**Final Project: Animal Rescue Returns Classification**

**Naïve Project Team**

*Rachel Kelley (gtID: 903749193) and Justin Schulberg (gtID: 903737135)*

Table of Contents

[Breakdown of Roles 2](#_Toc90366262)

[Problem Statement 2](#_Toc90366263)

[Data Source 3](#_Toc90366264)

[Data Preparation/Cleaning 5](#_Toc90366265)

[Columns 5](#_Toc90366266)

[Dealing with NAs 8](#_Toc90366267)

[Dimensionality Reduction 8](#_Toc90366268)

[Balancing the Distribution of Data 10](#_Toc90366269)

[Analysis, Evaluation, and Final Results 11](#_Toc90366270)

[Classification 11](#_Toc90366271)

[Naïve Bayes 13](#_Toc90366272)

[KNN 14](#_Toc90366273)

[Logistic Regression 15](#_Toc90366274)

[Linear SVM 16](#_Toc90366275)

[Kernel SVM 17](#_Toc90366276)

[Neural Networks 18](#_Toc90366277)

[Decision Tree 19](#_Toc90366278)

[Random Forest 22](#_Toc90366279)

[Adaboost 23](#_Toc90366280)

[Conclusion 25](#_Toc90366281)

[An Example 25](#_Toc90366282)

[Opportunities for Further Analysis 26](#_Toc90366283)

# Breakdown of Roles

For the most part, the tasks in the project were equally-shared between the two team members, Rachel and Justin. Almost all code and accompanying write-up was worked on by both teammates. For a general breakdown of tasks and their respective assignee, we have:

|  |  |
| --- | --- |
| Task | Assignee |
| Requirements Gathering | Justin (Lead) & Rachel (Support) |
| Data Preparation | Justin (Lead) & Rachel (Support) |
| Data Cleaning | Rachel (Lead) & Justin (Support) |
| Classification Models + Analysis | Rachel (Lead) & Justin (Support) |

For a more thorough breakdown of the tasks covered by each team member, feel free to access the [*Issues* page of the GitHub project](https://github.com/jschulberg/Dog-Returns/issues), where various tasks are assigned to the team member who completed them.

# Problem Statement

For this final project, the Naïve Project Team will be analyzing a dataset from [a local Animal Rescue](https://www.luckydoganimalrescue.org/about), a nonprofit dedicated to rescuing homeless, neglected, and abandoned animals from euthanasia in kill shelters and getting them adopted into their forever homes. The nonprofit educates the community and all pet parents on responsible pet parenting, including the importance of spay/neuter, obedience training, and good nutrition.

Successful adoptions of cats and dogs depend on a variety of factors, both on the parts of the pet and of the family. The nonprofit helps bridge the gap, building strong relationships between the two. The nonprofit rescues hundreds of animals every year, provides them with loving temporary care, and finds them well-matched, carefully screened forever homes.

One of the struggles that the nonprofit runs into is pets being returned after adoption. Even though they adopt out ~2000 dogs per year, about 10% get returned for a variety of factors. The nonprofit assiduously tracks information on all their adoptions and returns. **In this project,** **the** **Naïve Project Team will use various analytical methods learned in Computational Data Analysis to help the nonprofit predict whether or not a dog that they adopt out will be returned**.

To approach this, we followed these steps:

1. Gather requirements
2. Get access to data
3. Clean data
4. Impute missing values
5. Resample data
6. Scale data
7. Split data into test-train sets
8. Run various classification methods on the train set
9. Evaluate the results against the test set
10. Tune the parameters of the most successful models

# Data Source

The project will be overseen by the *Program Manager for Volunteers and Data Integrity* at the nonprofit. She will provide the data needed for this analysis to the Naïve Project Team. Data will be provided across various spreadsheets, detailing the adoptions and returns per year (i.e. Adoptions 2020, Returns 2018, etc.) from the nonprofit, both of which contain records over the past decade, and can be easily linked by a unique ID field for each dog represented in each dataset. The team has worked to programmatically concatenate the various adoption and returns spreadsheets from various years, which unfortunately are not always in the same format and sometimes have different column headers, into two main data sources:

