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- STATE OF THE ART -

Audio Tagging

**Automatically recognize sounds and apply tags of varying
natures**

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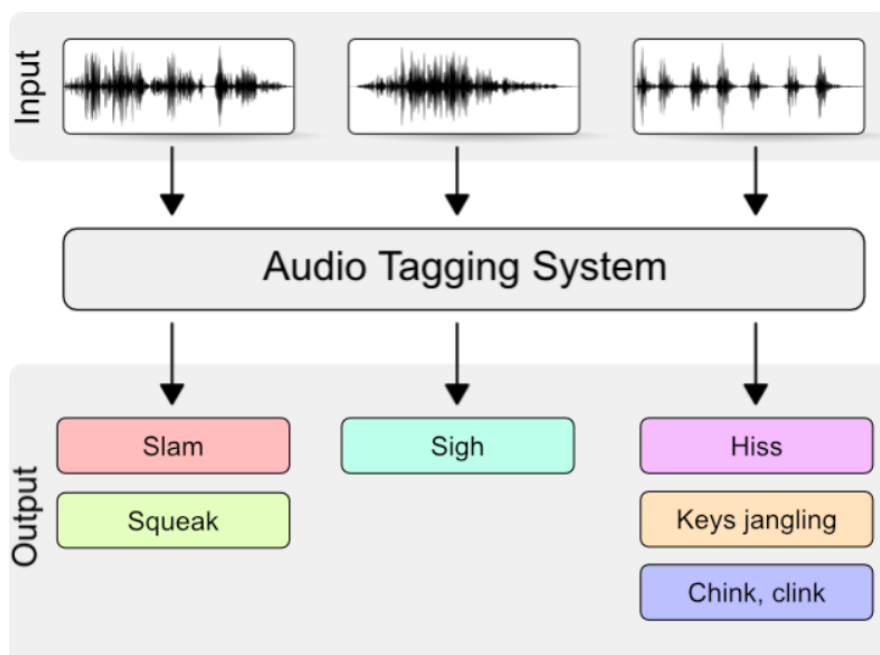
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I. Introduction

I.1. Competition's description

One year ago, **Freesound** and **Google's Machine Perception** hosted an audio tagging competition challenging Kagglers to build a general-purpose auto tagging system. This year they're back and taking the challenge to the next level with multi-label audio tagging, doubled number of audio categories, and a noisier than ever training set. [1]



Here's the background: **Some sounds are distinct and instantly recognizable, like a baby's laugh or the strum of a guitar.** Other sounds are difficult to pinpoint. If you close your eyes, could you tell the difference between the sound of a chainsaw and the sound of a blender?

Because of **the vastness of sounds we experience**, *no reliable automatic general-purpose audio tagging systems exist*. A significant amount of manual effort goes into tasks like annotating sound collections and providing captions for non-speech events in audiovisual content.

To tackle this problem, Freesound (an initiative by MTG-UPF that maintains a collaborative database with over 400,000 Creative Commons Licensed sounds) and Google Research’s Machine Perception Team (creators of AudioSet, a large-scale dataset of manually annotated audio events with over 500 classes) have teamed up to develop the dataset for this new competition.

To win this competition, Kagglers will develop an **algorithm to tag audio data automatically** using a diverse vocabulary of 80 categories.

If successful, these systems could be used for several applications, ranging from **automatic labelling of sound collections to the development of systems that automatically tag video content** or recognize sound events happening in real time.

I.2. Motivation

Current machine learning techniques require large and varied datasets in order to provide good performance and generalization. However, manually labelling a dataset is time-consuming, which limits its size. Websites like Freesound or Flickr host large volumes of user-contributed audio and metadata, and labels can be inferred automatically from the metadata and/or making predictions with pre-trained models. Nevertheless, these automatically inferred labels might include a substantial level of label noise.

The main research question addressed in this competition is **how to adequately exploit a small amount of reliable, manually-labeled data, and a larger quantity of noisy web audio data in a multi-label audio tagging task with a large vocabulary setting**. In addition, since the data comes from different sources, the task encourages domain adaptation approaches to deal with a potential domain mismatch.

