

Mushroom Edibility Classification Using Feature-Based Machine Learning Approach

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Summary

In this project, we developed and evaluated a machine learning model to classify mushroom edibility (i.e., whether they are edible or poisonous) based on features such as color, habitat, and structure. This is an important task as eating poisonous mushrooms can lead to severe health risks, while identifying toxic mushrooms through manual visual inspection can be challenging and time-consuming.

We built and fine-tuned a Support Vector Classifier (SVC), using both accuracy and F_β as performance metrics. The F_β score is a weighted harmonic mean of precision and recall. We calculated F_β with $\beta = 2$ to place greater emphasis on recall, as predicting a poisonous mushroom as edible (false negatives) could have severe consequences. Our final model achieved an overall accuracy of 0.996 and F_β score with $\beta = 2$ of 0.997 with 12134 correct predictions out of 12181 test observations. In terms of error, the model predicted 22 poisonous mushrooms as edible (false negative) and predicted 25 edible mushrooms as poisonous (false positive).

Even though the model shows promising performance, a limitation of this project is the lack of incorporation of biological domain knowledge about mushrooms into the feature engineering process, which could further reduce false negatives. This is an area that could be addressed in future work.

Introduction

Mushrooms are a widely consumed food source known for their rich nutritional content, including essential vitamins and minerals. However, not all mushrooms are safe for consumption, as many species are highly toxic. Eating poisonous mushrooms can lead to severe health consequences, including hospitalization and death, as highlighted in an incident report from Disease Control and (CDC) (2024).

Distinguishing between edible and poisonous mushrooms is particularly challenging, especially when dealing with large quantities. According to research by Occupational Safety and (NIOSH) (2019), in the commercial distribution of agricultural products, there is a risk of mixing edible and poisonous mushrooms. Traditional identification methods rely on human expertise, which can be time-consuming and inconsistent.

The primary goal of this project is to develop an accurate machine learning model that minimizes false negatives (i.e., misclassifying poisonous mushrooms as edible) while maintaining reasonable overall performance. To achieve this, our project applies machine learning techniques to classify mushroom edibility based on various features, such as color, habitat, and structure. The dataset used in this study contains detailed observations of mushrooms, categorized as either edible or poisonous Wagner and Hattab (2021). Our analysis applied three classification algorithms: Support Vector Classifier (SVC), K-Nearest Neighbors (KNN), and Logistic Regression. These models were chosen for their diverse approaches to classification and their ability to capture complex relationships between features.

Methods

Data

The dataset used in this project is the Secondary Mushroom Dataset Wagner and Hattab (2021). This dataset contains 61069 hypothetical mushrooms with caps based on 173 species (353 mushrooms per species). Each mushroom is identified as definitely edible, definitely poisonous, or of unknown edibility and not recommended (the latter class was combined with the poisonous class).

Analysis

The mushroom dataset is balanced with 55.22% of poisonous mushroom and 44.78% of edible mushroom. All variables were standardized and variables with more than 15% missing values are dropped, because imputing a variable that has a significant proportion of missing data might introduce too much noise or bias, making it unreliable. Data was splitted with 80% being partitioned into the training set and 20% being partitioned into the test set. Three classification models including Support Vector Classifier (SVC), K-Nearest Neighbors (KNN),

and Logistic Regression are used to predict whether a mushroom is edible or poisonous. The fine tuned Support Vector Classifier has the best overall performance. The hyperparameter was chosen using 5-fold cross validation with F_β score as the classification metric. β was chosen to be set to 2 for the F_β score to increase the weight on recall during fitting because predicting a mushroom to be edible when it is in fact poisonous could have severe health consequences. Therefore the goal is to prioritize the minimization of false negatives. The Python programming language Van Rossum and Drake (2009) and the following Python packages were used to perform the analysis: Matplotlib Hunter (2007)), Pandas: McKinney (2010), Scikit-learn: Pedregosa et al. (2011), NumPy: Harris et al. (2020), SciPy: Virtanen et al. (2020), UCIML-Repo: Wagner and Hattab (2021)., Pandera: Bantilan (2020), Pytest: Krekel et al. (2004), and Deepchecks: Chorev et al. (2022).