* **Dog List** | A list of every dog that has been adopted out by the nonprofit over the past 10 years. This list includes a variety of features describing each dog, where each row corresponds to a dog being adopted out, and each column represents a different attribute related to that dog. This dataset is composed of 10 spreadsheets, one for every year over the past decade. Each spreadsheet has records of ~2000 adoptions per year. The attributes in this dataset are as follows:

|  |  |
| --- | --- |
| Field | Description |
| Dog Name | Name of the adopted dog |
| ID | Unique ID corresponding to that dog |
| Link | Link to dog’s profile on the nonprofit site |
| Foster/Boarding | Type of adoption for the dog (short vs. long-term) |
| Sex | Gender of dog |
| Age | Estimated age (sometimes a range if actual age not known) of dog at time of adoption |
| Weight | Estimated weight of dog at time of adoption |
| Breed Mixes | Type of dog |
| Color | Color of dog |
| Behavioral Notes | Free text field describing the behavior of the dog. There’s some consistency in entries depending on the individual entering this field, along with some key words to describe the dogs behavior around others |
| Dogs in Home | Number of other dogs in adoptee’s house, if any at all |
| Cats in Home | Number of cats in adoptee’s house, if any at all |
| Kids | Number of kids in adoptee’s house, if any at all |
| BS/W | Indicator for whether or not the dog is part pitbull or other ‘bully’ breed |
| Medical Notes | Free text field describing any health conditions of the dog, if any exist at all |
| Transport Date | Date of adoption |

* **Returns List** | A list of every dog that’s been returned *after being adopted out* by the nonprofit. This list also includes a variety of features describing each dog, where each row corresponds to a dog being adopted out, and each column represents a different attribute related to that dog. This dataset is composed of 10 spreadsheets, one for every year over the past decade. Each spreadsheet has records of ~200 returns per year.

|  |  |
| --- | --- |
| Field | Description |
| Dog Name | Name of the adopted dog |
| ID | Unique ID corresponding to that dog |
| Dog Info | Free text field with general information on the dog |
| Reason for Return | Free text field describing the reason the dog was returned by the adopters. There’s some consistency in this field, but it generally depends on the person entering the information into the spreadsheet |
| Behavior with Dogs | Free text field describing the dog’s general behavior around other dogs |
| Behavior with Kids | Free text field describing the dog’s general behavior around kids |
| Behavior with Cats | Free text field describing the dog’s general behavior around cats |
| Energy Level | General energy of the dog |
| Socialization/Daycare | Categorical field for whether the dog was in a daytime program for dogs |
| Vetting | Categorical field for whether the dog was being taken to the vet |
| Date of Adoption | Date dog was adopted |
| Previous Return? | Boolean for whether the dog has been returned in the past |
| Previous Return Info | Free text field describing why the dog had been returned in the past |
| Date of Return | Date dog was returned |
| Type | Boolean for dog vs. puppy |

# Data Preparation/Cleaning

To begin, we processed, prepared, and cleaned the data for analysis. Currently, all data is kept by the nonprofit in different spreadsheets by year (i.e. adoptions in 2021 are in the ‘Dog List 2021’; so we programmatically combined all of our datasets. On top of that, the Dog and Returns Lists are kept as two separate data sources, but share a linking variable ‘ID’ for dogs that were returned. We used a Left Join to find dogs that were returned; for any dogs which did not have a match in the join, we flagged those as ‘Not Returned’.

There were also some issues with the features provided in the data that needed to be addressed. Some of the work done to properly clean the different features is delineated below:

## Columns

#### [Color](https://github.com/jschulberg/Dog-Returns/issues/15)

We created a new column called *COLOR\_FIXED*, which is the cleaned up version of the COLOR column. After cleaning up the COLOR column with *COLOR\_FIXED*, we also made the following new features for predictive purposes:

* **multi\_color** | Variable indicating whether or not a dog has multiple colors denoted in it. This is calculated by seeing if the number of commas (',') in the COLOR\_FIXED column is greater than 1 or whether the color is denoted as 'tri-color'.
* **num\_colors** | Continuous variable counting up the number of commas (',') in the COLOR\_FIXED column.
  + Note: This feature is highly correlated to the feature **multi\_color** since any dog which has num\_colors = 1 🡺 multi\_color = 0; conversely, any dog which has num\_colors > 1 🡺 multi\_color = 1. Though we believe that **num\_colors** will be a better predictor than **multi\_color** because it contains more information, we will test each of these features in our models **separately** to see which one ends up being more predictive.
* **contains\_black** | Variable indicating whether 'black' appears in the COLOR\_FIXED column. This feature, in particular, is being incorporated to test the [hypothesis that black dogs are adopted less/returned more](https://en.wikipedia.org/wiki/Black_dog_syndrome) frequently than other-colored dogs.
* **contains\_white** | Variable indicating whether 'white' appears in the COLOR\_FIXED column.
* **contains\_yellow** | Variable indicating whether 'tan/yellow/golden' appear in the COLOR\_FIXED column.
* **contains\_dark** | Variable indicating whether the dog has a darker coat, since the colors can sometimes be guesses.