I.3. Timeline

- **June 3, 2019 11:59 PM UTC** - Entry deadline. You must accept the competition rules before this date in order to compete.
- **June 3, 2019 11:59 PM UTC** - Team Merger deadline. This is the last day participants may join or merge teams.
- **June 11, 2019 11:59 AM UTC** - Final submission deadline.

II. Dataset description

II.1. Audio Dataset

The dataset used in this challenge is called **FSDKaggle2019**, and it employs audio clips from the following sources:

- **Freesound Dataset (FSD)**: a dataset being collected at the **MTG-UPF** based on **Free-sound** content organized with the AudioSet Ontology
- The soundtracks of a pool of Flickr videos taken from the **Yahoo Flickr Creative Commons 100M dataset (YFCC)**

The audio data is labeled using a vocabulary of 80 labels from **Google’s AudioSet Ontology** [2], covering diverse topics: Guitar and other Musical instruments, Percussion, Water, Digestive, Respiratory sounds, Human voice, Human locomotion, Hands, Human group actions, Insect, Domestic animals, Glass, Liquid, Motor vehicle (road), Mechanisms, Doors, and a variety of Domestic sounds.

II.2. Ground Truth Labels

The ground truth labels are provided at the clip-level, and express the presence of a sound category in the audio clip, hence can be considered weak labels or tags. Audio clips have variable lengths (roughly from 0.3 to 30s, see more details below).

The audio content from **FSD** has been **manually labeled** by humans following a data labeling process using the **Freesound Annotator platform**. Most labels have inter-annotator agreement but not all of them. More details about the data labeling process and the Freesound Annotator can be found in [3].

The **YFCC soundtracks** were labeled using automated heuristics applied to the audio content and metadata of the original Flickr clips. Hence, a substantial amount of label noise can be expected. The label noise can vary widely in amount and type depending on the category, including in- and out-of-vocabulary noises. More information about some of the types of label noise that can be encountered is available in [4].

II.3. Format and License

All clips are provided as uncompressed PCM 16 bit, 44.1 kHz, mono audio files. All clips used in this competition are released under Creative Commons (CC) licenses, some of them requiring attribution to their original authors and some forbidding further commercial reuse. In order to be able to comply with the CC licenses terms, a full list of audio clips with their associated licenses and a reference to the original content (in Freesound or Flickr) will be published at the end of the competition. Until then, the provided audio files can only be used for the sole purpose of participating in the competition.

II.4. Train set

The train set is meant to be for system development. The idea is to limit the supervision provided (i.e., the manually-labeled data), thus promoting approaches to deal with label noise. The train set is composed of two subsets as follows:

II.4.1. Curated subset

The curated subset is a small set of manually-labeled data from FSD.

- **Number of clips/class:** 75 except in a few cases (where there are less)
- **Total number of clips:** 4970
- **Avge number of labels/clip:** 1.2
- **Total duration:** 10.5 hours

The duration of the audio clips ranges from 0.3 to 30s due to the diversity of the sound categories and the preferences of Freesound users when recording/uploading sounds. It can happen that a few of these audio clips present additional acoustic material beyond the provided ground truth label(s).

II.4.2. Noisy subset

The noisy subset is a larger set of noisy web audio data from Flickr videos taken from the YFCC dataset [6].

- **Number of clips/class:** 300
- **Total number of clips:** 19815
- **Avge number of labels/clip:** 1.2

- **Total duration:** 80 hours

The duration of the audio clips ranges from 1s to 15s, with the vast majority lasting 15s.

Considering the numbers above, per-class data distribution available for training is, for most of the classes, 300 clips from the noisy subset and 75 clips from the curated subset, which means 80

II.5. Test set

The test set is used for system evaluation and consists of manually-labeled data from FSD. Since most of the train data come from YFCC, some acoustic domain mismatch between the train and test set can be expected. All the acoustic material present in the test set is labeled, except human error, considering the vocabulary of 80 classes used in the competition.

The test set is split into two subsets, for the public and private leaderboards. In this competition, the submission is to be made through Kaggle Kernels. Only the test subset corresponding to the public leaderboard is provided (without ground truth).

