Lab 1: Data Preparation and Feature Extraction

January 24, 2017

The main goal of this lab is to get acquainted with Kaldi. We will begin by creating and exploring a data directory for the TIMIT dataset. Then we will extract features for TIMIT upon which we can train a complete speech recognition system in the coming labs. An underlying goal of this lab is to get you acquainted with Kaldi. Notes on UNIX commands are included in boxes; feel free to skip them if you're already familiar.

The work in this and future labs will use TIMIT. This corpus is interesting because it is *phonetically* labelled with 60 phone labels (and one end of sentence silence marker). TIMIT is often used as a benchmark for performance, although results on TIMIT are not always transferable to other corpora. Some historical results are shown in Figure 1.

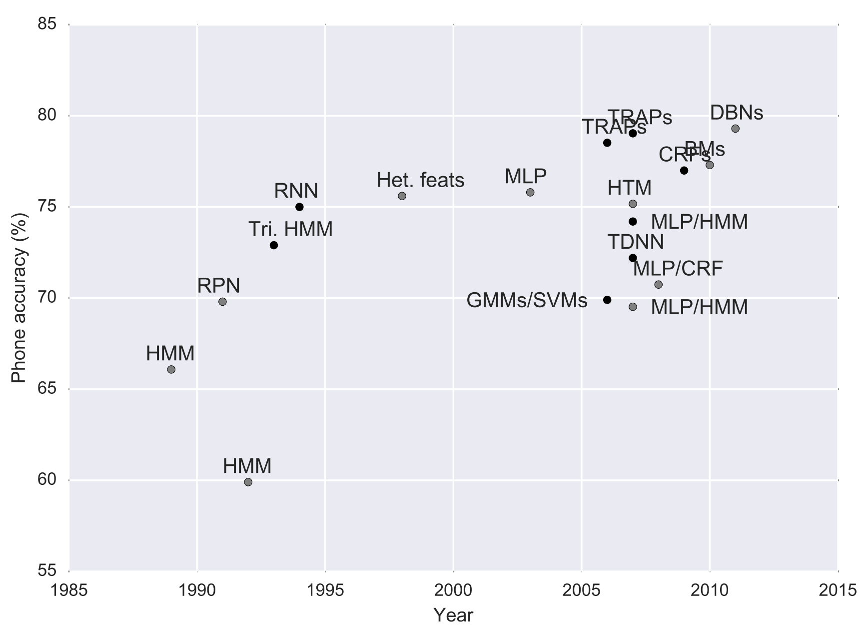


Figure 1: Results on TIMIT with various techniques. Most numbers from [1].

1 Kaldi setup

First, lets set up a local directory where we can run experiments. Open a terminal window on DICE. Change directory to a directory we've set up for you, inserting your UUN in place of <UUN>:

```
cd /afs/inf.ed.ac.uk/group/teaching/asr/Work/<UUN>
```

`cd dir` changes the directory to `dir`, and `ls` lists its contents. `cd ..` moves up one directory, `cd -` moves to the previous directory, and `cd ~` moves to your home directory.

This is your work directory. It is tedious to remember that long path, so lets go back to your home directory, create a soft link called `asrworkdir`, and `cd` back into it:

```
cd ~
ln -s /afs/inf.ed.ac.uk/group/teaching/asr/Work/<UUN> asrworkdir
cd asrworkdir
```

We'll now set up some files we need to run experiments in Kaldi. Run the following commands to create softlinks to your directory and to create a few empty directories. The dot means to create the links or copies in the current directory.

```
ln -s /afs/inf.ed.ac.uk/group/teaching/asr/tools/labs/steps .
ln -s /afs/inf.ed.ac.uk/group/teaching/asr/tools/labs/utils .
ln -s /afs/inf.ed.ac.uk/group/teaching/asr/tools/labs/local .
ln -s /afs/inf.ed.ac.uk/group/teaching/asr/tools/labs/path.sh .
cp -r /afs/inf.ed.ac.uk/group/teaching/asr/tools/labs/conf .
cp /afs/inf.ed.ac.uk/group/teaching/asr/tools/labs/run.sh .
mkdir data
mkdir exp
```

`ln -s f1 f2` creates a soft link from `f1` to `f2`, so that any changes made to one will affect the other. When you want to copy instead, use `cp`: `cp -r dir1 dir2` copies the directory `dir1` to `dir2`, the `-r` (recursive) flag is required for directories.