#### [Gender](https://github.com/jschulberg/Dog-Returns/issues/11)

From the *GENDER* column, due to issues with the manual entry of values, we had to standardize all values as either ‘Female’ or ‘Male’, and then one-hot encoded this; 1 for ‘Male’, 0 for ‘Female.

#### [Age](https://github.com/jschulberg/Dog-Returns/issues/10) at Adoption

In the original data set, age was described in either days, weeks, months, or years, or just a number with no age measure, and some dogs had a listed date of birth. To get the most accurate age for each dog, we calculated age at adoption in days by subtracting the date of birth from the adoption date. Where this information was not available, age at adoption was calculated via the age column and converted to an estimate in days.

#### [Breed](https://github.com/jschulberg/Dog-Returns/issues/13) Mixes

We cleaned the *BREED MIXES* column, which denotes a dog's breed. Because there are so many combinations of different breeds for dogs, we opted to create indicator features for the most popular groupings of dogs (Lab/Retriever, Shepherd, or Other).

#### [Mix](https://github.com/jschulberg/Dog-Returns/issues/14)

The column, *MIX*, denotes whether a dog is a mixed breed. We cleaned up some of the inconsistencies in the denotations of multiple breeds (i.e. the use of ‘&’, ‘and’, ‘/’, ‘with’, etc.). Also, we leveraged the *SECONDARY BREED* column to fill gaps for nulls. Lastly, we looked at the *BREED MIXES* column for a slash ‘/’ or and ‘&’ to determine if a dog is multiple (mixed) breeds. Lastly, we one-hot encoded this feature; 1 for ‘Mix’, 0 otherwise.

#### [Weight](https://github.com/jschulberg/Dog-Returns/issues/12)

The column, *WEIGHT*, denotes the weight, in pounds of a dog. Although this column was more consistent than others, some dogs have their weight as just a number (i.e. 60) while others have their weight along with the unit of measurement (i.e. ‘60lbs’ or ‘60 pounds’).

#### [Behavioral](https://github.com/jschulberg/Dog-Returns/issues/20) Notes

The column, *BEHAVIORAL NOTES*, includes comments about a dog's temperament. There's not too much cleaning that was performed here -- just some general standardization --, but there were a lot of good notes about dogs' temperaments. To pull out this data, we created the following features:

* **num\_behav\_issues** | Continuous variable denoting the number of behavioral issues/notes a dog has associated with it.
* **puppy\_screen** | Variable indicating whether a dog has a behavioral note that it should be screened with puppies.
* **new\_this\_week** | Variable indicating whether a dog has a behavioral note that it is new in a given week.
  + *Note: We expect this variable to be the least helpful, since a dog being new is not necessarily associated with its adoption date.*
* **needs\_play** | Variable indicating whether a dog has a behavioral note that it doesn’t walk alone enough and needs extra running or playtime.
* **no\_apartments** | Variable indicating whether a dog has a behavioral note that it should not be placed with adopters who live in an apartment, and should instead be placed with adopters who live in a residential home.
* **energetic** | Variable indicating whether a dog has a behavioral note that it exhibits medium-high energy.
* **shyness** | Variable indicating whether a dog has a behavioral note that it exhibits general shyness and should not be placed with kids (who generally expect dogs to be more energetic) and should be committed to a socialization program.
* **needs\_training** | Variable indicating whether a dog has a behavioral note that it should be screened with puppies.

#### [Medical](https://github.com/jschulberg/Dog-Returns/issues/20) Notes

The column, *MEDICAL NOTES*, includes comments about a dog's health conditions. There's not too much cleaning that was performed here -- just some general standardization --, but there were a lot of good notes about the different health conditions that each dog has. We extracted the following features by parsing through the medical notes:

