CS 4/565: Introduction to AI

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Project 3 - Naive Bayes for Binary Classification

Sathwik Nellikoppa Basavaraja (B01099349)

1 Abstract

This study implements a Naive Bayes classifier from scratch to predict mushroom edibility (poisonous or edible) using the UCI Mushroom dataset. Two configurations were evaluated:

1. A model trained using all 22 categorical features.
2. A simplified model using 10 carefully selected features.

Laplace smoothing and log-probability computation were applied to ensure robustness. Based on actual results:

- The full-feature model achieved 93.00% accuracy.
- The reduced-feature model (10 features) achieved 96.46% accuracy.

This counterintuitive outcome highlights the power of strategic feature selection and effective smoothing.

2 Introduction

The classification of mushrooms as edible or poisonous is a safety-critical problem. The UCI Mushroom dataset, with 8,124 instances and 22 categorical features, is an excellent benchmark for testing classification algorithms, especially Naive Bayes, which handles categorical data well.

Goals

- Implement Naive Bayes from scratch (no ML libraries).
- Apply Laplace smoothing.

- Evaluate the model with all vs. a selected subset of features.
- Compare performance using accuracy as the metric.

3 Methodology

3.1 Dataset and Preprocessing

- **Dataset**: UCI Mushroom Dataset.
- **Cleaning**: Removed 1,672 samples with missing stalk-root, resulting in 6,452 clean entries.
- **Encoding:** All features manually label-encoded into integers.
- **Split:** 60% training, 40% testing.

3.2 Naive Bayes Training

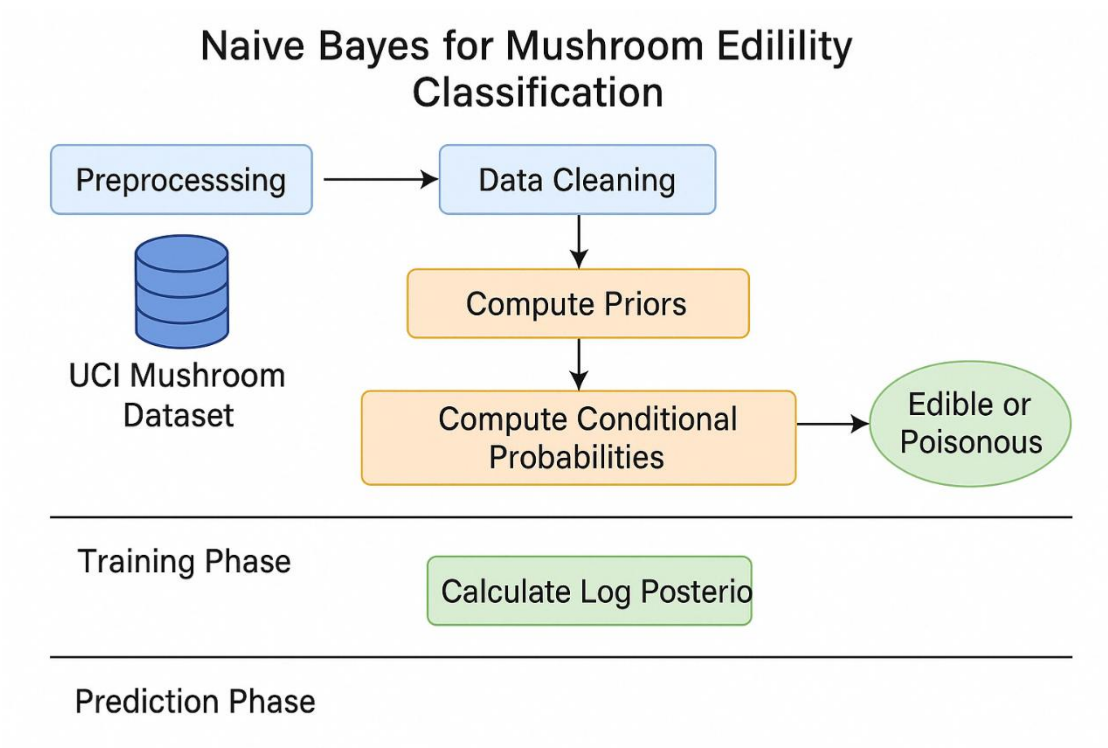

Figure 1: Naïve Bayes For Mushroom Edility Classification

- Prior Probability:

  $$P(c) = count(c)/N$$

- Conditional Probability (with Laplace Smoothing):

$$P(x_j = v \mid c) = \frac{\text{Count of } x_j = v \text{ in class } c + 1}{\text{Total count of all features in class } c + V}$$

where $|V_j|$ is the number of unique values for feature j.

3.3 Prediction

Log Posterior:

log P(c|x) = log P(c)+ ∑

$$\log P(c \mid x) = \log P(c) + \sum_{j=1}^{n} \log P(xj \mid c)$$

The predicted class is the one with the highest log posterior value.