II.6. Files

The structure of the data	
<i>train_curated.csv</i>	ground truth labels for the curated subset of the training audio files (see Data Fields below)
<i>train_noisy.csv</i>	ground truth labels for the noisy subset of the training audio files (see Data Fields below)
<i>sample_submission.csv</i>	a sample submission file in the correct format, including the correct sorting of the sound categories; it contains the list of audio files found in the test.zip folder (corresponding to the public leaderboard)
<i>train_curated.zip</i>	a folder containing the audio (.wav) training files of the curated subset
<i>train_noisy.zip</i>	a folder containing the audio (.wav) training files of the noisy subset
<i>test.zip</i>	a folder containing the audio (.wav) test files for the public leaderboard

II.7. Columns

Each row of the train_curated.csv and train_noisy.csv files contains the following information:

- **fname:** the audio file name, eg, 0006ae4e.wav
- **labels:** the audio classification label(s) (ground truth). Note that the number of labels per clip can be one, eg, Bark or more, eg, "Walk_and_footsteps,Slam".

II.8. Dataset problems

Detected corrupted files in the curated train set The following 5 audio files in the curated train set have a wrong label, due to a bug in the file renaming process: **f76181c4.wav**, **77b925c2.wav**, **6a1f682a.wav**, **c7db12aa.wav**, **7752cc8a.wav**

The audio file **1d44b0bd.wav** in the curated train set was found to be corrupted (contains no signal) due to an error in format conversion.

III. Sound classification predictive models

III.1. Models brief description from different Kaggle approaches

Kaggle [9] is an online community of data scientists and machine learners. Since Kaggle allows users to find and publish data sets, explore and build models in a web-based data-science environment, work with other data scientists and machine learning engineers, and enter competitions to solve data science challenges, it **can be used also as a source of inspiration when solving different tasks machine learning related**. We extracted some of the predictive models that we have found in the public kernels that were attached to the subject competition.

III.1.1. Bidirectional LSTM for audio labeling with Keras

Long short-term memory (LSTM) is an artificial **recurrent neural network (RNN)** architecture used in the field of deep learning. Unlike standard feedforward neural networks, LSTM has feedback connections. It can not only process single data points (such as images), but also entire sequences of data (such as speech or video). For example, LSTM is applicable to tasks such as **unsegmented, connected handwriting recognition or speech recognition**. **LSTM** in its core, *preserves information from inputs that has already passed through it using the hidden state*.

Unidirectional LSTM only **preserves information of the past** because the only inputs it has seen are from the past. Using **bidirectional** will **run your inputs in two ways, one from past to future and one from future to past** and what differs this approach from unidirectional is that **in the LSTM that runs backwards you preserve information from the future** and using the two hidden states combined you are able in any point in time to preserve information from both past and future.

What they are suited for is a very complicated question but BiLSTMs show very good results as they can understand context better, but this can be explain through a simple example. Lets

say we try to predict the next word in a sentence, on a high level what a unidirectional LSTM will see is:

The boys went to

And will try to predict the next word only by this context, with bidirectional LSTM you will be able to see information further down the road for example

Forward LSTM:

The boys went to ...

Backward LSTM:

... and then they got out of the pool

You can see that using the information from the future it could be easier for the network to understand what the next word is.

