA_0*, the first PCA component with its top ten constituent features and weights. The bottom part of the graph shows the cumulative retained variance of the components, starting at *PCA_0* with 8%. Also shown is the point where the cutoff was made, at *PCA_195* with retained variance reaching 90%.

K-Means Clustering: Next, the complexity of the problem was further reduced by segmentation (clustering). The idea behind clustering is to turn the 891,221 observations from the general population into a smaller number, say **k**, of so-called clusters of points. If each observation can be thought of as a point, then each cluster, as the name indicates, is a conglomerate of points, a super-point that for all intents and purposes can be viewed as a good representative of the observations near it. *"K-Means is one of the simplest unsupervised learning algorithms that solve the well known clustering problem ... through a certain number of clusters fixed a priori"* (p. 91), Trupti et al (2013). Without a priori knowledge of the number of clusters to use, several segmentation attempts were made by varying the number of clusters **k**, to examine how thinly or densely populated the resulting clusters were. Figure 8 shows the results of plotting the average cluster centroid distances against the values of **k** attempted.

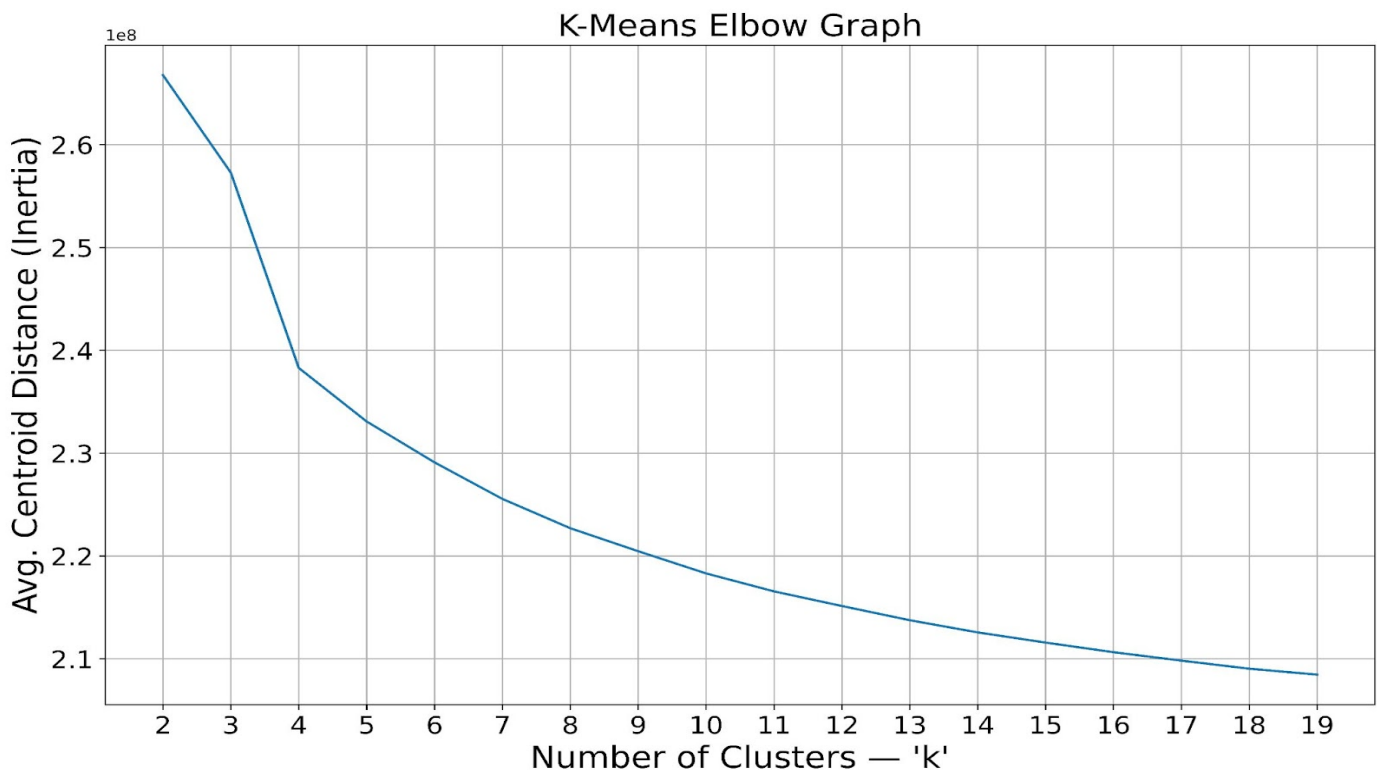


Figure 8 — K-Means Average Centroid Distance vs Number of Clusters.

With K-Means, the value of "**k**" is chosen so that the average centroid distance is low, i.e., the clusters are packed. *"The oldest method for determining the true number of clusters in a data set is inelegantly called the elbow method. ... at some value for K the cost drops dramatically, and after that it reaches a plateau when you increase it further. This is the K value you want"* (p.92), Trupti et al (2013). Following this advice, a choice was made at "**k=4**" for our analysis.

