AUTOMATIC AUDIO TAG CLASSIFICATION VIA SEMI-SUPERVISED CANONICAL DENSITY ESTIMATION

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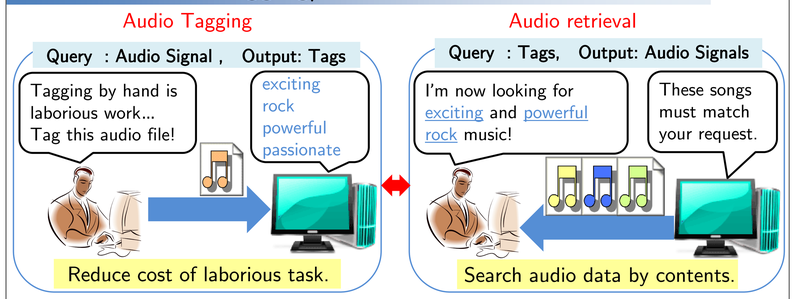
Overview

Apply semi-supervised method to audio tagging/retrieval.

Utilize untagged samples and reduce the needed number of expensive tagged samples.

What is Audio Tagging/Retrieval?



SSCDE can cope with both tasks in the same framework!

Technical Challenges : Use Inexpensive Untagged Audios

Audio samples having high-quality tags are very expensive!

Semi-supervised method utilizes inexpensive untagged audio samples!

Easy to collect at low cost!

Technical Challenges : Use Tag Co-occurrence Information

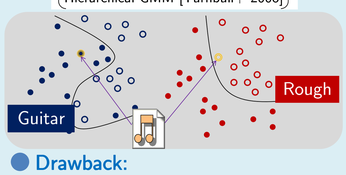
Tag co-occurrence information seems to be useful for tagging/retrieval task.

But almost all of existing method cannot utilize this information.

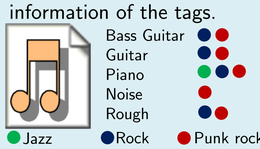
Typical approach

- Train a dedicated classifier for each tag separately.

Linear regression [Whiteman+ 2004]
Hierarchical GMM [Turnbull+ 2008]



- Drawback: Difficult to use co-occurrence information of the tags.



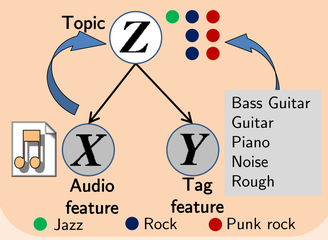
→ How to incorporate the co-occurrence information into the classifier?

Topic model based approach

- Design probabilistic generative model for audio signals and tags.

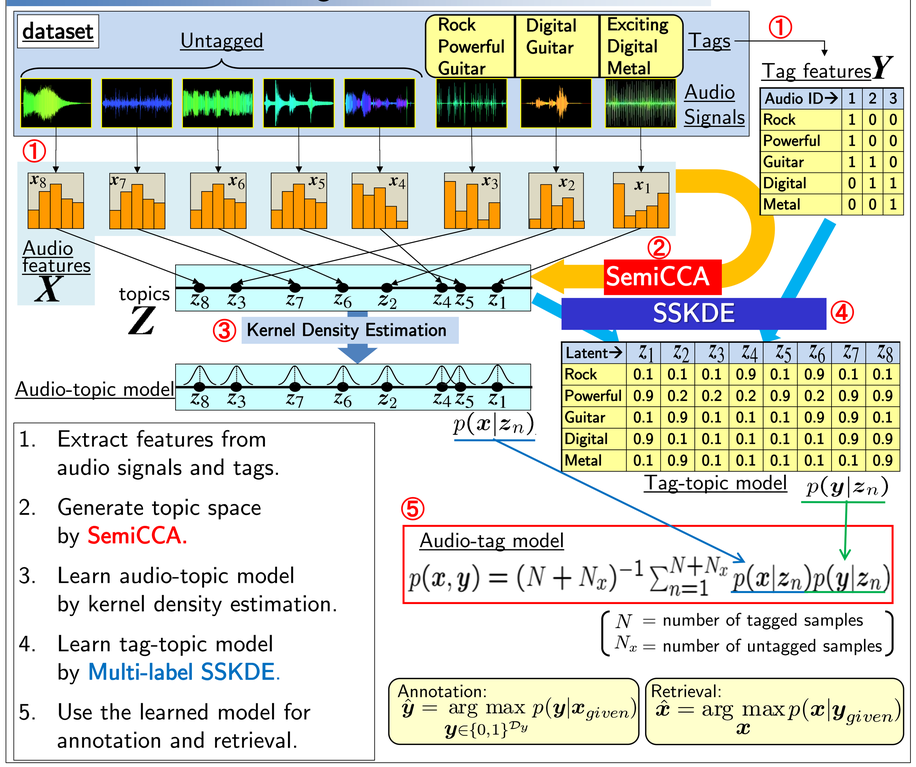
pLSA: NLP [Hofmann 1999] Image [Barnard+ 2001]
LDA : NLP[Blei+ 2003], Image [Li+ 2005]