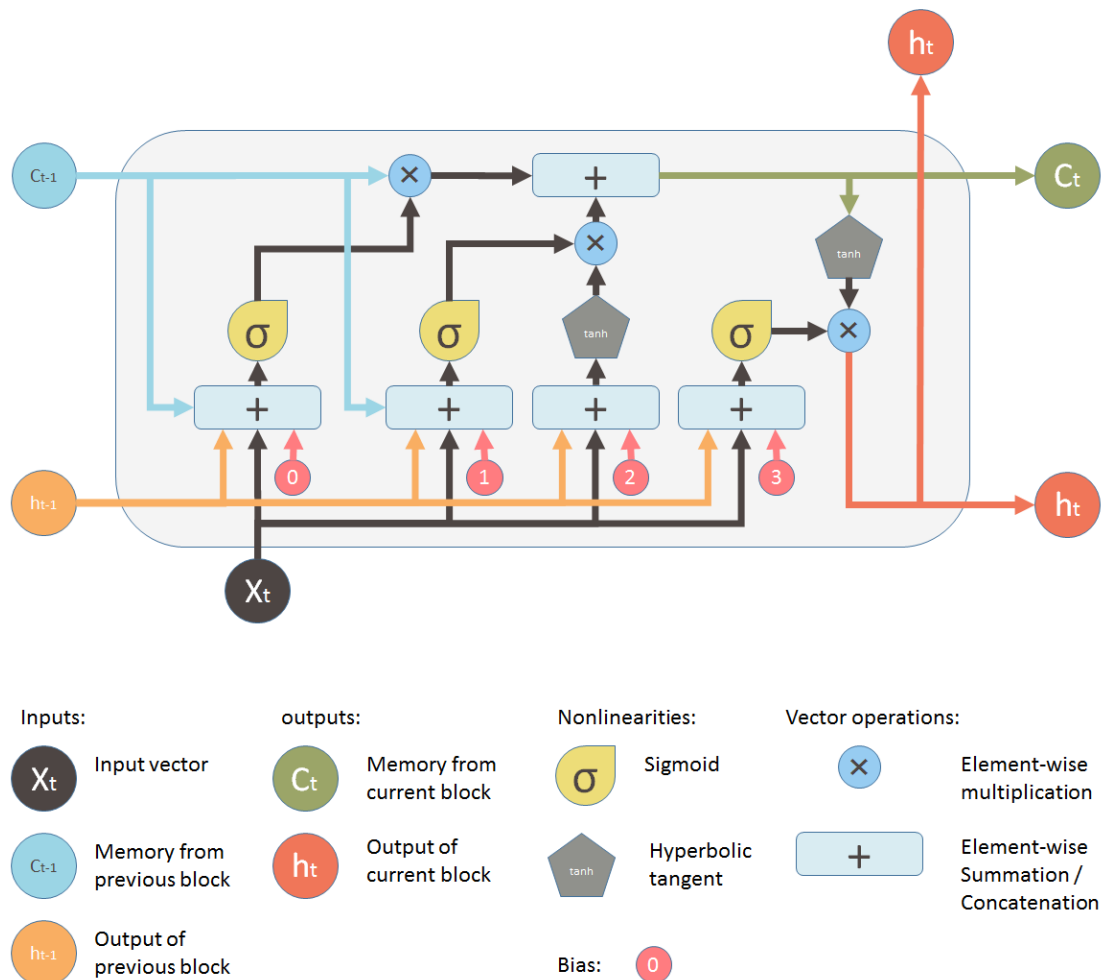


Fig. III.1.1.a: Overview LSTM

In a public Kaggle kernel [8] it was used the following architecture for the **Freesound classification problem** inspired from an article named *Convolutional RNN: an Enhanced Model for Extracting Features from Sequential Data* [11].

```
# Neural network model
input_shape = (636,128)
optimizer = Adam(0.005, beta_1=0.1, beta_2=0.001, amsgrad=True)
n_classes = 80

model = Sequential()
model.add(Bidirectional(CuDNNLSTM(256, return_sequences=True),
                        input_shape=input_shape))
model.add(Attention(636))
model.add(Dropout(0.2))
model.add(Dense(400))
model.add(ELU())
model.add(Dropout(0.2))
model.add(Dense(n_classes, activation='softmax'))
model.compile(loss='categorical_crossentropy',
              optimizer=optimizer,
              metrics=['acc'])
```

Another likely model that develops a bird sound classification problem and uses bidirectional LSTM neural networks had the following architecture:

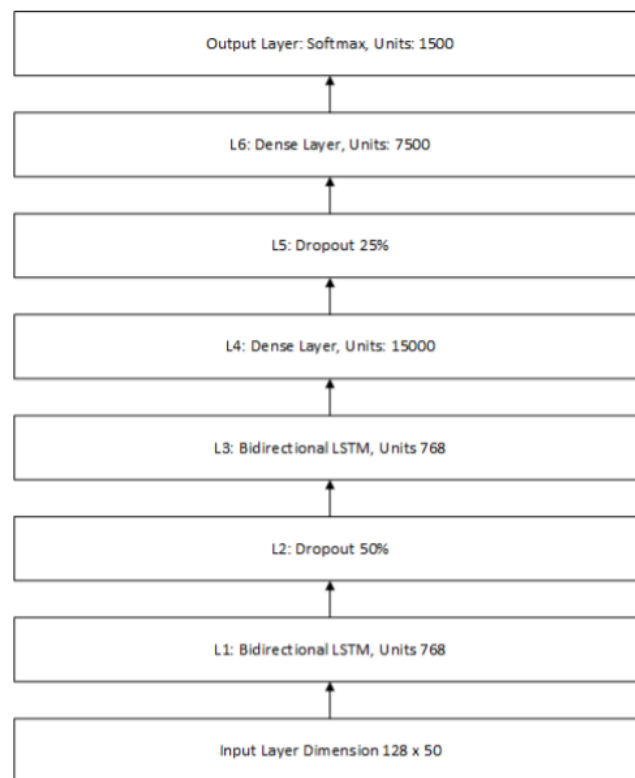


Fig. III.1.1: Architecture *bidirectional LSTM*. [10]

III.2. Evaluation metric

The task consists of **predicting the audio labels (tags) for every test clip**. Some test clips bear one label while others bear several labels. The predictions are to be done at the clip level, i.e., no start/end timestamps for the sound events are required.

The primary competition metric will be **label-weighted label-ranking average precision** [7](lwlap, pronounced "Lol wrap"). This **measures the average precision of retrieving a ranked list of relevant labels** for each test clip (i.e., the system ranks all the available labels, then the precisions of the ranked lists down to each true label are averaged). This is a generalization of the mean reciprocal rank measure for the case where there can be multiple true labels per test item. The novel "label-weighted" part means that the overall score is the average over all the labels in the test set, where each label receives equal weight (by contrast, plain lraps gives each test item equal weight, thereby discounting the contribution of individual labels when they appear on the same item as multiple other labels).

The formula for label-ranking average precision (LRAP) is as follows:

$$LRAP(y, \hat{f}) = \frac{1}{n_{samples}} \sum_{i=0}^{n_{samples}-1} \frac{1}{\|y_i\|_0} \sum_{j:y_{ij}=1} \frac{|\mathcal{L}_{ij}|}{rank_{ij}} \quad (1)$$

```
def calculate_overall_lwlap_sklearn(truth, scores):  
    """Calculate the overall lwlap using sklearn.metrics.lrap."""  
    # sklearn doesn't correctly apply weighting to samples with no labels  
    # so just skip them.  
    sample_weight = np.sum(truth > 0, axis=1)  
    nonzero_weight_sample_indices = np.flatnonzero(sample_weight > 0)  
    overall_lwlap = label_ranking_average_precision_score(  
        truth[nonzero_weight_sample_indices, :] > 0,  
        scores[nonzero_weight_sample_indices, :],  
        sample_weight=sample_weight[nonzero_weight_sample_indices])  
    return overall_lwlap
```

IV. State of the art

IV.1. Problem description

The environmental sound classification problem can come in many different shapes, from having to classify short audio files with a label from a specified set to having to tag live audio streaming with one or multiple labels.

Automatic environmental sound classification or tagging is a growing area of research. Work done in this area is comparatively scarce with work done in related audio fields such as speech and music. Applications are numerous and include multimedia indexing and retrieval, environmental sounds subtitles, assisting deaf individuals or even monitoring illegal deforestation. A very interesting project regarding this last use case is created by a non-profit organization called Delta Analytics. They helped build a system where a lot of old mobile phones are attached to trees in rain forests which listen to chainsaw noises. Their role is to identify when a chainsaw is being used and alert rangers who can stop illegal deforestation [13].

Because of the recent success in image classification, the question that raises is: can we bring techniques used in image classification to sound classification by representing sound in various image formats?

IV.2. Short audio files classification

IV.2.1. Problem statement

Classify environmental sounds with focus on identification of particular urban sounds. Given an audio sample of a few seconds duration determine if it contains one of the target urban sounds [12].

IV.2.2. Dataset description

The dataset is called Urbansound8K and contains 8732 sound excerpts (under 4s) of urban sounds from 10 classes, which are:

- Air Conditioner
- Car Horn
- Children Playing

- Dog bark
- Drilling
- Engine Idling
- Gun Shot
- Jackhammer
- Siren
- Street Music

By taking a closer look to the dataset, the following observation can be made: it's tricky to visualize the difference between some sounds, especially the continuous ones like jackhammer and engine idling.