Cluster Analysis: The PCA and K-Means models were fitted using the general population, and then used to transform the customers dataset. Figure 9 compares how the observations in both datasets were assigned to one of four cluster labels. The top part shows the clustering in absolute terms (number of observations), the middle in relative terms (densities), and most importantly, the bottom subplot shows the degree to which each cluster over represents (green) or under represents (red) the customers. To guide a targeted marketing campaign, we need to investigate what these clusters mean in terms of demographic traits, i.e., in terms of the original features that are now obscured behind the PCA components and clusters. We are particularly interested in clusters 3 and 2 which highly overrepresent the customers.

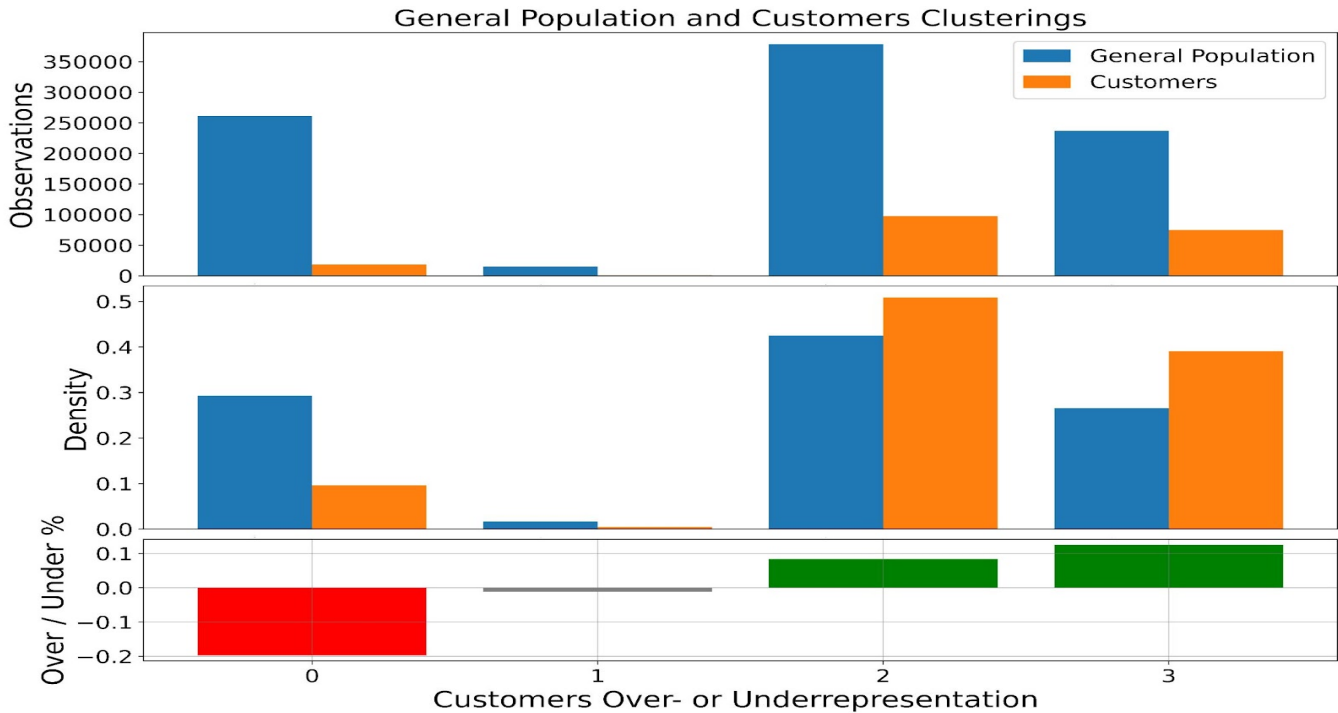


Figure 9 — Cluster Observations, Densities, and Over- Under-Representation.

Getting back the original features is a two-step process. First, the coordinates of the clusters in 195-dimensional PCA space are examined. These coordinates get progressively closer to the origin for higher components, so the search for meaning can be narrowed to the first 20 or so PCA axes. Figure 10 shows a heatmap using only the first 20 PCA components. The stronger shading reveals the axes with the largest cluster projections; for example, for cluster 0 (**C_0**) the largest coordinates project onto **PCA_2**, **PCA_7**, **PCA_10**, **PCA_9**, and **PCA_5** in that order. Further projections can be extracted, but their impact drops quickly in relevance. For our study, only the top five projections were considered, for the sake of expediency.