* **has\_med\_issues** | Variable indicating whether a dog has a medical condition associated with it.
* **diarrhea** | Variable indicating whether a dog has a medical note that contains mention of diarrhea.
* **erlichia** | Variable indicating whether a dog has a medical note that contains mention of Ehrlichia (the disease Ehrlichiosis)/Lyme transmitted by ticks.
* **uri** | Variable indicating whether a dog has a medical note that contains mention of Ehrlichia (the disease Ehrlichiosis)/Lyme transmitted by ticks.
* **ear\_infection** | Variable indicating whether a dog has a medical note that contains mention of an ear infection.
* **tapeworm** | Variable indicating whether a dog has a medical note that contains mention of Tapeworm.
* **general\_infection** | Variable indicating whether a dog has a medical note that contains mention of the word ‘infection’.
* **demodex** | Variable indicating whether a dog has a medical note that contains mention of Demodex (Demodectic mange aka mites).
* **car\_sick** | Variable indicating whether a dog has a medical note that contains mention of car sickness.
* **dog\_park** | Variable indicating whether a dog has a medical note that the dog has not yet been exposed to a dog park, indicating a lack of general immunity to common diseases.
* **leg\_issues** | Variable indicating whether a dog has a medical note that contains mention of any leg issues, including amputated, sprained, swollen, lesions, etc.
* **anaplasmosis** | Variable indicating whether a dog has a medical note that contains mention of Anaplasmosis.
* **dental\_issues** | Variable indicating whether a dog has a medical note that contains mention of any teeth/dental issues.
* **weight\_issues** | Variable indicating whether a dog has a medical note that contains mention of weight issues, including overweight and underweight.
* **hair\_loss** | Variable indicating whether a dog has a medical note that contains mention of hair loss.
* **treated\_vaccinated** | Variable indicating whether a dog has a medical note that contains mention of treatment or vaccination for the dog.

## Dealing with NAs

For various reasons, a number of the columns mentioned above were missing values. It could be because no medical notes were reported, thus making it impossible to know whether a dog actually has a given medical issue; or because the information was unable to be discerned. To deal with these null values, we had the following options:

* Fill using mean of column
* Fill using median of column
* Fill using clustering algorithm (KNN, K-Means, etc.)

With guidance from the program manager at the nonprofit, we decided to combine a mixture of column fills and KNN imputation to deal with NAs. For column fills, the program manager advised us that some of the features, if not noted, would be 0 – for example, *shyness* and *needs\_play* are two features that are generally always noted for dogs with those features, so for the rest of the dogs we can safely assume to fill with zeros. For other columns, such as weight, number of colors, and *no\_apartments*, we used KNN imputation in order to fill those values, as they are harder to generalize as all 0s or 1s. By using KNN imputation, we are filling the NAs with values appropriate to other features of the dog.

## Dimensionality Reduction

After all the above data cleaning steps were completed, we found ourselves with 43 features! Many of these features were binary variables, while some were continuous variables. To tackle this, we applied PCA on our dataset. Here is what the first two principal components look like, shaded by whether or not a dog was returned:

There’s not much separating out the dogs that were returned (1) from the dogs that stayed adopted (0). Expanding this out to the first three principal dimensions, gives us the following 3-dimensional representation of our principal components, featured in the image to the right.

Again, it’s hard to see much linear structure from these components in regard to the indicator variable. Looking at how much variance in our data is actually explained by each successive principal component, we get the image to the bottom-left.

Looking at this graph, we see that the variation in the data is rather evenly described by each of the principal components. We can see this in the almost linear shape of the graph. That is, for each successive principal component included, about the same amount of variance gets explained. This generally makes sense; most of our features are binary variables. While we are theoretically able to transform the linear space of binary variables, the result is not particularly interpretable since their values are only 0 or 1. The results of this PCA lend this notion credence; going forward, our analysis will be applied directly on the data at hand and not a linear combination of the data.

We also attempted to use [Multiple Correspondence Analysis (MCA)](https://github.com/MaxHalford/prince#multiple-correspondence-analysis-mca), a method similar to PCA that functions better with data that contains *both* numerical and categorical variables. Unfortunately, when running our final classification models afterwards, we found that applying either PCA or MCA usually resulted in accuracy scores of up to 10% less than the scores when not using these methods.

## Balancing the Distribution of Data

When we started our analysis, 7.8%, or 824 dogs had been ‘returned’ after adoption. That left our majority class of ‘not returned’ dogs at an overweighted distribution of 92.2%, or 9664 dogs. We sought to balance these two classes using resampling techniques before running the classification models.