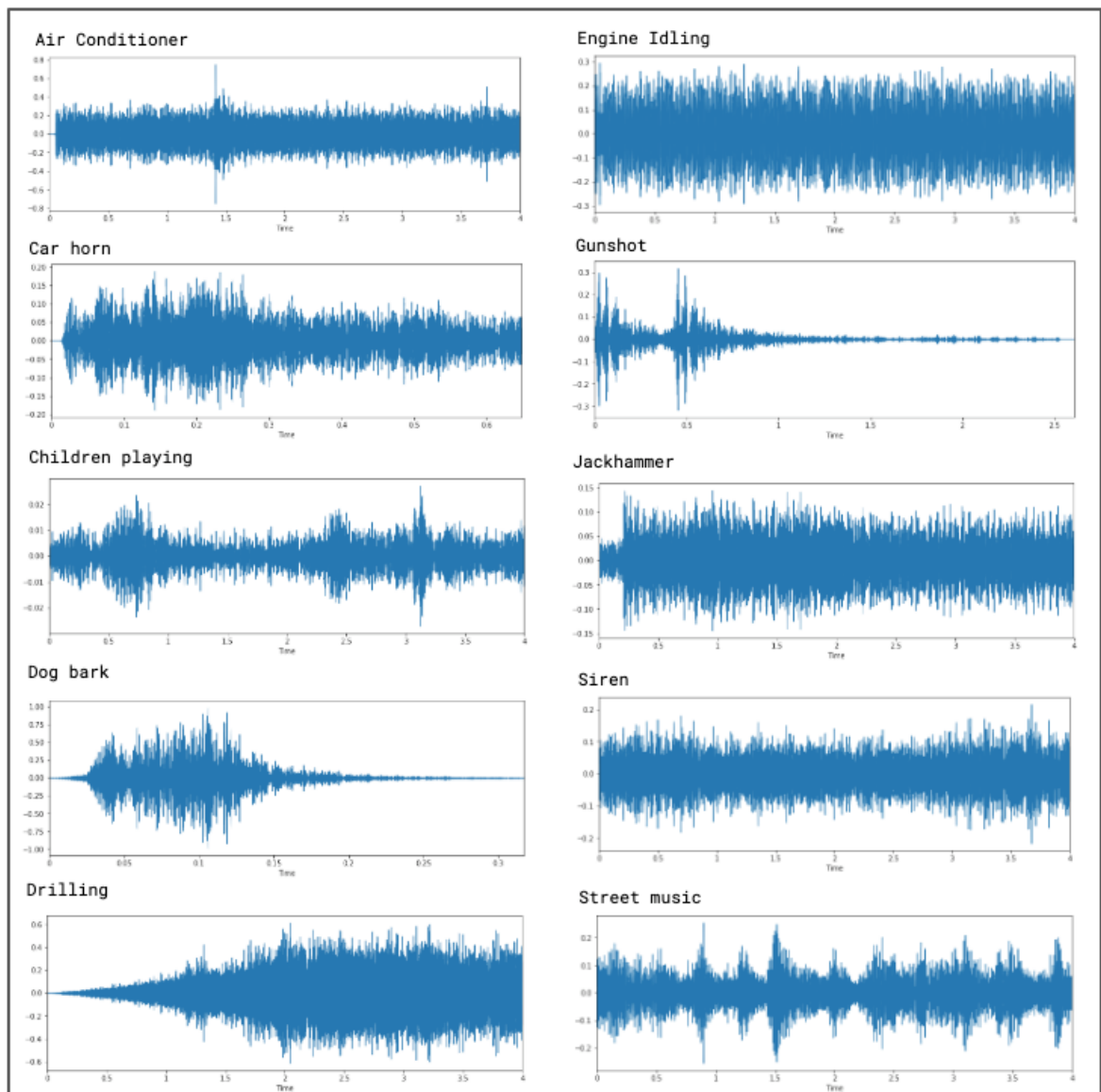


Fig. : *Visualization of sound amplitude with respect to time*

A deeper dive into the data show that: most samples have 2 audio channels with a few having just 1 channel, sample rate varies from 8kHz to 48kHz and bit depth also varies from 4bit to 32bit which leads to requiring a data normalization step.