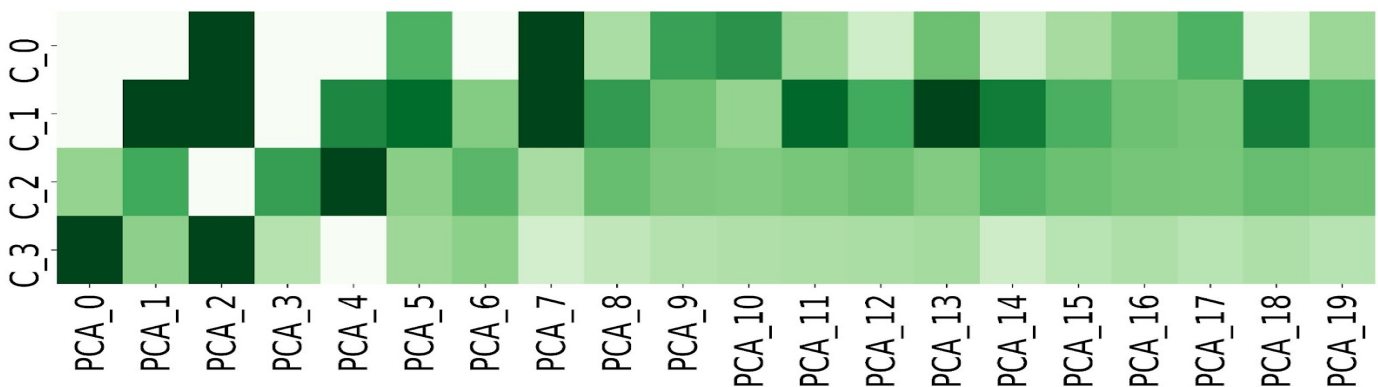


Figure 10 — Cluster PCA Components Heatmap.

The second step in getting back the original features consists of breaking down the main PCA cluster projections into their constituent features by weight, as was done in the previous PCA analysis depicted in Figure 7. These two steps can be combined and automated to dissect the clusters as shown in the abridged output snippet below. The clusters are sorted by over (green) or under (red) representation with customers; their main PCA axes are listed, and along with them, the main features. It is then a simple matter of looking up the meaning of these features in the spreadsheets, and examining the feature slots over or under representation by customers, as was shown in Figure 6, to arrive at the desired meaning of the segmentation exercise.

```
C_3 Overrepresentation by 12.51%
PCA_0 : ['LP_STATUS_FEIN +12.35', 'MOBI_REGIO +12.28', ...]
PCA_2 : ['ONLINE_AFFINITAET +14.4', 'D19_GESAMT_ANZ_24 +14.28', ...]
PCA_6 : ['SEMIO_KAEM +34.44', 'ANREDE_KZ +33.28', 'SEMIO_VERT -32.39', ...]
PCA_1 : ['KBA05_SEG6 +17.89', 'KBA05_KRSOBER +16.33', ...]
PCA_5 : ['KBA13_KW_0_60 +21.01', 'KBA13_KW_61_120 -20.9', ...]

C_2 Overrepresentation by 8.38%
PCA_4 : ['FINANZ_ANLEGER +18.51', 'FINANZ_SPARER +18.27', ...]
PCA_3 : ['KBA13_HERST_BMW_BENZ +19.74', 'KBA13_MERCEDES +17.04', ...]
PCA_1 : ['KBA05_SEG6 +17.89', 'KBA05_KRSOBER +16.33', ...]
PCA_14: ['D19_BANKEN_ANZ_12 +25.09', 'D19_BANKEN_ANZ_24 +24.35', ...]
PCA_6 : ['SEMIO_KAEM +34.44', 'ANREDE_KZ +33.28', 'SEMIO_VERT -32.39', ...]

C_0 Underrepresentation by -19.71%
PCA_2 : ['ONLINE_AFFINITAET +14.4', 'D19_GESAMT_ANZ_24 +14.28', ...]
PCA_7 : ['VERS_TYP +29.37', 'HEALTH_TYP +29.23', ...]
PCA_10: ['LP_LEBENSPHASE_GROB +16.89', 'LP_LEBENSPHASE_FEIN +16.73', ...]
PCA_9 : ['KBA13_KMH_140_210 +18.75', 'KBA13_CCM_1401_2500 +18.25', ...]
PCA_5 : ['KBA13_KW_0_60 +21.01', 'KBA13_KW_61_120 -20.9', ...]

C_1 Underrepresentation by -1.17%
PCA_1 : ['KBA05_SEG6 +17.89', 'KBA05_KRSOBER +16.33', ...]
PCA_2 : ['ONLINE_AFFINITAET +14.4', 'D19_GESAMT_ANZ_24 +14.28', ...]
PCA_7 : ['VERS_TYP +29.37', 'HEALTH_TYP +29.23', 'KOMBIALTER -28.8', ...]
PCA_13: ['KBA13_HERST_AUDI_VW +20.48', 'KBA13_VW +19.22', ...]
PCA_11: ['LP_FAMILIE_FEIN +17.1', 'LP_FAMILIE_GROB +16.58', ...]
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This exercise revealed that the population can be grossly considered to be comprised of four types of individuals, two of which (Clusters 3 and 2) are worthwhile pursuing with targeted marketing campaigns. A brief description of the clusters follows:

- Cluster 3 — Wealthy Older West German Males: This group has the highest customer overrepresentation and consists of men who grew up in post-war West Germany. They are sedentary, culturally minded high income earners, with unremarkable online presence. Some are new homeowners and live in areas where there are some upper class cars, such as BMWs, and some trailers, but not many cars built between 2000 and 2003.