To do so, we opted to leverage the [Adaptive Synthetic (ADASYN)](https://imbalanced-learn.org/stable/references/generated/imblearn.over_sampling.ADASYN.html#imblearn.over_sampling.ADASYN) oversampling technique on the ‘returned’ minority class; and a Random undersampling technique on the ‘not returned’ majority class. We found ADASYN, because of its ability to put synthetic points in low distributed areas of the data and then use K-Nearest Neighbors to classify them, to give us the best representation of the minority class. However, we opted not to use ADASYN to get the minority class to the same size (9664) as the majority class; instead opting to increase the size by 3x (2871 ‘returned’ dogs). To get the majority class down in size, we just used a random undersampler to randomly select data points from the majority class (‘not returned’) to keep, ultimately ending with about half as many points (5742 ‘not returned’ dogs).

|  |  |  |  |
| --- | --- | --- | --- |
| Class | # of Original Data Points | | Resampled Data |
| ‘Returned’ | 824 | 2871 | |
| ‘Not Returned’ | 9664 | 5742 | |

Even though this is still not perfectly balanced (i.e. a 1:1 ratio), we contend that this prepares the data in an accurate and unbiased manner for classification. As we tried different techniques and ratios of data points to under/oversample, we applied PCA after the resampling to observe the distribution. Here are the 2-D and 3-D representations of the top three principal components of the resampled data:

Chart, scatter chart

Description automatically generatedChart, scatter chart

Description automatically generated

# Analysis, Evaluation, and Final Results

After preparing the data, we analyzed the data using the various classification models that we have learned so far in class including, but not limited to, Naïve Bayes, K Nearest Neighbors, SVM, Logistic Regression, and Neural Networks. We split the data into training, test, and validation sets. By testing each of these methods, we hope to identify which one is most successful in classifying the adopted dogs as returned vs. not-returned.

## Classification

As we went through running the various classification models, we best compared them using confusion matrices. While maximizing the overall accuracy of the model is an important metric to achieve our goal, we had a long conversation about which errors (Type I vs. Type II) would be more tolerable. In discussion with the *Program Manager for Volunteers and Data Integrity* at the animal rescue, we agreed that it was generally better that a model predicts a dog would be returned (1) even if it stayed adopted (0) than to have a dog be predicted as staying adopted (0) when in actuality it was returned (1). That is, it is better for us to focus on minimizing our false negatives (Type II Error). The best metric to actualize that is to look at the Specificity (true negatives / all actual negatives).

After running our classifiers, we compared them all based on their accuracy, misclassification, precision, recall, specificity, and F1 scores. These scores show the degree to which the different classifiers correctly sort the data points. Below, positive equals returned, and negative is not returned.

Accuracy is a general measure of how many data points are correctly classified out of the total number of data points, so the percent of true positives and negatives out of the total.

Misclassification is the opposite of accuracy and tells us how many data points were incorrectly classified, so the percent of false positives and negatives out of the total.

Precision is the correct positive rate, that is the number of true positives out of predicted positives.

Specificity gives us the true negative rate; true negatives out of all actual negatives.

Recall/Sensitivity is the number of true positives out of all actual positives, so it tells us how many dogs we correctly predicted to be returned out of all dogs that were actually returned. Thus, this score is especially important as we are seeking to maximize the correct classification of true positives, as we want to focus on the dogs that we believe will be returned.

The F1 Score is a statistical measure of accuracy for machine learning models, which combines the precision and recall score. As we can see from the chart below, Random Forest has the best F1 score overall.

Here are the final results of the models we tested, with each model’s performance being discussed in further depth below:

Table

Description automatically generated

To evaluate our models, we looked at their classification/misclassification rates using a confusion matrix, as well as their precision, recall, and F1 scores. These metrics are essential in judging the outcome of a classification model, which is why we will use it to evaluate ours. We will compare the results of our test and validation sets in order to determine which model is the most accurate. We’ll also take note of the performance efficiency of each model.

If our models are accurate, they can be integrated into the nonprofit’s systems to classify new dogs that come into the nonprofit. If a dog is classified into the return group, the nonprofit can ensure that the dog is well matched with its new adopter and reach out to the adopter to provide additional support to prevent the dog from being returned. We plan to construct this project so that the nonprofit’s data team can continue to use it, helping to place more rescued dogs in loving homes and keep them there.

### Naïve Bayes

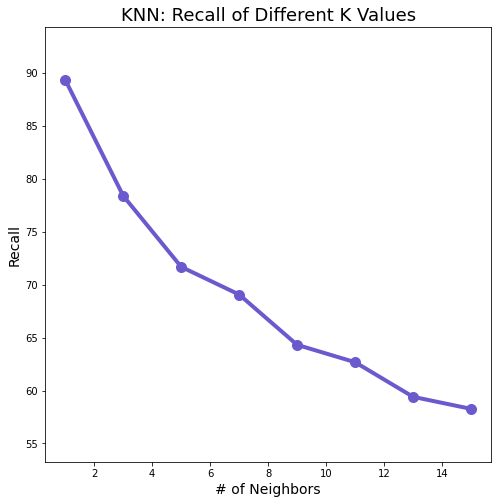
Chart, treemap chart

Description automatically generatedThe Naïve Bayes classifier was overall the worst classifier tested. Without any tuning, its accuracy score of 35.2% was mostly brought down by its abysmal specificity score of 2.3%. That is, the classifier predicted that almost all dogs in the test dataset would be returned, even though in actuality only about 10% of dogs will be returned.