IV.2.3. Proposed solution

The proposed solution involves mapping the audio files, after the normalization step, to a visual representation. Spectrograms are a useful technique for visualizing the spectrum of frequencies of a sound and how they vary during a very short period of time. A similar technique known as mel-spectrogram will be used for this case. The main difference is that a spectrogram uses a linear spaced frequency scale (so each frequency bin is spaced an equal number of Hertz apart), whereas a mel-spectrogram uses a quasi-logarithmic spaced frequency scale, which is more similar to how the human auditory system processes sounds.

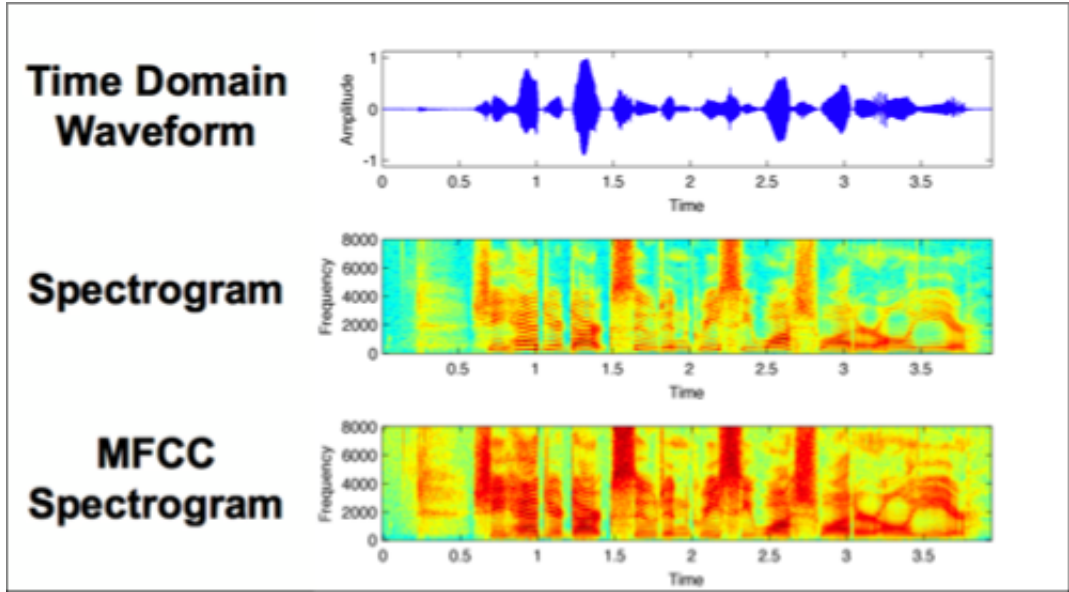


Fig. : *Spectrogram and mel-spectrogram*

The problem will be solved by using deep learning on the visual representation of the audio file. In this case a Convolutional Neural Network (CNN) will be used. The model used is a sequential one consisting of 4 Conv2D convolution layers with the final output being a dense layer. The output layer will have 10 nodes which matches the number of possible classifications.

IV.2.4 Results

The trained model obtained a Training accuracy of 98.19% and a Testing accuracy of 91.92%.

IV.3. Tagging longer audio files

By providing a solution to solving the short audio files tagging problem we can extend it to work on longer audio files. The idea behind this extension is to divide the audio into smaller parts, transform these parts into mel-spectrograms and feed them into a more complex network that will be able to provide the correct label(s).

IV.4. State of the art solution

State of the art solution to solving this problem is deep learning. By dividing the audio and transforming it into mel-spectrograms [14] we can use some of the success of image classification and bring it to audio classification. Just applying image classification on mel-spectrograms doesn't work because sound in form of mel-spectrograms doesn't have the same properties as an image but by adapting the network to the new context we can obtain a solution to solving this problem.