$$p(x, y) = \int_z p(z)p(x|z)p(y|z)dz$$



- Merits:
  1. Tag co-occurrence is considered in the model.
  2. Scalable to many features.

SSCDE : Model Learning Framework



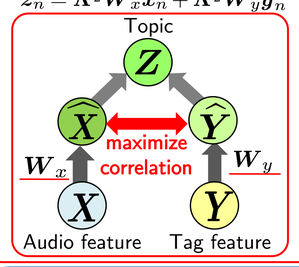
1. Extract features from audio signals and tags.
2. Generate topic space by SemiCCA.
3. Learn audio-topic model by kernel density estimation.
4. Learn tag-topic model by Multi-label SSKDE.
5. Use the learned model for annotation and retrieval.

Technical Points of SSCDE

1. Learn topic space with tagged and untagged samples : SemiCCA [Kimura+ ICPR2010]

Learn the map :

$$z_n = \Lambda^{\frac{1}{2}} W_x x_n + \Lambda^{\frac{1}{2}} W_y y_n$$



SemiCCA can utilize untagged samples differently from standard CCA.

Solution

generalized eigenproblem.

$$B \begin{bmatrix} w_x \\ w_y \end{bmatrix} = \lambda C \begin{bmatrix} w_x \\ w_y \end{bmatrix}$$

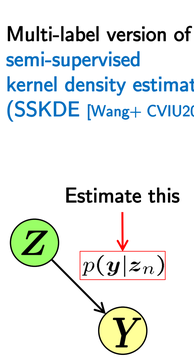
CCA (tagged samples) PCA (tagged and untagged samples)

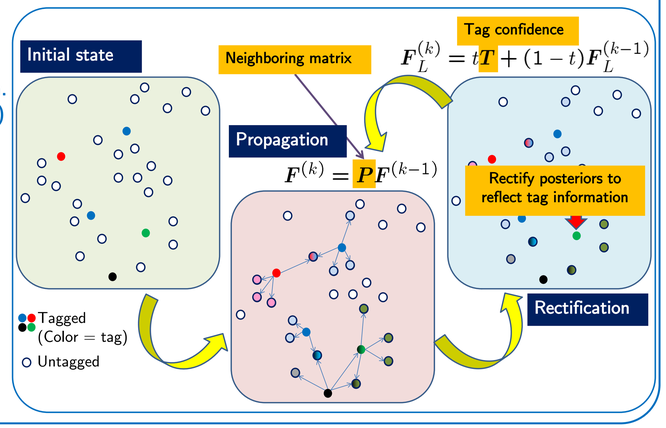
$$B = \beta \begin{bmatrix} 0 & S_{xy}^{(T)} \\ S_{yx}^{(T)} & 0 \end{bmatrix} + (1-\beta) \begin{bmatrix} S_{xx} & 0 \\ 0 & S_{yy} \end{bmatrix}$$

$$C = \beta \begin{bmatrix} S_{xx}^{(T)} & 0 \\ 0 & S_{yy}^{(T)} \end{bmatrix} + (1-\beta) \begin{bmatrix} I_{D_x} & 0 \\ 0 & I_{D_y} \end{bmatrix}$$