After tuning using *GridSearchCV* on the *var\_smoothing* parameter, we were able to increase the accuracy up to 72.2%; however, this still included a lot of key misclassifications in our returned set.

### KNN

For K-Nearest Neighbors, we tested all values of ‘k’ for the odd numbers between 1 and 15. As found in the graph below, we achieved a maximum accuracy and specificity when we used a ‘k’ value of 1. That is, the KNN classifier was most accurate when a given test point was only compared to the point nearest to it. This likely has to do with the distribution of our data, which is difficult to parse in a general feature space because of how many of our features are categorical and not continuous, thus making them hard for an algorithm like KNN to properly map and relate different test points together.

Chart, line chart

Description automatically generated

After applying a ‘k’ value of 1 on our entire test dataset, we found a much higher overall accuracy for our dataset:

Chart, treemap chart

Description automatically generated

### Logistic Regression

Chart

Description automatically generatedLogistic Regression appeared to be an enticing classifier. If it proved to be accurate, we could leverage not just the prediction values, but also the associated probabilities (calculated from the log-odds ratios) of return. During our testing of the Logistic Regression classifier, we looked at various solvers and values of the inverse of regularization strength (C) to find the most fitting value.

After using our optimal values, we still only managed to achieve an accuracy score of 70.3%, with many of our misclassified dogs being the ones we want to avoid (False Negatives).

One other benefit to Logistic Regression worth mentioning is that it’s a very explainable model. That is, we can specifically call out the values for the coefficients that make up our final equation, like so:

Chart, histogram

Description automatically generated

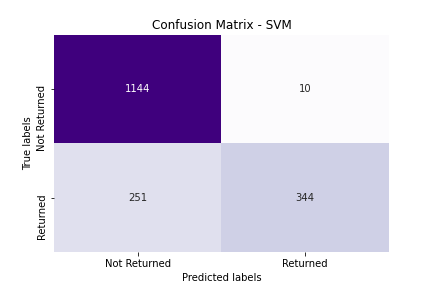
y = 2.0427 – 0.4804 \* num\_colors + 0.4013 \* contains\_black + 0.1397 \* weight\_issues + … + 0.0274 \* HW\_FIXED

where the coefficients/intercept above are rounded to the 4th decimal point and y is of the form

In a binary classification problem, we can simplify our equation by exponentiating both sides, giving us a better sense of the weights of our actual coefficients in calculating P(y = 1). Doing so, gives us the following top 10 coefficients:

### Linear SVM

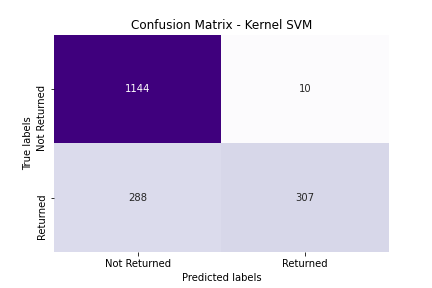
The team attempted to use a Support Vector Machine (SVM) classifier, but set its expectations low. SVM often works off a well-defined mapping space; however, we learned from our attempts at dimensionality reduction through PCA that the data does not lend itself well to such interpretations. This is again because most of the features in our dataset are binary/categorical.



Still, with proper scaling of the data, SVM can still work in theory. That is, it can still create linear vectors separating data points between 0 and 1. Thus, building a linear decision boundary would be possible, but not likely as meaningful as if our features were continuous variables. In practice, the accuracy of Linear SVM was ~85%. Linear SVM produced the following confusion matrix:

### Kernel SVM

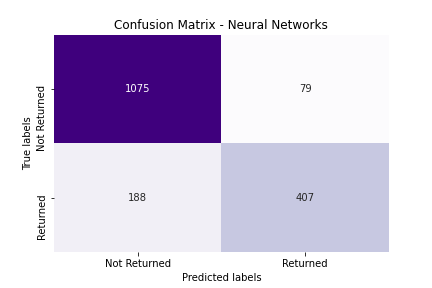
Kernel SVM provided the team a bit more flexibility in capturing the nuances of binary/categorical data than did Linear SVM. That is, because Kernel SVM allows us to use a kernel function to project our data into a higher dimensional space, it may be able to better capture the non-linear shape of our data.