IV.5. Relevant articles

- AUDIO TAGGING WITH NOISY LABELS AND MINIMAL SUPERVISION - <https://arxiv.org/pdf/1906.02975.pdf>
- Convolutional RNN: an Enhanced Model for Extracting Features from Sequential Data - <https://arxiv.org/pdf/1602.05875v3.pdf>

IV.6. Relevant links

- Kaggle competition 1st place solution - <https://github.com/lRomul/argus-freesound>
- Kaggle competition 2nd place solution - <https://www.kaggle.com/c/freesound-audio-tagging-2019/discussion/97815>
- Kaggle competition 3rd place solution - <https://www.kaggle.com/c/freesound-audio-tagging-2019/discussion/97926>

V. Application prototype

V.1. Use cases

- Semi-automatized System:
 - can use reinforcement learning for improving tagging accuracy
- Signals that may help deaf users in:
 - dangerous situations (outdoor activities/ fire alarms)
 - daily activities
 - movie captioning
 - * different details like gun shooting in background may help deaf users having a better entertainment experience while watching movies
- video indexing for search engines
- security (e.g. detecting breaking in sounds, hearth attack/ people suffering, etc.)
- analyzing audience behavior(excitement, boredom, etc.)

V.2. Model integration

Based on the business needs the following approaches may be applied:

Use model on a remote server and expose it via:

- remote REST API
 - can process full media file
 - disadvantage: harder to infer in a live stream
- remote streaming data (e.g. sending data over websockets)

Export the model to be used on an end device

- for tensorflow, the models can be converted to either tflite for Android or coreML for iOS

V.3. Application flow

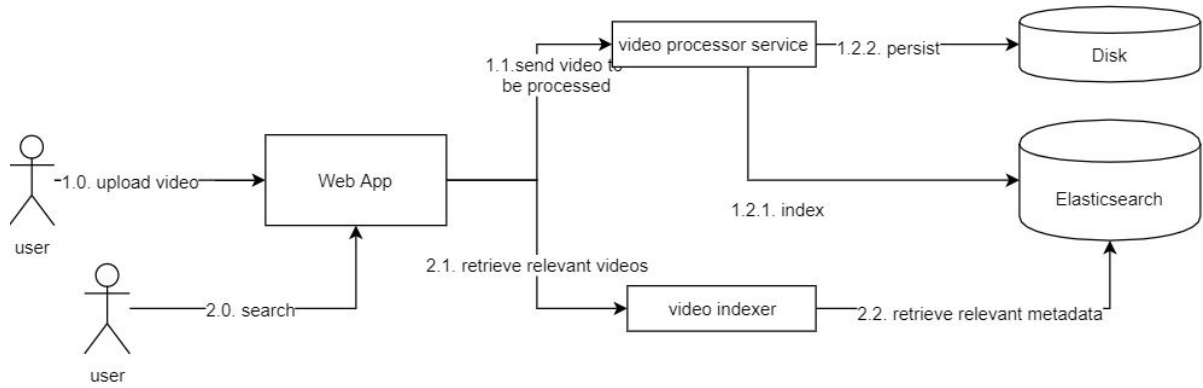


Fig. V.3.1: *Application flow overview*

Video processing flow

1. Upload video via web app
2. Send video to processor service
3. Index extracted metadata into ElasticSearch
4. Persist video in a blob/ on disk

Video indexer flow

1. Search for videos using certain keywords
2. Retrieve relevant metadata from ElasticSearch
3. Construct relevant list of videos that will be send to the user

VI. Risk assessment

Risk type	Risk details	Likelihood	Severity	Mitigation measures
Requirements	Requirements will be added in the middle of the project	Probable	Moderate	Brainstorm as many variants of the application as possible and keep the best one
Schedule	Not all components will be done in time	Possible	Serious	Evaluate how difficult each component will be and choose only those that can be finished
Performance	The classification model will perform poorly	Possible	Serious / Major	Read from various sources of what other did
Organizational	Bad distribution of tasks. Two people doing the same thing independently	Unlikely	Moderate	Organizing tasks on <i>trello</i> and occasional meetings to discuss the current state of the project
System architecture	Choose the wrong architecture for the application	Possible	Serious	Read other architectures used in solving the same problem and create something similar
Resources	Personal laptops not powerful enough to train the model	Possible / Probable	Major	Consider using cloud solutions to train the model

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