L21: HTK

Introduction

Building an HTK recognizer

Data preparation

Creating monophone HMMs

Creating tied-state triphones

Recognizer evaluation

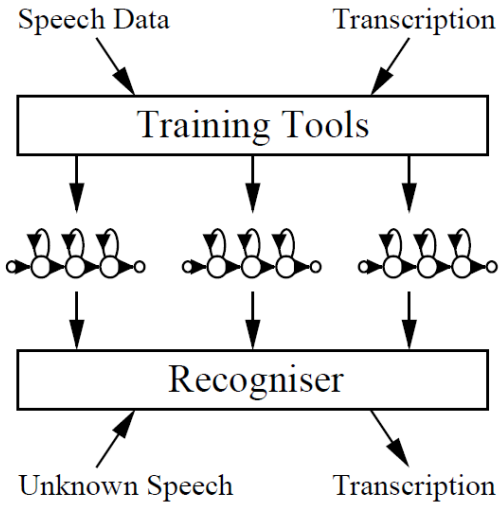
Adapting the HMMs

This lecture is based on The HTK Book, v3.4 [Young et al., 2009]

Introduction

What is HTK?

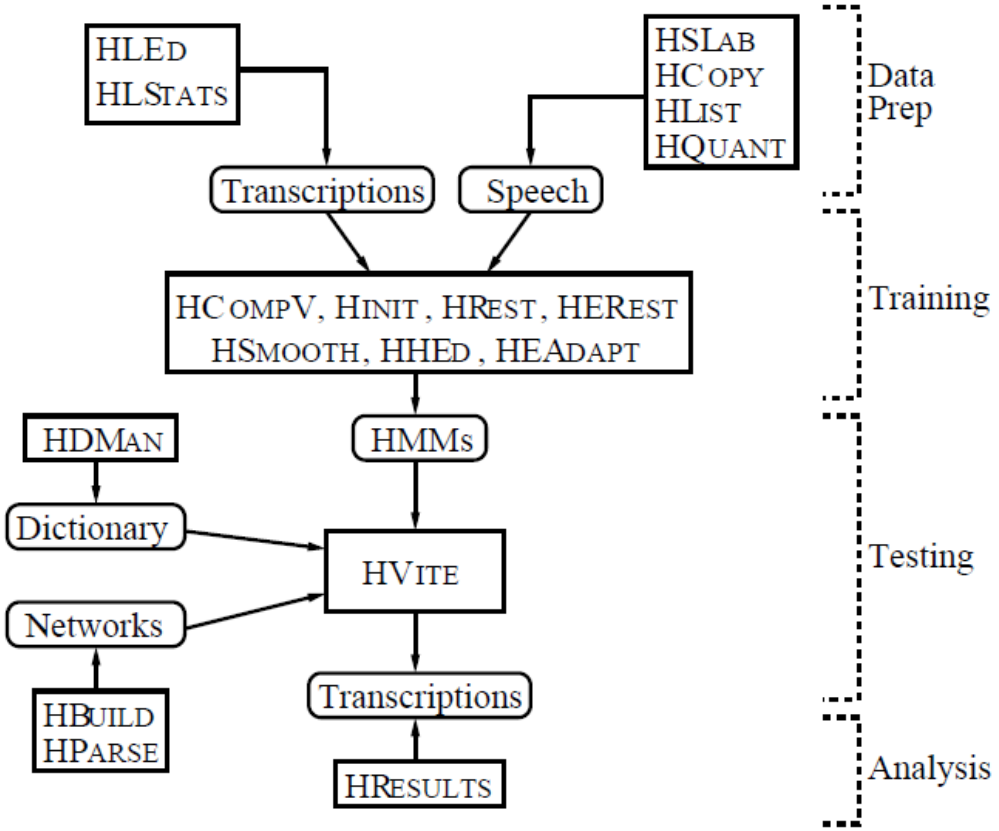
- HTK is a toolkit for building Hidden Markov Models
- HTK is primarily designed for building speech recognizers
  - Estimating HMM parameters from a set of training utterances
  - Transcribing unknown utterances