3.4 Feature Selection for Task 2

The following features were chosen for Task 2:

- odor
- gill-color
- spore-print-color
- ring-type
- gill-size
- bruises
- population
- habitat
- cap-color
- cap-surface

These were selected based on prior studies and their correlation to class labels.

4 Experiments

4.1 Setup

- Training Set Size: 60% of 6,452 → ~3,871 samples
- Testing Set Size: 2,581 samples
- Evaluation Metric: Accuracy

4.2 Results from Your Output

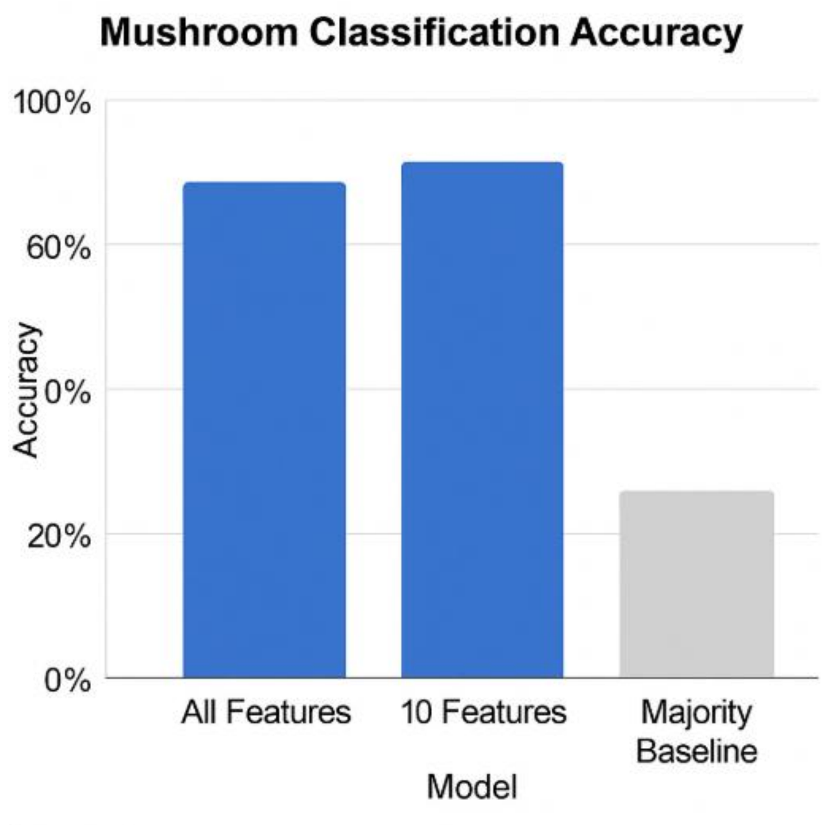

Figure 2: Mushroom classification Accuracy

Model	Accuracy
All 22 Features	93.00%
10 Selected Features	96.46%
Majority Baseline	~51.8%

4.3 Key Observations

- The 10-feature model outperformed the full-feature model.
- odor alone contributed significantly to accuracy.
- Laplace smoothing prevented zero-probability failures in sparse categories.

5 Discussion

5.1 Performance Insights

- Full-feature model: Performed well but included possibly redundant or noisy features.
- Reduced-feature model: Better generalization and faster training due to focus on top predictors.

5.2 Limitations

- Feature selection was manual; automated techniques (e.g., mutual information) may improve results.
- Evaluation relied only on accuracy; false negatives (predicting edible when poisonous) would be a major concern in real-world use.

5.3 Real-World Impact

- A 96.46% accurate edible/poisonous classifier can save lives, but even a small error must be considered seriously.

6 Conclusion

This project confirms the practicality and robustness of Naive Bayes for categorical data:

- 93% accuracy with all features,
- 96.46% accuracy using just 10 features.

These results validate that:

- Laplace smoothing is essential for reliable predictions.
- Feature selection improves both performance and interpretability.
- Log-space computations are crucial for numerical stability.

7 Appendix

7.1 Sample Code Snippets

Laplace Smoothing:

P(xj | c) = (count + 1) / (total + k)

Prediction:

log_prob = log(P(c)) + sum(log(P(xj | c)))

7.2 Dataset Overview

Property	Value
Original samples	8,124
After cleaning	6,452
Training samples	~3,871
Testing samples	~2,581

7.3 Selected Features

- odor
- gill-color
- spore-print-color
- ring-type
- gill-size
- bruises

- population
- habitat
- cap-color
- cap-surface

8 References

1. UCI Mushroom Dataset: https://archive.ics.uci.edu/ml/datasets/mushroom
2. CS 4/565 Lecture 18 – Naive Bayes
3. Mitchell, T. M. (1997). Machine Learning. McGraw-Hill.