Your work dir now has a typical directory structure for Kaldi. Type the following command to list its contents

```
ls
```

You should see the following files and folders:

steps contains scripts for creating an ASR system

utils contains scripts to modify Kaldi files in certain ways, for example to subset data directories into smaller pieces

local this directory typically contains files that relate only to the corpus we're working on (e.g. TIMIT). In this case it also may contain files we have provided for you.

data will contain any data directories, such as a `train` and `test` directory for TIMIT. We will create these below.

exp contains the actual experiments and models, as well as logs.

conf contains configurations for certain scripts that may read them. More on this later.

path.sh contains the path to the Kaldi source directory

run.sh is a recipe which you will complete in this lab.

Kaldi binaries are stored some place else than the experiment directory. To access them from anywhere, we set - inside the file `path.sh` - an environment variable `KALDI_ROOT` to point to the Kaldi installation. To set this variable type

```
source path.sh
```

or equivalently

```
. ./path.sh
```

To see whether it is set and where it points run

```
echo $KALDI_ROOT
```

> The command `echo` prints any string to the terminal along with any variables (e.g. `$KALDI_ROOT`). To omit newlines use the flag `-n`.

Similarly, the `steps` and `utils` directories are symbolic links to directories in the base install. `steps` includes essential scripts to train and decode ASR systems, while `utils` contains a number of scripts to for example manipulate the data directory. Local files pertaining to the current experiment go in `local`. This is a good place to put any utility scripts you write.

The `path.sh` file is called at the beginning of all Kaldi scripts, e.g. look at the first 18 lines of the script that computes MFCCs:

```
head -18 steps/make_mfcc.sh
```

head -l file and tail -l file prints the first and last l lines of file. A useful variation is tail -n +l which prints from line l to the end.

Now that the environment variables are set, try to run a typical Kaldi binary *without any arguments*, e.g.

```
feat-to-dim
```

It should provide an explanation of its purpose and usage instructions. This is common to all Kaldi binaries and scripts.

Kaldi comes with recipes for various corpora. These are typically embodied in a run.sh script in the main directory, with supporting files in local. This script will call high level scripts in steps and utils, which in turn call binaries which perform the actual computation.

2 TIMIT

We will create a data directory for TIMIT and extract features. A barebones recipe that you will complete is provided in run.sh.

- Open run.sh in a text editor inside the terminal (if you're unfamiliar with vi or emacs try nano run.sh).

To open the file in nano, type

```
nano run.sh
```

Inside nano, use the arrow keys to move around the text file. To exit, hit ctrl+X and hit Y or N to the question of whether to save any changes or not. Other commands are listed at the bottom of the window.

The main commands that you will be asked to enter will be present here, as well as commands that you will complete yourself. It might be practical to open another terminal window and cd to the same directory, so that you can copy and paste commands.

Any text after the # symbol is a comment and is not evaluated.

If you're new to Bash scripting or need a refresher, here's a few resources you may find useful. The first three expect no previous knowledge of Bash, the last is good to get to know many useful commands.

- BASH Programming - Introduction How-To: `http://tldp.org/HOWTO/Bash-Prog-Intro-HOWTO.html`
- Advanced Bash-Scripting Guide: `http://www.tldp.org/LDP/abs/html/index.html`
- Bash Guide for Beginners: `http://www.tldp.org/LDP/Bash-Beginners-Guide/html/index.html`
- UNIX for Poets: `http://www.cs.upc.edu/~padro/Unixforpoets.pdf`

2.1 Data preparation

In the data preparation step we will create directories in `data` which will store any training and test sets, features and eventually a language model.