Available HTK tools

- Data preparation tools
  - Convert speech waveforms into parametric format (e.g. MFCC)
  - Convert the associated transcriptions into appropriate format (e.g., phone or word labels)
- Training
  - Define the topology of the HMMs (i.e., prototypes)
  - Initialize models (e.g., bootstrap, flat start)
  - Train models (e.g., parameter tying, Baum-Welch, adaptation)
- Testing
  - Viterbi based recognizer (HVite) – can also be used for forced alignment
  - Decoder for large vocabulary speech recognition (HDecode)
- Analysis
  - Evaluate model performance (e.g., WER, ROC, …)

HTK Processing Stages



Using HTK

- HTK consists of a set of tools to be run with a command-line interface
  - Each tool contains a set of required arguments and optional arguments
  - Optional arguments are always prefixed by a minus sign

```
HFoo -T 1 -f 34.3 -a -s myfile file1 file2
```

Optional arguments (4) Main arguments (2)

  - HTK tools can also be controlled by parameters in a configuration file

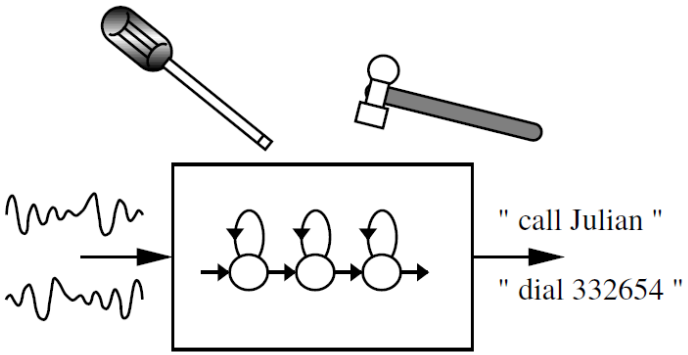
```
HFoo -C config1 -C config2 -f 34.3 -a -s myfile file1 file2
```

Configuration files (2)

Building an HTK recognizer

A tutorial example

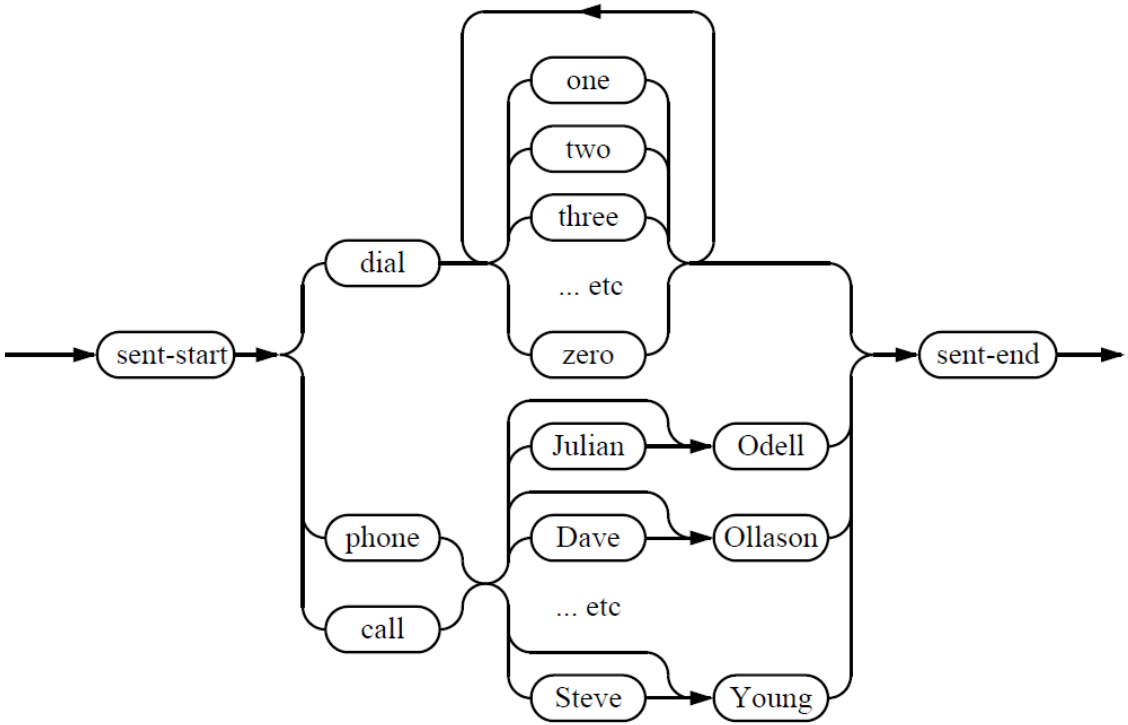
- For the remainder of this lecture, we will introduce HTK by constructing a recognizer for a simple voice dialing application
  - Corpus will consist of continuously spoken digits and proper names
  - Though the task is simple, the recognizer will be sub-word-based so it can be easily expanded
  - HMMs will be continuous Gaussian mixture tied-state triphone with clustering performed using phonetic decision trees