2. Propagate tag information : Multi-label SSKDE

Multi-label version of semi-supervised kernel density estimation. (SSKDE [Wang+ CVIU2009])





Experiment

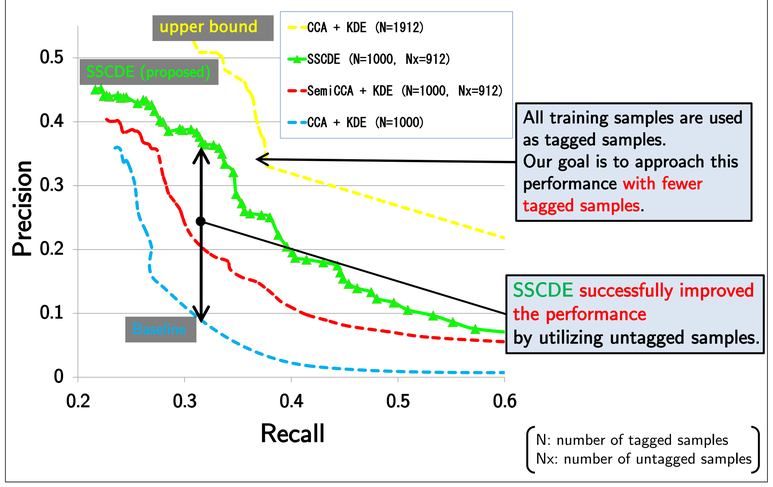
Annotation performance of SSCDE is evaluated under following condition.

- **Dataset**: 2012 audio files taken from "Freesound" (http://www.freesound.org/).
  - Database of Creative Commons licensed sounds.
  - Annotated with vocabulary.
- **Evaluation condition:**
  - 2012 audio clips with WAV format.
  - Each clip has multiple tags selected from 230 words.

Tagged audio signal	Untagged audio signal	Evaluation sample
1000	912	100

- **Audio feature**: bag-of-feature-vectors extracted by the following process.
  1. Audio signals are splitted into half-overlapping 23ms windows, and 39-dimensional vector (including first 13 MFCC, MFCC-Δ, MFCC-Δ-Δ) is extracted from each window.
  2. 500 vectors are sampled from each audio signal (about 1,000,000 vectors in total). LBG algorithm (Linde-Buzo-Gray algorithm, algorithm for vector quantization : VQ) is applied to them, and VQ codebook (size :1024) is obtained.
  3. 1024-dimensional normalized vector representing each audio signal is created by VQ.
- **Tag feature**: 230-dimensional binary vector. (Each element of the vector corresponds to specific tag.)

Result



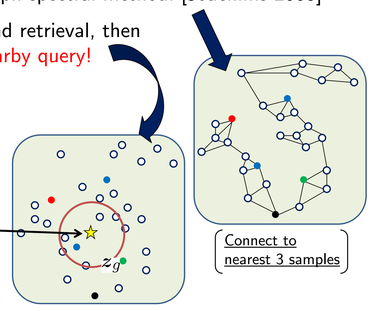
Use Sparse Matrix as Neighboring Matrix

- Fix the number of non-zero elements in each row, then required memory size to hold the neighboring matrix decreases. $(\mathcal{O}(N^2) \longrightarrow \mathcal{O}(N))$
- In this case, SSKDE is equivalent to Graph spectral method. [Joachims 2003]
- Apply the same idea to audio tagging and retrieval, then calculation needs only a few samples nearby query!

$$\hat{y} = \sum_{n=1}^{N} \kappa(z_g, z_n)\ p(y = all\ 1|z_n)$$

Gaussian kernel — Posterior probability of y given Zn

$$\hat{y} = \sum_{z_n \in \mathcal{N}(z_g)} \kappa(z_g, z_n)\ p(y = all\ 1|z_n)$$



Annotation/Retrieval task becomes equivalent to neighboring search problem! (Computational complexity is $\mathcal{O}(\log N)$!)