The first line sets the environment variables, *if path.sh exists*. It's a good idea to run this at the beginning of any Kaldi scripts:

```
[ -f ./path.sh ] && . ./path.sh
```

`&&` will execute the next command if the previous succeeded (a typical Kaldi convention is using the opposite, `||` in its scripts, ending lines with `command || exit 1`, which means to exit the script with status 1 (error) if the preceding commands did *not* succeed).

Next, create we create data directories for TIMIT by running the following two lines from `run.sh`. Don't worry about warnings of nonzero return status.

```
timit=/group/corporapublic/timit/original
local/timit_create_data.sh $timit
```

The data we just created is in the `data` directory. To appreciate better what this script does, navigate to the original TIMIT corpus training data directory and list its contents:

```
cd /group/corporapublic/timit/original/train
ls
```

It's split into multiple folders. Dive into the first and look at it

```
cd dr1
ls
```

Each of these directories represent a speaker. Move into the first speaker's directory and list the contents

```
cd fcjf0
ls
```

For each utterance there are four files: `.phn`, `.txt`, `.wav` and `.wrd`.

Look at each file in turn to figure out what they represent using the command `less`. You can use the up and down arrows to navigate. Hit `q` to exit.

```
less sa1.phn
less sa1.txt
less sa1.wav
less sa1.wrd
```

> `less` is useful when you only want to view a file and not edit it. It is also smart in that it doesn't read the entire file into memory at once, so files like `sa1.wav` which are not normally something you would look at, are handled neatly.

It's probably more interesting to listen to `sa1.wav`. On DICE you can write

```
play sa1.wav
```

Let's go back to our Kaldi work directory and see what we created with the command above:

```
cd ~/asrworkdir
```

Navigate to one of the created subdirs and look at the contents:

```
cd data/train
ls
```

The following files should be present. Have a look at each:

```
less text
less spk2utt
less wav.scp
less spk2gender
```

The script has combined all the information from the TIMIT directory we just looked at into files that neatly contain the information in a way that Kaldi can work with it.

The files are closely related by *utterance* and *speaker* ids, abbreviated to *utt_id* and *spk_id* in Figure 2. If each utterance is from a different speaker, or if we have no information about speakers, then the utterance and speaker ids match. Otherwise the speaker information is used to pool statistics across utterances for speaker adaptation and for speaker specific scoring. In the absence of a `segments` file, which sets out what portions of each audio file should be used for an utterance id, the recording ids are equivalent to the utterance ids. In this case we use the entire length of each audio file set out in `wav.scp`.

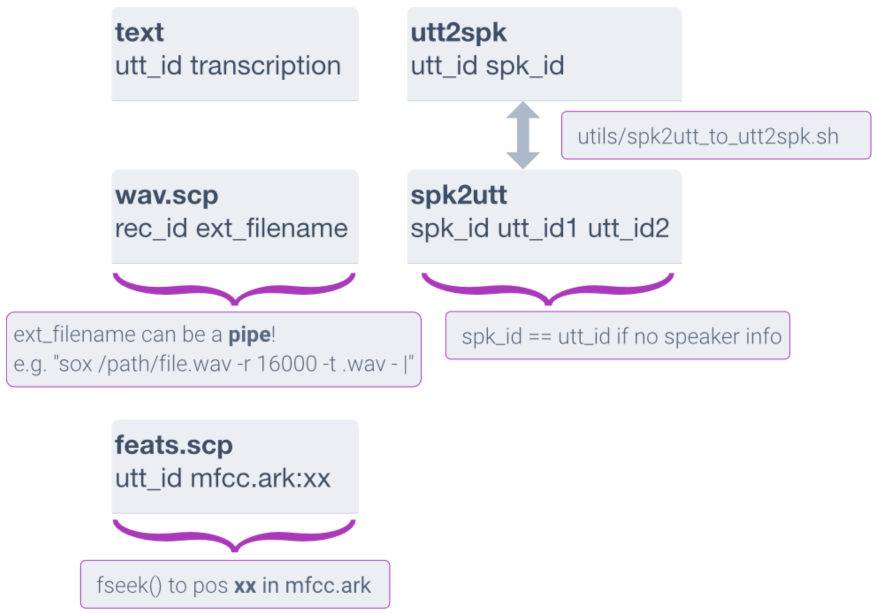


Figure 2: Illustration of a Kaldi data directory structure.