Data preparation

Step 1 – the Task Grammar

- Application: voice-operated interface for phone dialing
- ASR must handle digit strings and personal names such as
  - "Dial nine zero four one oh nine"
  - "Phone Woodland"
- HTK provides a grammar definition language for simple tasks, consisting of variable definitions and regular expressions
  - Vertical bars denote alternatives
  - Square brackets denote optional items
  - Angle braces denote one or more repetitions



gram

```
$digit = ONE | TWO | THREE | FOUR | FIVE |
         SIX | SEVEN | EIGHT | NINE | OH | ZERO;
$name  = [ JOOP ] JANSEN |
         [ JULIAN ] ODELL |
         [ DAVE ] OLLASON |
         [ PHIL ] WOODLAND |
         [ STEVE ] YOUNG;
( SENT-START ( DIAL <$digit> | (PHONE|CALL) $name) SENT-END )
```

– The HTK recognizer will require a word network, which can be created automatically from the grammar above using the HParse tool

```
HParse gram wdnet
```

  - where ‘gram’ contains the above grammar

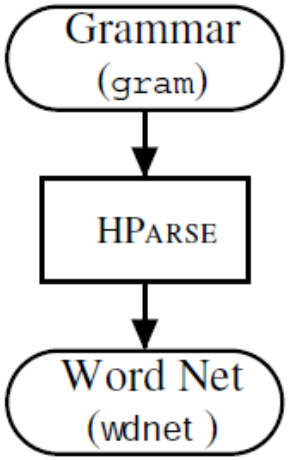


Fig. 3.2
Step 1

Step 2 – the Dictionary

- Create a sorted list of all required words (file ‘wlist’)
  - For our grammar, this can be done manually
- Obtain a pronunciation dictionary (file ‘beep’)
  - Publicly available; see p. 27 for URL
- The HTK tool HDMan will then create a new dictionary by finding pronunciations for each word in ‘wlist’

  HDMan -m -w wlist -n monophones1 -l dlog dict beep names
  - ‘names’: phonetic transcription of all proper names in our grammar
  - ‘global.ded’: edit script with additional commands (p. 27)
  - ‘monophones1’: list of phones used (output)
- The general format for each dictionary entry will be
  - `WORD [outsym] p1 p2 p3 ....`