With that, we used a radial basis function (RBF) kernel to achieve an accuracy of ~84% and the following confusion matrix:

With more time, it would be worthwhile to try to define our own kernel function that operates better in a feature space heavily defined by categorical variables. [This paper](https://upcommons.upc.edu/bitstream/handle/2099.1/17172/MarcoVillegas.pdf) by Marco Antonio Villegas Garcia lays out an interesting framework to build a kernel function of that sort.[[1]](#footnote-1)

### Neural Networks

The team ran a neural network using a Multi-layer Perceptron (MLP) classifier, incorporating two hidden layers – the first with 20 neurons and the second with 10 neurons. With this, we achieved a general accuracy of ~82%.

One thing to note is that, unlike other classifiers whose errors were mostly Type II, the Neural Network did a better job balancing Type I and Type II errors.

### Decision Tree

The team used a Decision Tree classifier, and achieved an accuracy of 84.0%. When taking a look at the first few layers of the decision tree, we found promising results. Variables that we would have expected to be key decision makers appear at the top. For example, *num\_behav\_issues*, which tracks the number of behavioral issues related to a given dog, is the first node. If there are 0 behavioral issues reported, we look to see if the dog has a warning attached to them that they are a bully (in the *BULLY\_WARNING* variable).

Diagram

Description automatically generated

Which variables ended up being the most important? **Not necessarily the variables at the top nodes**. Why is that? Well, feature importance in decision trees is based on an algorithm that also looks at the number of times a feature appears at a given node. With that, we get:

Chart, bar chart, histogram

Description automatically generated

Chart, treemap chart

Description automatically generated

This also lines up generally with what we expected. For example, dogs that have a large number of behavioral issues tend to get returned more frequently than dogs that do not. With these variables of interest, the Decision Tree classifier achieved an accuracy of 84.0% and the following confusion matrix:

### Random Forest

Our most successful classifier in terms of accuracy is the Random Forest, achieving an accuracy rate of 90.4%. As seen below, we tested a varying number of trees, ultimately finding that the optimal number of estimators is at 191. Across most values for the number of trees, Random Forest performed better, in terms of accuracy, than did the Decision Tree classifier.

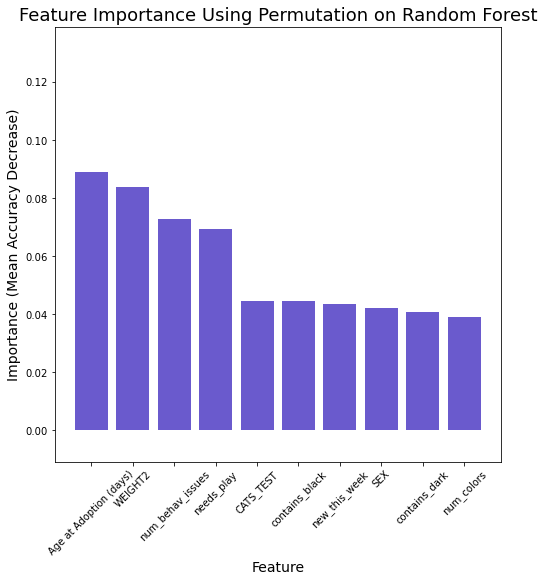
Chart, histogram

Description automatically generated

Chart, treemap chart

Description automatically generatedAfter identifying the optimal number of trees to be 191, we re-ran the Random Forest classifier to get the following confusion matrix:

This is our best result out of all the classifiers tested. When we take a look at the features that prove to be the most meaningful (using a permutation importance), we find promising results. That is, features which we would expect to be indicative of a return (a dog being too old, over/underweight, having many behavioral issues, etc.) are all reflected as the most important features.



### Chart, treemap chart Description automatically generatedAdaboost

The Adaboost classifier achieved a final accuracy of 89.5%. We tested various parameters, including the maximum number of estimators at which boosting is terminated and the learning rate, which shrinks the contribution of each successive classifier (since Adaboost is an ensemble of weak learners). We found that *n\_estimators = 500* and *learning\_rate = .1* performed best, yielding the following confusion matrix:

**Mapping the Decision Space**

In order to get a better picture of how some of the classifiers are splitting the data, we attempted to plot the first two principal components as separated by the classifiers below. As outlined in the dimensionality reduction section earlier on in the report, the first few principal components do not represent a large percent of the variance in the data, so these plots cannot fully represent how our classifiers are performing. We do see a trend of blue (or returns) being concentrated in the top right corner for these models, but it is not completely helpful in trying to show the classification of the dogs, as the data is much more reliant on multiple components/features, which is difficult to plot as a two-dimensional image.