Change directory back to the main workdir:

```
cd ~/asrworkdir
```

To check that the data directories conforms to Kaldi specifications, run the next two lines in `run.sh`:

```
utils/validate_data_dir.sh data/train
utils/validate_data_dir.sh data/test
```

Uh oh. We're missing `utt2spk`, but we have `spk2utt`. These two files contain the same information, just with the mapping reversed. So we can easily convert one into the other. In the `utils` directory there is a file called `spk2utt_to_utt2spk.pl`. This is a Perl script which reads from `stdin` and writes to `stdout`. To pipe into the script we use `<`, to pipe out and into a file (instead of `stdout`) we use `>`. Run the following commands:

```
utils/spk2utt_to_utt2spk.pl < data/train/spk2utt > data/train/utt2spk
utils/spk2utt_to_utt2spk.pl < data/test/spk2utt > data/test/utt2spk
```

Run the validation scripts again. There should only be a `feats.scp` file missing, which we'll create next.

Have a look at the file you just created. How does it relate to `spk2utt`?

```
less data/train/utt2spk
less data/train/spk2utt
```

To see how many utterances there are in the training directory, we can use the command `wc`:

```
wc -l < data/train/utt2spk
```

- How many *speakers* are there in the training data? Add this command to `run.sh`.

2.2 Features

We'll now generate the features and the corresponding `feats.scp` script file, that will map utterance ids to positions in an archive, e.g. `feats.ark`.

For GMM-HMM systems we typically use MFCC or PLP features, and then apply cepstral mean and variance normalisation.

> For the next step it can be handy to use a `for` loop, to loop over directory names. In Bash the syntax is:
>
> ```
> for var in item1 item2 item3; do
>   echo $var;
> done
> ```
>
> This will print:
>
> ```
> item1
> item2
> item3
> ```

We will create MFCCs for our data. Run the following lines, which loops over the data directories and extracts features for each.

```
for dir in train test; do
  steps/make_mfcc.sh data/$dir exp/make_mfcc/$dir mfcc
done
```

This will have created `feats.scp` with corresponding archives in a folder called `mfcc` and written log files to `exp/make_mfcc`.

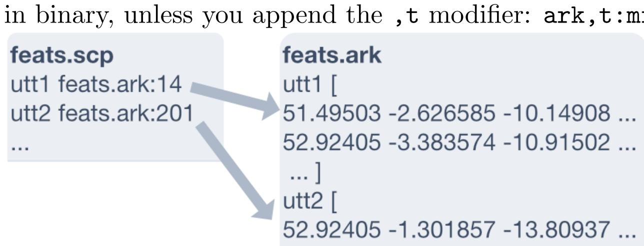
- Repeat the above step, but this time apply cepstral mean and variance normalisation. See `run.sh`. This will create `cmvn.scp`. Add the lines of code to `run.sh`.

- *Extra:* Look in either of the scripts for a line that involves `split_scp.pl`, then confirm what it does by comparing files in the `mfcc` feature directory with `wav.scp` (e.g. use `wc`).

- Validate the data directory again.

2.2.1 Script and archives (*.scp, *.ark)

`scp` files map utterance ids to positions in `ark` files. The latter contain the actual data. Kaldi binaries generally read and write script and archives interchangeably, as long as the filename is prepended with the type of file you wish to read or write, e.g. `scp:feats.scp` or `ark:mfcc.ark` or `ark:-` to write to stdout. Archives will be written in binary, unless you append the `,t` modifier: `ark,t:mfcc.ark`.