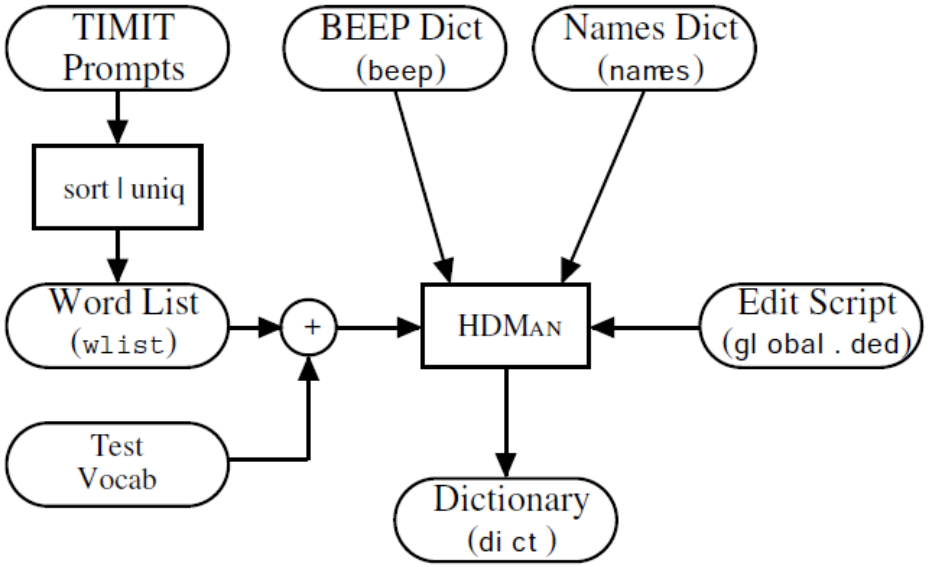

TIMIT
Prompts
BEEP Dict
(beep)
Names Dict
(names)
sort | uniq
Word List
(wlist)
+
HDMAN
Edit Script
(global.ded)
Test
Vocab
Dictionary
(dict)

Fig. 3.3 Step 2

Step 3 – Recording the Data

- Generate list of prompts for training and test sentences with HSGen

```
HSGen -l -n 200 wdnet dict > testprompts
```

  - which will randomly traverse the word network, generate 200 numbered utterances, and pipe them to file ‘testprompts’

- Record training and test sentences
  - You can use HTK tool HSLab or other audio recording program

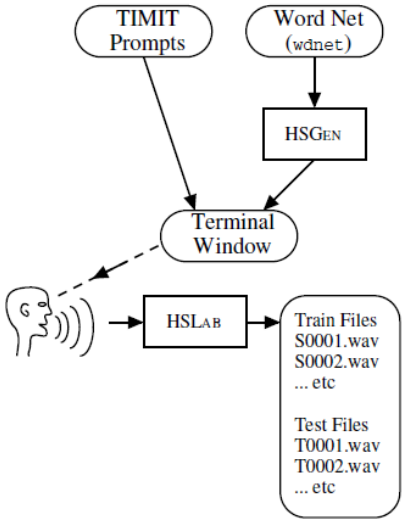


Fig. 3.4 Step 3

Step 4 – Creating the Transcription Files

- The first step is to create an orthographic transcription in HTK label format (MLF), which can be done with Perl script 'prompts2mlf'

```
prompts2mlf words.mlf trainingprompts
```

  - 'trainingprompts': list of training utterances
  - 'words.mlf': orthographic transcription (output)
    - This is an example of a Master Label File (MLF), a single file containing a complete set of transcriptions (HTK allows each individual transcription to be stored in its own file but it is more efficient to use an MLF)
- The second step is to generate phone-level MLFs, using HLEd

```
HLEd -l '*' -d dict -i phones0.mlf mkphones0.led words.mlf
```

  - 'phones0.mlf': phone-level transcription
  - 'mkphones0.led': edit script (see p. 30), which commands HLEd to
    - Replace every word in 'words.mlf' with its pronunciation in 'dict'
    - Insert a silence model at the start and end of every utterance, and
    - Delete all short-pause labels

trainingprompts

```
S0001 ONE VALIDATED ACTS OF SCHOOL DISTRICTS
S0002 TWO OTHER CASES ALSO WERE UNDER ADVISEMENT
S0003 BOTH FIGURES WOULD GO HIGHER IN LATER YEARS
S0004 THIS IS NOT A PROGRAM OF SOCIALIZED MEDICINE
etc
```