Exploratory data analysis

Part 1: Numeric Features

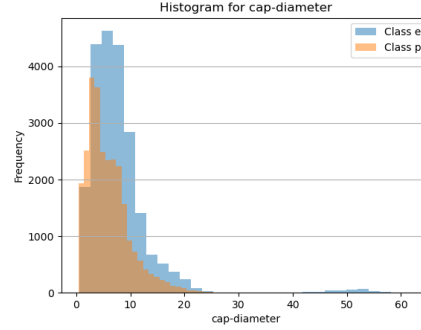


Figure 1: The Distribution of Feature Cap Diameter

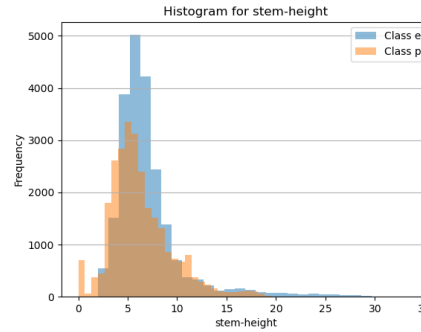


Figure 2: The Distribution of Feature Stem Height

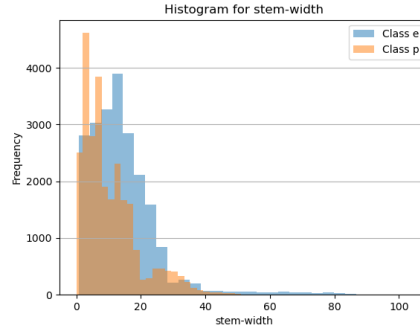


Figure 3: The Distribution of Feature Stem Width

The EDA shows that all numeric columns in the mushroom dataset are nearly normal with some skewness. A robust preprocessing scheme **QuantileTransformer** is used because it can transform skewed data or heavy-tailed distributions into a more Gaussian-like shape and reduce the impact of outliers. **OneHotEncoder** is applied for categorical features in the mushroom dataset, because each feature does not contains much categories and they are not ordered. It is critical to keep all important information in the features. Since ring type feature has many missing values, it was filled in with a “Missing” class. Treating missing values as a distinct category provides a way to model the absence of data directly. This can be valuable because missingness itself might carry information; for example, some mushrooms may not have particularly unique ring types that cannot be classified into the other groups, or simply may not have rings at all.

Part 2: Categorical Features

Table 1: The distribution of cap shape.

| cap-shape | Count | Proportion |
|-----------|-------|------------|
| x | 21510 | 0.441484 |
| f | 10698 | 0.219572 |
| s | 5717 | 0.117339 |
| b | 4615 | 0.0947211 |
| o | 2634 | 0.0540618 |
| p | 2098 | 0.0430606 |
| c | 1450 | 0.0297607 |

Table 2: The distribution of mushroom cap colors.

| cap-color | Count | Proportion |
|-----------|-------|------------|
| n | 19407 | 0.398321 |
| y | 6876 | 0.141127 |
| w | 6175 | 0.126739 |
| g | 3410 | 0.0699889 |
| e | 3205 | 0.0657814 |
| o | 2905 | 0.059624 |
| r | 1399 | 0.0287139 |
| u | 1355 | 0.0278108 |
| p | 1332 | 0.0273388 |
| k | 1016 | 0.020853 |
| b | 964 | 0.0197857 |
| l | 678 | 0.0139157 |

Table 3: The distribution of mushrooms that bruise or bleed.

| does-bruise-or-bleed | Count | Proportion |
|----------------------|-------|------------|
| f | 40333 | 0.827819 |
| t | 8389 | 0.172181 |

Table 4: The distribution of mushroom gill colors.

| gill-color | Count | Proportion |
|------------|-------|------------|
| w | 14836 | 0.304503 |
| n | 7742 | 0.158902 |
| y | 7595 | 0.155884 |
| p | 4769 | 0.0978819 |
| g | 3295 | 0.0676286 |
| f | 2734 | 0.0561143 |
| o | 2312 | 0.0474529 |
| k | 1908 | 0.039161 |
| r | 1131 | 0.0232133 |
| e | 842 | 0.0172817 |
| u | 827 | 0.0169739 |
| b | 731 | 0.0150035 |

Table 5: The distribution of mushroom stem colors.

| stem-color | Count | Proportion |
|------------|-------|------------|
| w | 18377 | 0.377181 |
| n | 14478 | 0.297155 |
| y | 6291 | 0.12912 |
| g | 2090 | 0.0428964 |
| o | 1733 | 0.0355691 |
| e | 1628 | 0.0334141 |
| u | 1189 | 0.0244038 |
| p | 814 | 0.016707 |
| f | 705 | 0.0144698 |
| k | 676 | 0.0138746 |
| r | 420 | 0.00862034 |
| l | 181 | 0.00371495 |
| b | 140 | 0.00287345 |