For more see the documentation on Kaldi I/O mechanisms, see: `http://kaldi-asr.org/doc/io.html#io_sec_tables`

Kaldi binaries typically read and/or write script and archive files. When this is the case, the usage message will show `rspecifier` or `wspecifier`. Scripts and archives represent the same data, so passing either to a program yields the same results.

Let's try using the programme `feat-to-dim` to find the dimensions of the features we just created:

```
feat-to-dim scp:data/train/feats.scp -
feat-to-dim ark:mfcc/raw_mfcc_train.1.ark -
```

Are they the same?

Let's have a look at the actual features too. The archives are by default written in binary, but we can make a suitable copy using the program `copy-feats` and a suitable write specifier (see box above). We pipe it into `head` to avoid overflowing the terminal window:

```
copy-feats scp:data/train/feats.scp ark,t:- | head
```

Do the features match what you got from `feat-to-dim`?

Read specifiers can take pipes as arguments. This can be handy if you only want to look at the features for a particular utterance.

- Try replacing the read specifier to your previous solution with

  ```
  'grep fdfb0_sx58 data/train/feats.scp |'
  ```

  What does this do?

> `grep` will search for a string in a file and output that entire line by default: `grep string filename`. The string could be a regex query and there are a lot of options. See `man grep` for more.

- Try the same trick as above, but find how many frames that utterance has using the program `feat-to-len`.

While a write specifier can write to stdout (e.g. `ark:-`), it can also read from stdin. What does the following command do? This syntax is crucial to piping Kaldi programmes together.

```
head -10 data/train/feats.scp | tail -1 | copy-feats scp:- ark,t:- | head
```

`steps/make_mfcc.sh`, which you ran above, will use the program `compute-mfcc-feats` to extract features. This program looks for `conf/mfcc.conf` in the `conf` folder for any non-default parameters. These are passed to the corresponding binaries.

Look at that file

```
less conf/mfcc.conf
```

and compare it to the options for the program by running it without arguments:

```
compute-mfcc-feats
```

If you have time, let's combine what we've learned and create filterbank features.

- Create copies of your data directories and generate filterbank and pitch features for each (look in the `steps` folder for a suitable script). However, first create a `conf/fbank.conf` file and include an argument to set the dimension of the filterbank features to 40. To create a new file just use `nano` as you otherwise would. (Hint: Look at `compute-fbank-feats` for arguments). Finally, check the feature dimension and make sure it is 43 (there are three pitch features).

We're done! Next time we'll build a GMM-HMM system.

2.3 Appendix: Common errors

- Forgot to source `path.sh`, check current path with `echo $PATH`
- No space left on disk: check `df -h`
- No memory left: check `top` or `htop`
- Lost permissions reading or writing from/to AFS: run `kinit && aklog`. To avoid this, run long jobs with the `longjob` command.
- Syntax error: check syntax of a Bash script without running it using `bash -n scriptname`
- Avoid spaces after \when splitting Bash commands over multiple lines
- Optional params:
- command line utilities: `--param=value`
- shell scripts: `--param value`
- Most file paths are absolute: make sure to update the paths if moving data directories
- Search the forums: `http://kaldi-asr.org/forums.html`
- Search the old forums: `https://sourceforge.net/p/kaldi/discussion`

2.4 Appendix: UNIX

- `cd dir` - change directory to `dir`, or the enclosing directory by `..`
- `cd -` - change to previous directory
- `ls -l` - see directory contents
- `less script.sh` - view the contents of `script.sh`
- `head -l` and `tail -l` - show first or last `l` lines of a file
- `grep text file` - search for `text` in `file`
- `wc -l file` - compute number of lines in `file`

References

[1] Carla Lopes and Fernando Perdigao. Phone recognition on the timit database. *Speech Technologies/Book*, 1:285–302, 2011.