words.mlf

```
#!MLF!#
"*/S0001.lab"
ONE
VALIDATED
ACTS
OF
SCHOOL
DISTRICTS
.
"*/S0002.lab"
TWO
OTHER
CASES
ALSO
WERE
UNDER
ADVISEMENT
.
```

phones0.mlf

```
#!MLF!#
"*/S0001.lab"
sil
w
ah
n
v
ae
l
ih
d
.. etc
```

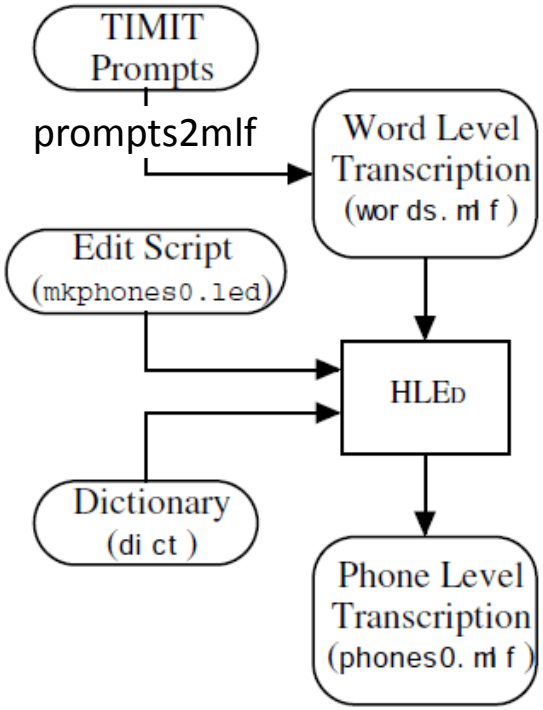


Fig. 3.5 Step 4

Step 5 – Coding the data

- The final stage of data preparation is to parameterize the speech into sequence of feature vectors
  - HTK supports both FFT-based and LPC-based analysis
  - Here we will use MFCCs
- Coding is performed with the HTK tool HCopy

```
HCopy -T 1 -C config -S codetr.scp
```

  - 'config': specifies all the conversion parameters
  - 'codetr.scp': script file, containing list of source files and their corresponding outputs
- The output is a separate MFCC file (*.mfc) for each audio file (*.wav) in the script file 'codetr.scp'

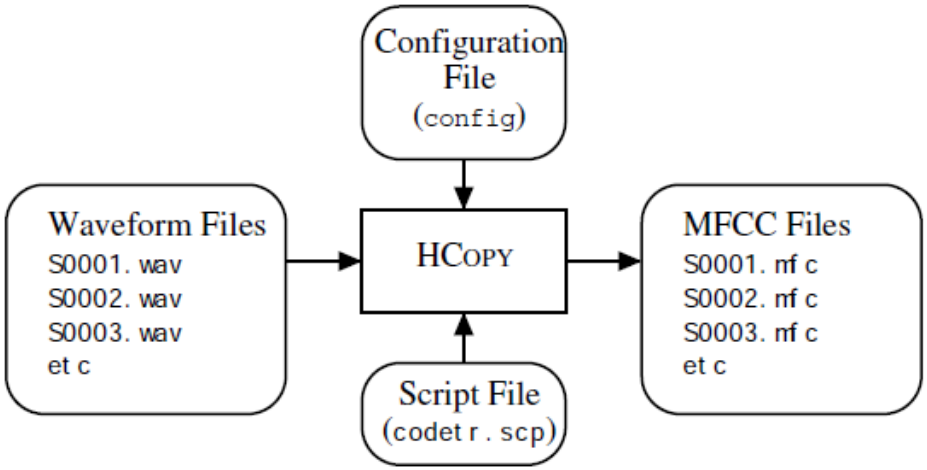


Fig. 3.6 Step 5

config

```
# Coding parameters
TARGETKIND = MFCC_0
TARGETRATE = 100000.0
SAVECOMPRESSED = T
SAVEWITHCRC = T
WINDOWSIZE = 250000.0
USEHAMMING = T
PREEMCOEF = 0.97
NUMCHANS = 26
CEPLIFTER = 22
NUMCEPS = 12
ENORMALISE = F
```

