

Math Properties

$$\log_a b = \frac{\log_c b}{\log_c a} = \frac{1}{\log_b a}$$

$$P(A|B) = \frac{P(A \cap B)}{P(B)} = \frac{P(B|A)P(A)}{P(B)}$$

Pre-Processing

Data Cleaning

Deletion: Remove missing values, remove duplicates

Imputation: Fill in missing values, mean/median/mode, similar case, forward fill, interpolation, default values

Outliers: Legitimate unusual values with respect to rest of data

Noise: Random errors and variations

Feature Engineering

Feature Transformation: Transform features to make them more useful

Feature Creation: Create new features from existing features

Normalization: Scale features to be between 0 and 1;

$$\frac{x_i - x_{\min}}{x_{\max} - x_{\min}}$$

Standardization: Scale features to $\mu = 0$ and $\sigma = 1$;

$$\frac{x_i - \mu}{\sigma}$$

Binning: Continuous \rightarrow Categorical

Encoding: Categorical \rightarrow Numerical

Sampling: Reduce dataset size

Aggregation: $(x_i, y_i, z_i) \rightarrow w_i$

Dimensionality: Attributes/columns in single case

Curse of Dimensionality: More dimensions \rightarrow More sparse

Dimensionality Reduction:

Feature Selection: Subset of attributes, Filter, Embedded

Feature Extraction: Decrease dimensions while keeping max variance, PCA, SVD, LDA

Decision Trees

Grown recursively by partitioning data into subsets based on attribute values

Forms axis-parallel hyperplanes

c = number of classes, p = probability/fraction of class

$$\text{Entropy: } \sum_{i=1}^c -p_i \log_2 p_i$$

$$\text{Gini: } 1 - \sum_{i=1}^c p_i^2$$

r = parent, k = number of partitions, n_i = number of records in partition i , Impurity = (Entropy, Gini)

Entropy \rightarrow Information Gain, Gini \rightarrow Gini Gain

$$\text{Gain: } \text{Impurity}(r) - \left(\sum_{i=1}^k \frac{n_i}{n} \text{Impurity}(i) \right)$$

$$\text{Split Info: } - \sum_{i=1}^k \frac{n_i}{n} \log_2 \frac{n_i}{n}$$

$$\text{Gain Ratio: } \frac{\text{InfoGain}}{\text{SplitInfo}}$$

Classification: Assign labels to objects

Descriptive Modeling: Explain, describe, summarize

Predictive Modeling: Predict label of unknown record

Split Conditions:

Continuous: Threshold value, binning

Nominal & Ordinal: Multiway, binary w/ grouping

Characteristics: Inexpensive to construct, fast to test, easy to interpret, robust to outliers (especially when pruned), redundant/irrelevant attributes don't affect tree structure, eager learner

Pre-Pruning: Stop growing tree before it's fully grown

Linear Regression

Finds best fit line through data

Use one-hot encoding/dummy encoding for categorical data

There's also polynomial and non-linear regression

Least Squares: Minimize SSE

$$\beta_0 = \bar{Y} - \beta_1 \bar{X}$$

$$\beta_1 = \frac{\sum (X_i - \bar{X})(Y_i - \bar{Y})}{\sum (X_i - \bar{X})^2}$$

$$\text{SSE: } \sum_{i=1}^n (y_i - \hat{y}_i)^2$$

$$\text{MSE: } \frac{\text{SSE}}{n}$$

$$\text{RMSE: } \sqrt{\text{MSE}}$$

$$\text{MAE: } \frac{\sum_{i=1}^n |y_i - \hat{y}_i|}{n}$$

$$\text{var(mean): } \frac{\sum_{i=1}^n (y_i - \bar{y})^2}{n}$$

$$\text{var(fit): } \frac{\sum_{i=1}^n (y_i - \hat{y}_i)^2}{n}$$

$$R^2: \frac{\text{var(mean)} - \text{var(fit)}}{\text{var(mean)}}$$

Multiple Linear Regression: $y = \beta_0 + \beta_1 x_1 + \beta_2 x_2 + \dots + \beta_d x_d$