Table 6: The distribution of samples that have and do not have rings.

| has-ring | Count | Proportion |
|----------|-------|------------|
| f | 36495 | 0.749046 |
| t | 12227 | 0.250954 |

Table 7: The distribution of mushroom ring types.

| ring-type | Count | Proportion |
|-----------|-------|------------|
| f | 38440 | 0.822827 |
| e | 1964 | 0.0420404 |
| z | 1713 | 0.0366676 |
| l | 1151 | 0.0246377 |
| r | 1129 | 0.0241668 |
| p | 1028 | 0.0220048 |
| g | 1005 | 0.0215125 |
| m | 287 | 0.00614337 |

Table 8: The distribution of mushroom habitats.

| habitat | Count | Proportion |
|---------|-------|------------|
| d | 35162 | 0.721686 |
| g | 6403 | 0.131419 |
| l | 2539 | 0.052112 |
| m | 2344 | 0.0481097 |
| h | 1598 | 0.0327983 |
| p | 298 | 0.00611633 |
| w | 288 | 0.00591109 |
| u | 90 | 0.00184721 |

Table 9: The distribution of the seasons of which mushrooms are present.

| season | Count | Proportion |
|--------|-------|------------|
| a | 24079 | 0.494212 |
| u | 18300 | 0.3756 |
| w | 4149 | 0.0851566 |
| s | 2194 | 0.045031 |

Table 10: Features dropped from the original dataset prior to processing.

| columns_to_drop |
|-------------------|
| cap-surface |
| gill-attachment |
| gill-spacing |
| stem-root |
| stem-surface |
| veil-type |
| veil-color |
| spore-print-color |

Based on the Frequency and Percentage distributions, here are our findings:

1. Table 1: The most common cap shape is **x** (convex), comprising 44.15% of the data. Other shapes like **f** (flat) and **s** (sunken) are also prevalent, while **c** (conical) is the least common with 2.98% appearance.
2. Table 2: The most frequently appeared color is **n** (brown), with 39.83% of the data. Other colors like **y** (yellow), **w** (white), and **g** (gray) are also well-represented, while rare colors like **b** (buff) and **l** (blue) appear in less than 2% of the data.
3. Table 3: The majority of the mushrooms are **f** (do not bruise or bleed), while their counterpart makes up 17.22% of the data.
4. Table 4: The most common gill color is **w** (white), with 30.45% of the data. Other colors such as **n** (brown) and **y** (yellow) are also frequent, while rare gill colors like **e** (red), **b** (buff), and **u** (purple) appear in less than 2% of the data.
5. Table 5: **w** (white) and **n** (brown) are the dominating stem colors, accounting for 37.72% and 29.72% of the data, respectively. Other colors like **r** (green), **l** (blue), and **b** (buff) are less frequent, appearing in less than 1% of the observations.
6. Table 6: Most mushrooms are **f** (do not have a ring), with 74.90% observations. The remaining 25.10% mushrooms are **t** (have a ring).
7. Table 7: **f** (none) is the most common ring type, accounting for 82.28% of the data. Other types like **e** (evanescent) and **z** (zone) are less frequent, while rare types like **m** (movable) occur in less than 1% of the data.
8. Table 8: The predominant habitat is **d** (woods), with 72.17% appearance. Other habitats such as **g** (grasses) and **l** (leaves) are less common, while **w** (waste), **p** (paths), and **u** (urban) only make up less than 1% of the data individually.
9. Table 9: Most mushrooms grow in **a** (autumn), comprising 49.42% of the data, followed by **u** (summer) at 37.56%. The other two seasons **w** (winter) and **s** (spring) are less frequent.

Categorical features will be encoded into binary format in the following preprocessing phase with `OneHotEncoder`. Since we are dealing with a mix of binary and non-binary categorical features, for features like `does-bruise-or-bleed` and `has-ring` that have two unique values, they will be handled with `drop='if_binary'` argument to reduce redundancy while still capturing the information.

It should be noted that many categorical features from the original dataset were dropped: See Table 10 for a full list. These features were found to have a substantial, and in some cases majority of entries missing. In this case, it appeared unreasonable to make assumptions about how to fill such entries without stronger domain-specific knowledge, so these features were dropped.