codetr.scp

```
/root/sjy/waves/S0001.wav /root/sjy/train/S0001.mfc
/root/sjy/waves/S0002.wav /root/sjy/train/S0002.mfc
/root/sjy/waves/S0003.wav /root/sjy/train/S0003.mfc
/root/sjy/waves/S0004.wav /root/sjy/train/S0004.mfc
```

Creating monophone HMMs

Introduction

- In this step, we create a set of identical monophone HMMs and train them, realign the training utterances, and retrain the HMMs

Step 6 – Creating flat-start HMMs

- Define prototype model containing HMM topology (file 'proto')
  - For phone-based systems, a 3-state left-right with no skips is appropriate
- Compute global mean and variance of data, and initialize HMM proto

  ```
  HCompV -C config -f 0.01 -m -S train.scp -M hmm0 proto
  ```

  - 'train.scp': script containing the list of all training WAV files
  - 'hmm0': directory where new HMM proto with global mean and variance will be saved
    - HCompV also creates file 'vFloor' containing a variance floor for the HMMs
- Manually generate two files and save them on 'hmm0'
  - 'macro': contains global-options macro and the variance floor macro generated earlier (see p. 34)
  - 'hmmdefs': contains a copy of 'proto' for each phoneme, including 'sil'

13 MFCC + Δ + Δ^2

proto

```
~o <VecSize> 39 <MFCC_0_D_A>
~h "proto"
 <BeginHMM>
  <NumStates> 5
  <State> 2
     <Mean> 39
       0.0 0.0 0.0 ...
     <Variance> 39
       1.0 1.0 1.0 ...
  <State> 3
     <Mean> 39
       0.0 0.0 0.0 ...
     <Variance> 39
       1.0 1.0 1.0 ...
  <State> 4
     <Mean> 39
       0.0 0.0 0.0 ...
     <Variance> 39
       1.0 1.0 1.0 ...
  <TransP> 5
   0.0 1.0 0.0 0.0 0.0
   0.0 0.6 0.4 0.0 0.0
   0.0 0.0 0.6 0.4 0.0
   0.0 0.0 0.0 0.7 0.3
   0.0 0.0 0.0 0.0 0.0
 <EndHMM>
```

macros

```
~o
   <VecSize> 39
   <MFCC_0_D_A>
~v "varFloor1"
   <Variance> 39
      0.0012 0.0003 ...
```

hmmdefs

```
~h "aa"
   <BeginHMM> ...
   <EndHMM>
~h "eh"
   <BeginHMM> ...
   <EndHMM>
... etc
```

– Re-estimate flat-start monophone HMMs in directory ‘hmm0’

```
HERest -C config -I phones0.mlf -t 250.0 150.0 1000.0 -S
train.scp -H hmm0/macros -H hmm0/hmmdefs -M hmm1 monophones0
```

- ‘monophones0’: same as ‘monophones1’ without short-pause (sp)
- Results will be saved in new directory ‘hmm1’

– Repeat HERest twice more, generating directories ‘hmm2’ and ‘hmm3’