- Cluster 2 — Money Savvy Wealthy Males: Also strongly overrepresented with customers. These are men who save or invest their money, rather than spending it in the home, or in being prepared; they are not known for online-banking. They are culturally minded, and live in areas with a very high share of newly built cars as well as upper class cars, such as BMWs and Mercedes Benz, but not too many 5-seaters.
- Cluster 0 — Power Couples & Retirees: Hugely underrepresented with customers. These are either high-earning couples or retiring single high-earners that live in multigenerational households in areas with a high share of newly-built cars. They have Germanic last names and are very demanding shoppers, but have an unremarkable online presence.
- Cluster 1 — Older Couples & Households: Also underrepresented with customers, but only slightly. This rather neutral group, consists mostly of people who are not single and who are living in multigenerational households. Nothing is known of their wealth status, but their online presence is unremarkable and they are very demanding shoppers. They have Germanic last names and grew up in post-war Germany.

It should be noted that these observations are based on incomplete information. Many features were ignored when we decided to analyze only the top five features per PCA component. Furthermore, of the features considered for analysis, several could not be decoded from the spreadsheets, and had to be ignored as well. But if we had to venture a guess as to where the firm ought to focus its marketing efforts, it would be on culturally minded men living in areas with a high share of new and upper class vehicles. Men who are either money savvy from anywhere in Germany, or wealthy and older "grandpa" types from the west of the country. Conversely, not much can be gained by advertising to *Cluster_0* individuals who live in multigenerational households, regardless of wealth or share of new and upper class cars in their area. *Cluster_1* type customers, if any, are indistinguishable for the general population.

Supervised Learning — Classifier

The next part of the project entailed training a classifier model, and fine-tuning some of its parameters in order to make predictions to submit into a [Kaggle Competition](#). To start, all the prior data exploration and preprocessing steps were applied to both mailout datasets, the training piece with 42,962 observations, and the test piece with 42,833 rows. An extra column, "RESPONSE", in the training part, was to be used as ground truth labels to train the classifier. Figure 11 shows a bar plot of these labels. Observations labeled with "1", correspond to true customers, while those labeled with "0" are known to be non-customers. There is an obvious and overwhelming imbalance in the labels, with only 532 customers in the entire 42,962 rows. In classifier parlance, the customers are known as a "rare class", and this poses limitations as to how to train, tune, and gauge the performance of classifiers.

Metric Selection: Given the imbalanced nature of the training dataset, it is crucial that an appropriate metric is selected, in order to ensure that the classifier that we train performs well under equally imbalanced test environments. This eliminates accuracy as a metric for our study. Indeed, with highly imbalanced labels, any model predicting "non-customer" for all observations would be highly accurate, but of no use. *"Considering the case of imbalanced data assessment; Accuracy places more weight on the common classes than on rare classes, which makes it difficult for a classifier to perform well on the rare classes"* Bekkar et al (2013 p.28).

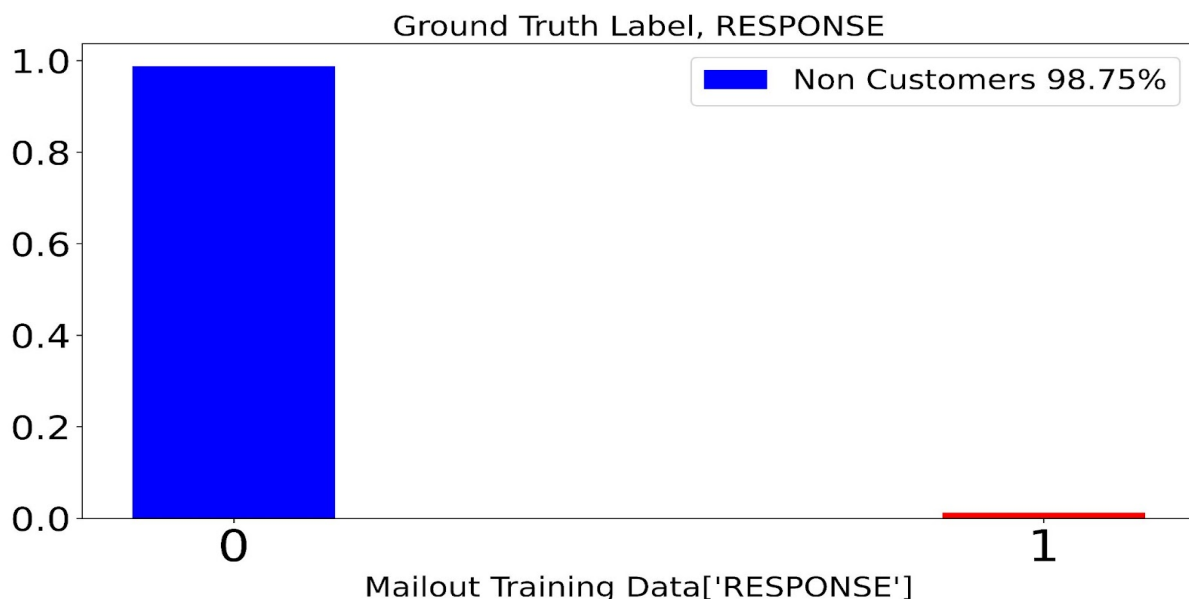


Figure 11 — Mailout Training Data, Labels Imbalance.

