GENERAL

# automatic music genre classification using ensemble of

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## Automatic Music Genre Classification Using Ensemble of Models: A Comprehensive Guide

In an era where streaming platforms deliver millions of tracks daily, the ability to automatically categorize music into genres has become indispensable. Whether it's for personalized recommendations, playlist generation, or music discovery, automatic music genre classification powers the algorithms that keep listeners engaged. This article dives deep into the world of **automatic music genre classification using ensemble of**machine learning models, exploring the science behind audio feature extraction, the strengths of individual classifiers, and the synergistic power of ensemble learning. By the end, you'll have a clear roadmap for building robust, high accuracy genre classifiers that can scale across diverse musical datasets.

## Understanding Music Genre Classification

### What Is Music Genre Classification?

Music genre classification refers to the process of assigning a musical piece to one or more predefined categories—such as Rock, Jazz, Classical, Hip Hop, or Electronic—based solely on its audio characteristics. Unlike human listeners, who rely on cultural context and personal experience, automated systems depend on objective, quantitative representations of sound.

### Why It Matters

- Personalized Recommendations: Streaming services use genre labels to recommend tracks that match a listener's taste.
- Content Organization: Digital libraries and radio stations rely on accurate genre tags for cataloging.
- Musicological Research: Scholars analyze genre trends and evolution over time.
- Business Intelligence: Record labels monitor genre popularity for marketing strategies.

## Why Ensemble Methods Matter

Individual machine learning models can excel at specific aspects of the classification task, but each comes with inherent limitations. Ensemble methods combine multiple base learners to mitigate weaknesses, reduce variance, and improve generalization. The phrase **automatic music genre classification using ensemble of**captures this strategy: leveraging diverse algorithms—such as Support Vector Machines (SVM), Random Forests, Gradient Boosting Machines, and Deep Neural Networks—to create a unified, more accurate system.

### Key Advantages of Ensembles

1. Increased Accuracy: Aggregating predictions often yields a higher F1 score than any single model.
2. Robustness: Ensembles are less sensitive to noise and outliers.
3. Model Diversity: Different algorithms capture varied patterns in audio data.
4. Scalability: Ensemble frameworks can be parallelized across multiple GPUs or CPUs.

## Key Audio Features for Genre Classification

Before feeding data into classifiers, the raw audio waveform must be transformed into a feature space that captures

perceptually relevant information. The most effective feature sets combine spectral, temporal, and high level descriptors.

### Spectral Features

- Mel Frequency Cepstral Coefficients (MFCCs): Capture timbral texture; widely used in speech and music.
- Spectral Centroid & Roll Off: Indicate brightness and spectral spread.
- Spectral Flux: Measures how rapidly the spectrum changes, useful for percussive detection.
- Chroma Features: Represent pitch class profiles, effective for harmonic analysis.

### Temporal Features

- Zero Crossing Rate (ZCR): Reflects noisiness; higher in percussive or high frequency content.
- Beat Tracking & Tempo: Capture rhythmic structure, essential for genres like EDM or Hip Hop.
- Rhythm Histograms: Summarize beat strengths across time.

### High Level Descriptors

- Key Estimation: Provides harmonic context.
- Mode & Scale Detection: Distinguish between major/minor tonalities.
- Instrumental Fingerprints: Derived from spectral templates.

### Feature Extraction Workflow

1. Pre Processing: Normalization, noise reduction, and trimming silence.
2. Segmentation: Divide audio into overlapping windows (e.g., 3 second frames).
3. Feature Computation: Use libraries such as LibROSA, Essentia, or MIRToolbox.
4. Statistical Aggregation: Compute mean, variance, skewness, and kurtosis across frames.
5. Dimensionality Reduction: Apply PCA or t SNE if necessary to mitigate the curse of dimensionality.

## Popular Machine Learning Models for Genre Classification

### Support Vector Machines (SVM)

SVMs are effective for high dimensional feature spaces, especially when using radial basis function (RBF) kernels. They excel at separating classes with clear margins but can struggle with large datasets due to quadratic time complexity.

### Random Forests

Random Forests build an ensemble of decision trees, each trained on a bootstrapped subset of data. They handle non linear relationships well and are robust to overfitting, making them a staple in many music genre classification pipelines.

### Gradient Boosting Machines (GBM)

Algorithms like XGBoost or LightGBM iteratively add weak learners to correct the errors of previous models. GBM often achieves state of the art accuracy on tabular audio features but requires careful hyper parameter tuning.

### Deep Neural Networks (DNN)

- Convolutional Neural Networks (CNN): Operate directly on spectrogram images, learning hierarchical feature representations.
- Recurrent Neural Networks (RNN) & Long Short Term Memory (LSTM): Capture temporal dependencies in sequences of audio frames.
- Transformer Based Models: Emerging architectures that model long range dependencies without recurrence.

### Transfer Learning

Pre trained models such as VGGish or OpenL3, trained on large audio corpora, can be fine tuned on genre classification tasks, reducing the need for extensive labeled data.

## Ensemble of Models: Combining Strengths

### Bagging (Bootstrap Aggregating)

Bagging trains multiple instances of the same base learner on different bootstrap samples and aggregates predictions via majority voting or averaging. Random Forests are essentially bagged decision trees.

### Boosting

Boosting methods like AdaBoost, Gradient Boosting, or XGBoost sequentially train models, each focusing on the misclassified examples of its predecessor. Boosting can achieve high precision but may overfit if not regularized.

### Stacking (Stacked Generalization)

Stacking trains several heterogeneous base learners and a meta learner that learns how to best combine their outputs. For music genre classification, one might stack an SVM, a Random Forest, and a CNN, using a logistic regression or shallow neural network as the meta learner.

### Voting Strategies

- Hard Voting: The class with the majority of votes wins.
- Soft Voting: Class probabilities are averaged, and the highest probability class is selected.

### Hybrid Ensembles

Combining traditional machine learning models with deep learning architectures yields hybrid ensembles that leverage both handcrafted features and learned representations. For instance, an ensemble might merge a Random Forest trained on MFCC statistics with a CNN that processes raw spectrograms.

## Case Studies and Results

Several research projects demonstrate the effectiveness of ensemble approaches for genre classification.

### Example 1: Combining SVM and CNN on GTZAN

In a study on the GTZAN dataset, researchers extracted MFCCs and trained an SVM, while simultaneously training a 2 D CNN on log mel spectrograms. They then used hard voting to merge predictions, achieving an overall accuracy of 92.5%, surpassing the best single model performance of 88.7%.

### Example 2: Stacked Ensemble on Million Song Dataset

Using the Million Song Dataset, a team trained five base models: Random Forest, Gradient Boosting, XGBoost, a CNN, and a bidirectional LSTM. A logistic regression meta learner combined their outputs, yielding a weighted F1 score of 0.84, a notable improvement over individual models.

### Example 3: Transfer Learning Ensemble on Spotify Dataset

A hybrid ensemble combined VGGish based embeddings with handcrafted features, feeding both into a LightGBM classifier. The ensemble achieved 91% accuracy on a curated Spotify dataset, outperforming both the VGGish only and handcrafted only baselines.

## Implementing Automatic Music Genre Classification Using Ensemble of

## Models

Below is a practical outline for building an end to end ensemble system. The example assumes a Python environment with libraries such as LibROSA, scikit  learn, TensorFlow/Keras, and XGBoost.

### Step 1: Data Collection & Labeling

- Gather audio files from public datasets (GTZAN, Million Song, Free Music Archive).
- Ensure balanced representation across genres.
- Store metadata (genre label, artist, track length) in a CSV or database.

### Step 2: Feature Extraction

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