Part 4: The distribution of the target

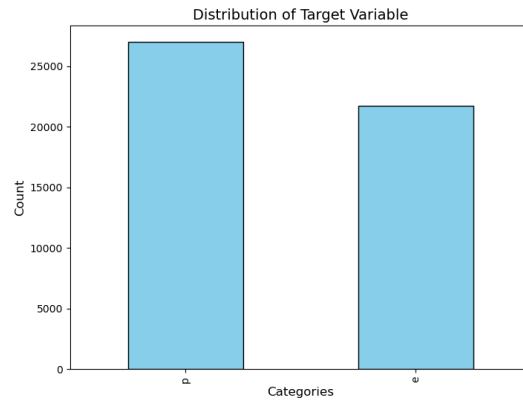


Figure 4: The Distribution of Feature Stem Color

The target variable `class` represents whether a mushroom is `p` (poisonous) or `e` (edible). Understanding the distribution of the target helps assessing class balance, which might have impact on models' performance.

Based on the Frequency and Percentage distribution Figure 4, here are our findings:

1. `p` (Poisonous): There are 26,996 instances of poisonous mushrooms, accounting for 55.41% of the data.
2. `e` (Edible): There are 21,726 instances of edible mushrooms, constituting 44.59% of the data.

Using F_β , precision, recall, or confusion matrix to evaluate the model's performance is advisable in the following procedure.

Result & Discussion

Preprocessing and Model Building

Three classification models including Support Vector Classifier (SVC), K-Nearest Neighbors (KNN), and Logistic Regression are used to predict whether a mushroom is edible or poisonous. Predicting a mushroom to be edible when it is in fact poisonous could have severe health consequences. Therefore the best model should prioritize the minimization of this error. To do this, we can evaluate models on an F_β score with $\beta = 2$.

Table 11: Cross-Validation Results by Model

| Model | mean_test_accuracy | mean_test_f2_score |
|---------------------|--------------------|--------------------|
| KNN | 0.930791 | 0.935691 |
| Logistic Regression | 0.745495 | 0.77728 |
| SVC | 0.996613 | 0.997111 |

In Table 11, we can see that after tuning the hyperparameter, the Logistic Regression model has the mean accuracy of 0.745 and mean F_β score of 0.777 on the validation set. The KNN model has the mean accuracy of 0.931 and mean F_β score of 0.936. The SVC outperforms both Logistic Regression and KNN significantly in both accuracy of 0.997 and F_β score of 0.997. Thus, SVC is the ideal choice to identify edible or poisonous mushroom (recall is the highest priority), however it should be noted that this model takes extensive time to train. If faster training is preferred, the Logistic Regression model may be chosen as a suitable alternative due to comparable performance and a much faster fitting time.

Model Evaluation

Table 12: Confusion matrix for the SVM model on test data.

| Actual | e | p |
|--------|------|------|
| e | 5430 | 25 |
| p | 22 | 6704 |

The prediction model performed quite well on test data, with a final overall accuracy of 0.996 and F_β score of 0.997 Table 12. The model only makes 47 mistakes out of 12181 test samples. 22 mistakes were predicting a poisonous mushroom as edible (false negative), while 25 mistakes were predicting a edible mushroom as poisonous (false positive). The model’s performance is promising for implementation, as false negatives represent potential safety risks and these errors could lead to consuming poisonous mushrooms, it is minimized to protect users. On the other hand, false positives are less harmful, they may lead to discarding safe mushrooms unnecessarily but do not endanger safety.

While the overall performance of the SVC model are impressive, efforts could focus on further reducing false negatives to enhance the safety of predictions. It might be important to take a closer look at the 47 misclassified observations to identify specific features contributing to these misclassifications. Implementing feature engineering on those features such as encoding rare categories differently can enhance the model’s power and reduce the misclassification cases. Additionally, trying other classifiers like Decision Tree and Random Forest which are less sensitive to scaling or irrelevant features might improve the prediction.

Limitation and Future Work

While the model yield promising performance, a key limitation is the lack of feature engineering based on domain-specific biological knowledge. There may be interactions between features or specific biological metrics with strong predictive power that were not considered. In future work, integrating such domain knowledge could enhance model performance and further reduce false negatives.

Additionally, the model still makes mistakes, including false positives and false negatives. Further investigation into the misclassified cases could help us identify patterns and feature interactions that the model failed to capture. These insights could make improvements in both feature engineering and model architecture.

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