Instead of accuracy, a more fundamental evaluation metric is needed; one that accounts for false positives and false negatives in a way that makes sense for the targeted marketing problem at hand. The following observations regarding our asymmetric sensitivity to false negatives and false positives helped in deciding which metrics to use for this exercise. First, we are more inclined to tolerate false positives in our predictions, i.e., marketing to non-customers. This represents a minor cost to us, at the risk of slightly annoying someone with no interest in purchasing any of our products. Second, false negatives, on the other hand, are a serious problem for us; they translate directly into missing out on the potential revenue from misidentified true customers, and getting this revenue is the entire point of this project.

In our metaphorical search for needles in a haystack, it is fine to pick some hay, but we definitely don't want to throw any needles back into the haystack by mistake. This means that we care more about *Recall* or *Sensitivity*, than we do about *Precision*. The concept of Recall, as it applies to the problem of customer classification, is worth reviewing: Recall, or *True Positive Rate* (TPR), captures the fraction of correctly predicted customers to the total pool of customers, ***Recall = true positives / (true positives + false negatives)***.

Similarly, *False Positive Rate* (FPR), captures the fraction of incorrect predictions to the total pool of non-customers,

False Positive Rate (FPR) = false positives / (false positives + true negatives).

The Receiver Operating Characteristic — ROC, is a curve that gives TPR as a function of FPR. *"The more inclined the curve is toward the upper left corner, the better is the classifier's ability to discriminate between positive and negative class"* Bekkar et al (2013 p.30). By measuring the ROC Area Under Curve (AUC), we obtain a metric that summarizes the performance of classifiers as a single number. This number can then be used as a scoring mechanism to tell how well a model distinguishes customers from non-customers; ROC AUC can help with model selection by ranking the models, and it can be used in parameter tuning by guiding the tuning mechanism to try combinations of parameters that increase the ROC AUC. For all these reasons, ROC AUC was picked as our metric of choice. Figure 12 shows a typical classifier's ROC curve and ROC AUC. The straight baseline represents a worthless model with ROC AUC of 50%. The jagged blue line stands for a typical fair-to-good model with AUC of 70%.

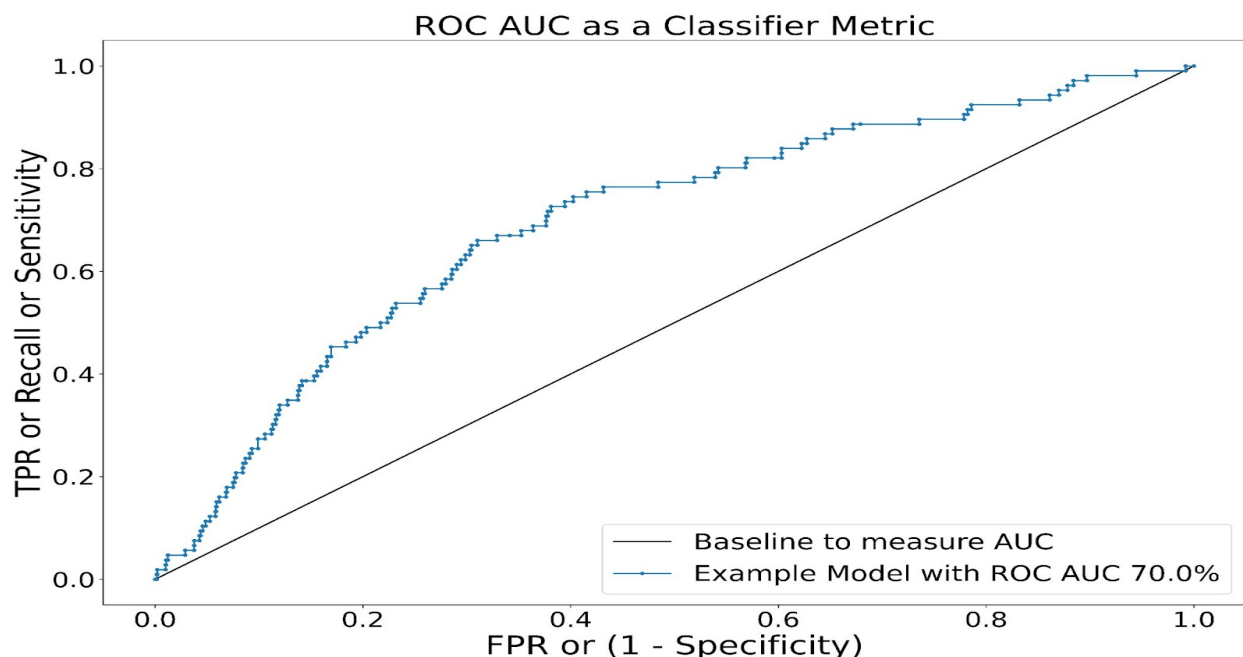


Figure 12 — ROC Curve, and ROC AUC Metric.