The nature of this data is thus why the Neural Network, Decision Tree, Random Forest, and AdaBoost Models performed the best. Our data is difficult to separate solely by a boundary, so the classification methods of these models, which work by separating the data into smaller groups based on their features, suit the data better.

A picture containing text, tree, screenshot

Description automatically generated

## Conclusion

The models with the best performing accuracy are Random Forest and Adaboost; however, KNN has the highest recall and does the best job at minimizing the Type II Errors (prediction: Not Returned | actual: Returned) that we care about.

It’s important to note that we were able to achieve a high accuracy on the test set despite using KNN to impute missing values and ADASYN to resample the data, both of which add a degree of error to our final model.

## An Example

What does all this mean? Well, let’s use our best classifier, Random Forest, two predict whether the following two dogs will be returned:



* [Zach](https://www.petfinder.com/dog/zach-27904783/dc/washington/lucky-dog-animal-rescue-dc20/) (*ID #PICK-MD-14-0037*), who was adopted and subsequently returned
  + - * Gender: Male
      * Weight: 50lbs
      * Age (days): 1460
      * Breed: American Staffordshire Terrier Mix

A picture containing dog, floor, sitting, indoor

Description automatically generated

* [Cajun](https://toolkit.rescuegroups.org/javascript/v2.0/template1?animalID=8120056&key=Mqr6gy1W) (*ID #MTHY-MD-15-0081*), who was adopted and stayed adopted (thus, never being returned)
  + - * Gender: Male
      * Weight: 40lbs
      * Age (days): 730
      * Breed: Shepherd

If we run these two dogs through the Random Forest model, we find that Zach is predicted as being ‘returned’ and Cajun is predicted as being ‘not returned'. This aligns with the true results of the two dogs. Even so, it is instructive to see why this might be the case. Earlier we saw that the variable `BULLY\_SCREEN` and `BULLY\_WARNING` played a strong role in the classification models. Zach was, in fact, returned due to a ‘Facial Bite’. We can see this reflected in his behavioral notes (`num\_behav\_issues = 6`) and him being marked for a bully screen (`BULLY\_SCREEN = 1`). Cajun, on the other hand, had minimal behavioral issues reported and was not screened or warned as a bully. Thus, the model did a good job in correctly predicting the results of these two.

# Opportunities for Further Analysis

During the course of this project, the team, along with the *Program Manager for Volunteers and Data Integrity* at the nonprofit, discussed a variety of different analytical approaches. Some approaches we opted not to pursue in the interest of time; however, we would be remiss if we did not mention some of these opportunities for further analysis.

One of the most pertinent opportunities lies in the viewpoint of *why* a dog is returned. Our project mainly focused on attributes related to the dog; thus, making a core assumption that the reason why a dog is returned is *solely* attributable to the dog. However, attributes of the dog only make up half of the picture when an adoption (and subsequent return) takes place. The other half of the picture lies on the shoulders of the adopter: the individual/family adopting the dog.

The animal rescue tracks extensive details and features about the adopters (largely collected from a thorough 45 minute interview and accompanying questionnaire) to better understand the individuals adopting the dogs. As is sometimes the case, the reason a dog is returned may be because of the adopter: a lack of experience with adoptions, an inability to train a dog, an allergy that they did not know existed, etc. To complete a thorough analysis, we would try to **incorporate these features about the adopter to better make predictions**.

In terms of preparing our data, we likely could have employed **feature selection methods like LASSO regression** to determine which features are meaningful and which ones are redundant (i.e. highly correlated). The way the features were built leads us to believe that inclusion of some of the features increases how overfit the models are; removing some of them (like the medical issues or behavioral issues) would likely not seriously degrade the performance of the models used.

Additionally, the results of this project would be most beneficial to the animal rescue if there were a way to **act on the results of the model**. That is, if the model identifies a dog will be returned, can we alert the animal rescue so they can follow-up with the family and provide better resources to ensure the dog happily remains adopted? There are programmatic ways of doing so, but finding a method that can work in near-real-time (and, most importantly, before a dog is actually returned) would require a bit more software engineering and likely a bit of webscraping than we initially implemented for this project.

1. [An investigation into new kernels for categorical variables](https://upcommons.upc.edu/bitstream/handle/2099.1/17172/MarcoVillegas.pdf) by Marco Antonio Villegas Garcia, January 2013 [↑](#footnote-ref-1)