Characteristics: Non-decreasing (More features never make R^2 worse), More features \neq better model, but can be better SSE)

n = number of samples, p = number of features

$$\text{Adjusted } R^2: 1 - \frac{(1 - R^2)(n-1)}{n-p-1}$$

Cross Validation

Training Error: Percentage misclassified (ex. SSE, R^2) on training set

Test/Generalization Error: Percentage misclassified on test/unseen set

Holdout Method: Split data into training and test sets; Issues- Less training data, overrepresentation/underrepresentation, varying performance

K-Fold Cross Validation

Split data into k folds, build model on k-1 folds, test on 1 fold, repeat k times, used **ONLY** to evaluate process

$$\text{Error} = \frac{1}{k} \sum_{i=1}^k \text{Error}_i$$

Build final model using **ALL** data

Cross Validation: Preprocess training set and apply exact same preprocessing to test set

Overfitting: Low training error but high test error, bad generalizations

Hyperparameter Tuning: Use validation set by partitioning training set

Nested Cross Validation: Use cross validation to tune hyperparameters, pick lowest error then test using entire training set

Get best hyperparameter using hyperparameter tuning on entire dataset, then build final model using the chosen hyperparameter and entire dataset

Nearest Neighbor

Usually Euclidean distance, can use weight factor = $\frac{1}{d^2}$

KNN: Find k nearest neighbors, assign majority class
k too small \rightarrow overfit, k too large \rightarrow underfit

Find best k using cross validation

Characteristics: Instance-based learning, lazy learner, no training (just retune k), slow testing, curse of dimensionality, feature selection critical

Naive Bayes

X = test record (x_1, x_2, \dots, x_d), C = class

$$P(C|X) \propto P(x_1|C) \cdot P(x_2|C) \cdot \dots \cdot P(x_d|C) \cdot P(C)$$

Requirements: Naïve \rightarrow Independence, Binning

Laplace Smoothing: $\frac{x_i + \alpha}{C + \alpha v}$ for multinomial / categorical data, add $\alpha = 1$ to numerator and v (options for the feature) to the denominator, α = smoothing factor

Characteristics: Fast, simple, scales with higher dimensions, independence assumption not always true

Evaluating Classifiers

Error Rate: Fraction of incorrect predictions on testing set; $\frac{FP+FN}{n}$

Accuracy: Fraction of correct predictions on test set; $\frac{TP+TN}{n}$

Confusion Matrix: P = predicted, A = actual

For cross validation, sum all confusion matrices

	+P	-P
+A	TP	FN
-A	FP	TN

TPR/Sensitivity/Recall/Coverage: $\frac{TP}{TP+FN}$, higher better

TNR/Specificity: $\frac{TN}{FP+TN}$, higher better

FPR: $\frac{FP}{FP+TN}$, lower better

FNR: $\frac{FN}{TP+FN}$, lower better

Precision: $\frac{TP}{TP+FP}$, higher better

F-Measure: $\frac{2 \times \text{precision} \times \text{recall}}{\text{precision} + \text{recall}}$, higher better

Fixing Class Imbalance:

Undersampling: Remove some majority class samples

Oversampling: Duplicate some minority class samples

Support Vector Machines

Hyperplane that maximizes margin between classes

Binary classifier, can be extended to multi-class

One-hot encoding for categorical data

Support Vectors: Changes hyperplane if moved, points on margin boundary or on the wrong side for its class

Goal: Minimize $\frac{\|w\|}{2}$ subject to $y_i(w \cdot x_i + b) \geq 1$

Soft Margin SVM: Minimize $\frac{\|w\|}{2} + C(\sum_{i=1}^N \xi_i)$ subject to $y_i(w \cdot x_i + b) \geq 1 - \xi_i$

$C \rightarrow \infty$ = Hard Margin SVM

Too little slack \rightarrow overfit, too much slack \rightarrow underfit

Trade-off between margin width and incorrect classification

Kernel Methods: Transform data into higher dimensions for linear separability

Characteristics: Global optimization, requires feature scaling, extendable to multi-class, no curse of dimensionality, needs cross validation (hyperparameters, kernel function, cost)

Non-Linear Regression

Regression Tree: Decision tree with continuous output rather than categorical, recursive partitioning, axis-parallel

KNN Regression: Continuous KNN with neighbors means as output

Support Vector Regression: Fit hyperplane to minimize error, aka. points outside tube

Ensembles: Bagging/Boosting, average of the base classifiers