As a relative metric, AUC finds many practical uses, such as the ones mentioned, i.e., model selection and tuning. As an absolute metric, however, its interpretation is somewhat arbitrary. It is just a number between .5 and 1, but tables such as the one in Figure 13 serve as guidance for the meaning of the AUC values, Allaire (2006).

AUC Value	Model performance
0.5 - 0.6	Poor
0.6 - 0.7	Fair
0.7 - 0.8	Good
0.8 - 0.9	Very Good
0.9 - 1.0	Excellent

Figure 13 — Area Under Curve Value Interpretation.

Model Selection: The training data was split into two pieces, one for training (80%) and the other for cross validating predictions (20%), ensuring that both contained the same proportion of customer to non-customer observations. This standard procedure protects against overfitting. Several classifiers were tried, their ROC curves plotted, and the corresponding ROC AUC scores computed in order to discern the most promising model for subsequent tuning. The list of models attempted, their ROC curves, and ROC AUC scores are shown together in Figure 14. We explored *Logistic Regression*, as well as ensemble techniques like *Random Forest*, *Adaptive Boosting*, *Gradient Boosting Machine* and the *XGBoost* variant.

Guided by the interpretations listed on the table in Figure 13, all the models attained fair to good performance, with the Gradient Boosting algorithm emerging as the clear choice for parameter tuning and predicting. Bekkar et al (2013 p.30) note that "Several ROC curves can be represented in the same space to compare the results of different models ... a curve dominating the others and modeling associated with the dominant curve is considered more efficient". The Gradient Boost ROC curve can be seen to be markedly above the rest, showing a trajectory nearest the upper left corner, and with an AUC score of 74.9%, it is several percentage points ahead of the next best classifier model (Fig. 14).

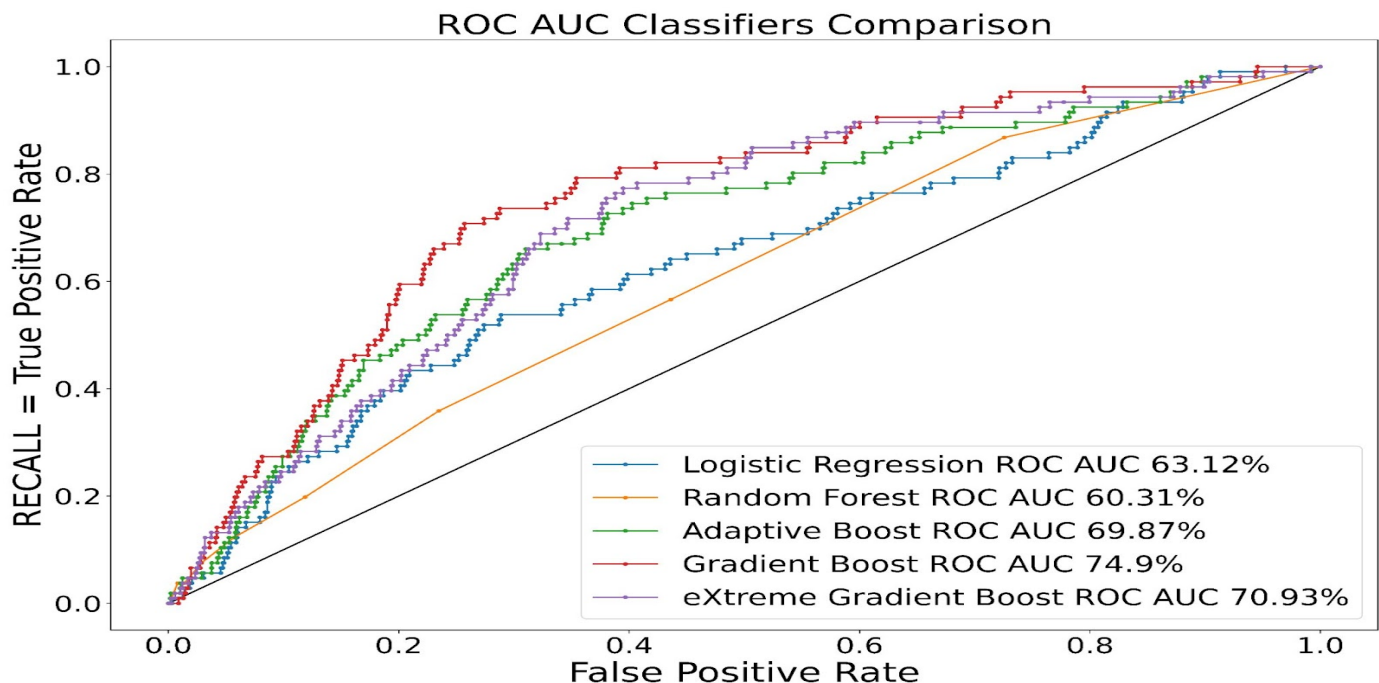


Figure 14 — ROC Curve and ROC AUC Metric for Classifier Model Selection.

Parameter Tuning: The parameters of the Gradient Boosting model can be divided into three categories: Tree-Specific Parameters, Boosting Parameters, and other miscellaneous parameters for overall functioning. The first tuning attempt focused on the learning rate (*learning_rate*), the number of trees (*n_estimators*), the tree depth (*max_depth*), and the number of randomly selected features to consider while searching for a split (*max_features*).

Boosting is a sequential process that may, in some cases, tend to overfit the training data. To avoid this, several Gradient Boost models were trained by varying the four parameters of interest over a range of values in isolation as follows. For each parameter, a range of values was chosen around its default setting. And for each value in the range, a Gradient Boost model was trained; the model was then used to make predictions over the training and test splits to obtain the ROC AUC scores shown in Figure 14.

The usefulness of these plots lies in their ability to show ranges where the gap of the model's learning curves between the train and test splits weren't too wide. The *learning_rate* parameter, for example, on the top-left graph, shows a very wide gap using a learning rate value of 0.1; there the ROC AUC difference between the learning curves, ~17%, indicates that the model is overfitting the training data, and thus not generalizing well. Ideally, these plots would have both lines tracing high ROC AUC values and a steadily tightening gap. The reality of parameter tuning, however, does not proceed as the graphs would suggest. The parameters do not work in isolation, but have interdependencies that make the search for the optimal combination of values a very time-consuming trial and error process. To aid with this tedious task, several automated search functions are available.

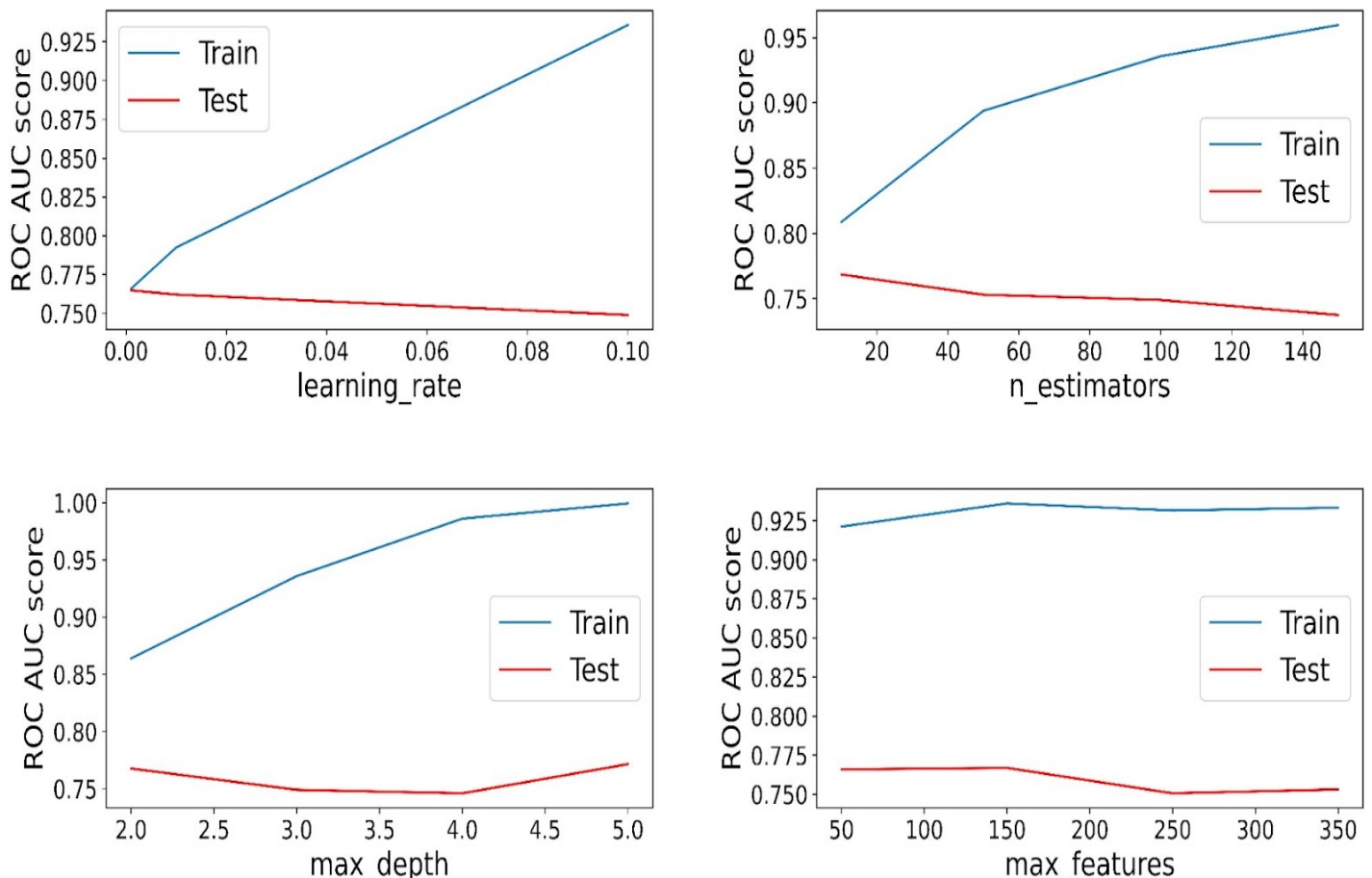


Figure 15 — Learning Curves, Train and Validation(Test), for Several Isolated Parameters.

The actual tuning was carried out with SK-learn's cross validated *GridSearchCV* library function, fitting 5 folds to the parameter value combinations. The GridSearch, as its name suggests, proceeds with systematic brute-force examination of all parameter value combinations over an n-dimensional grid (for n parameters). The Cross Validation here refers to a further splitting of the training piece into K-Folds, in our case five. One of these partitions is used for testing, and the others for training while the search proceeds.

The first tuning attempt resulted in slight improvement, with the ROC AUC reaching 77.4% using the following parameter values: `{'learning_rate': 0.01, 'max_depth': 4, 'max_features': 225, 'n_estimators': 50}`.

Two more parameters were selected for further tuning: the fraction of observations to be selected for each tree (*subsample*), and the minimum number of observations which are required in a node to be considered for splitting (*min_samples_split*). All six parameters were tuned following the same procedure. The resulting improvement was only marginal, with AUC now reaching 77.53% using the following parameter values: `{'learning_rate': 0.01, 'max_depth': 5, 'max_features': 220, 'min_samples_split': 5, 'n_estimators': 55, 'subsample': 0.95}`.

The final Gradient Booster model, with parameters tuned as shown above, was used to make predictions over the mailout test dataset and the results were submitted to the Kaggle competition for a score of 78.53%. Figure 16 displays a table summarizing the evolution of the Gradient Boost classifier parametrization.

	AUC	Kaggle	Parameters
Base Model	74.90%		Default
First Tuning	77.40%		<code>{'learning_rate': 0.01, 'max_depth': 4, 'max_features': 225, 'n_estimators': 50}</code>
Second Tuning	77.53%	78.53%	<code>{'learning_rate': 0.01, 'max_depth': 5, 'max_features': 220, 'min_samples_split': 5, 'n_estimators': 55, 'subsample': 0.95}</code>

Figure 16 — Gradient Boost Classifier Parameter Tuning.

Conclusion: In this project, ML techniques were implemented to analyze demographic data, in order to identify customers for a targeted marketing campaign. The data presented many challenges: 10% of the general population, and 20% of the customer data was missing. Some observations were missing more than 70% of their entries, there were jumps in the amounts of missing data, and the meaning of many columns was left unexplained. Some features needed extra wrangling steps to disambiguate their slot labels, to impute their missing entries, and to handle their outliers. One feature in particular, *GEBURTSJAHR*, registered 50% of individuals as born in the year zero. This may have had adverse consequences for the analysis.

To deal with missing data, a justifiable assumption (MCAR) was made about the “missingness”; this resulted in the random selection method of imputation being chosen. After exploring and preprocessing the data, the distributions were compared to focus on features and corresponding slots that over or under represented the customers. From this straight forward analysis, a broad first characterization of the customers emerged. Briefly, customers tend to be wealthy and sedentary nature lovers, mostly older West German men living without children at home. We noted the potential concealment of meaningful customer attributes in this study as a result of our handling of the “year of birth” noise, and the multiplicity of unexplained features. Features lacking description had to be ignored from the customer profiling task.

With unsupervised ML techniques, the complexity of the problem was made more tractable. First the number of variables was reduced from 366 to 195 by means of PCA. After this, using K-Means clustering, the near 1M observations were collapsed into four clusters that crystallized what made customers stand out from the general population. Two segments in particular were heavily representative of customers, namely, wealthy older West German males, and money-savvy wealthy males. The analysis also revealed a segment of the population that strongly underrepresents the customers, one which the marketing efforts will do well to exclude; these are power couples and retirees living in multi-generational households.

The supervised learning part of the project presented its own challenge; the data available for training was heavily imbalanced. To deal with this, an appropriate metric was picked based on considerations pertaining to the problem at hand, i.e., a targeted marketing strategy. Using ROC AUC as the metric of choice, several classifiers were tried and the Gradient Boosting Machine classifier was selected for tuning and predicting. After tuning some parameters, predictions were made and submitted to the [Kaggle Competition](#) to achieve a score of 78.53%.

As far as improvements, given the excessive amount of missing data in this project, it is probably here that that sweet spot can be found for improving both the unsupervised as well as the supervised learning results. Multivariate imputation techniques, such as MICE can be tried to see if indeed the random selection approach we opted to use is the best for these datasets. Features deemed important by the classifier can be explored first. Besides this, there were a few columns showing inner structure and non ordinal characteristics, suggesting that a split along the lines of One-Hot encoding or other feature engineering steps may result in better extraction of the information in them. Another area that should be explored to improve the performance of the classifier is to address the highly imbalanced training data by either oversampling the customers, or undersampling the non-customers, or both.

Overall, the project was fun; a lot was learned not only with regards to ML techniques, but also about the tools of the trade as applied to a real-life problem. I would recommend the course, and the project to anyone genuinely curious about Machine Learning. Having secured permission to access the datasets from [Udacity](#) or [Arvato - Bertelsmann](#), it is then possible to follow along the analysis of the project with the Jupyter [Notebook](#).

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