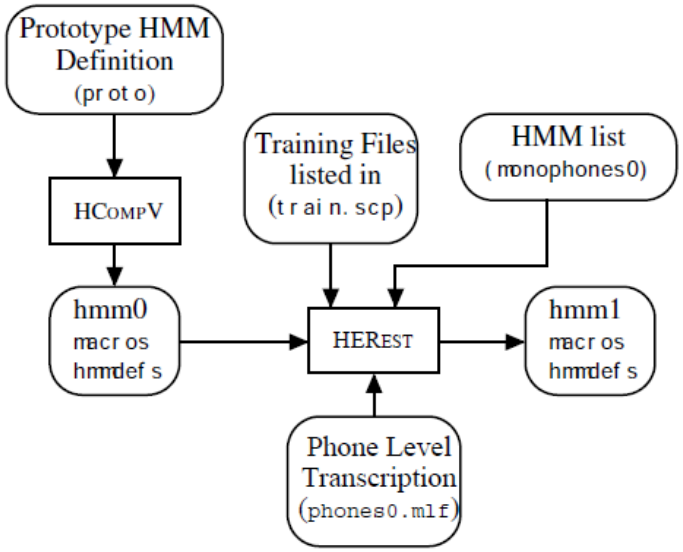


Fig. 3.8 Step 6

Step 7 – Fixing the Silence Models

- In this step, we make the models more robust by
  - Adding transitions to/from states 2 and 4 in the silence model,
  - Creating a 1-state short pause (sp) model tied to the center state of 'sil'
- This is done in two steps
  - Manually edit 'hmm3/hmmdefs' to add a new (sp) model, and save it in a new directory 'hmm4' (see p. 35)
  - Run tool HHEd to add extra transitions and tie the (sp) model

```
HHEd -H hmm4/macros -H hmm4/hmmdefs -M hmm5 sil.hed
monophones1
```

  - 'sil.hed': script containing code to add transitions and tie states
- Repeat HERest twice more, generating directories 'hmm6' and 'hmm7'

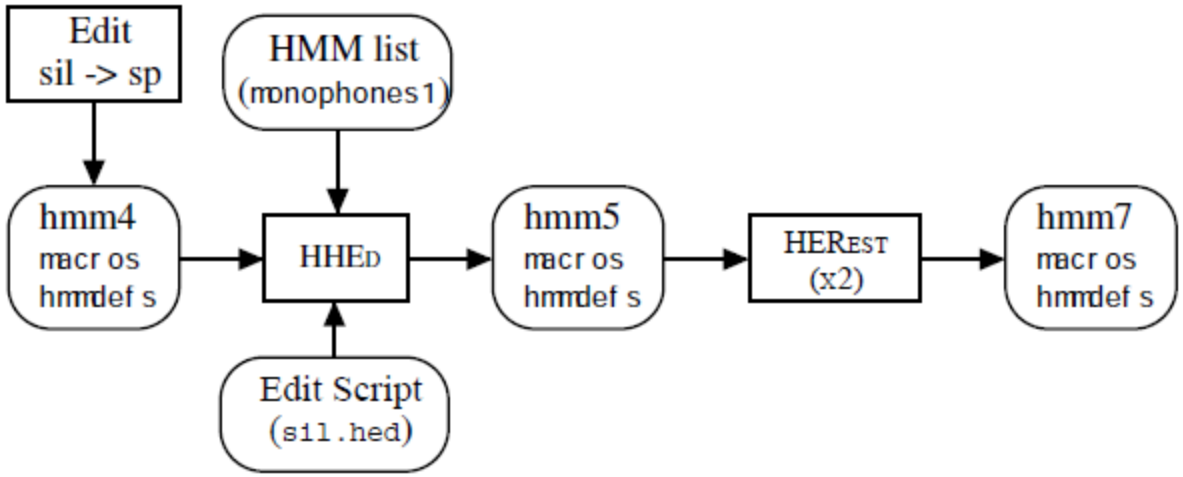


Fig. 3.10 Step 7

Step 8 – Realigning the Training Data

– Realign training data and create new transcriptions

```
HVite -l '*' -o SWT -b silence -C config -a -H hmm7/macros -H
hmm7/hmmdefs -i aligned.mlf -m -t 250.0 -y lab -I words.mlf -S
train.scp dict monophones1
```

- 'aligned.mlf': will contain the realigned utterances, in this case considering the best fit of all possible pronunciations in the dictionary
- Before doing this, we will need to manually insert an entry 'silence sil' at the end of the dictionary file 'dict'

– Repeat HERest twice more, generating directories 'hmm8' and 'hmm9'

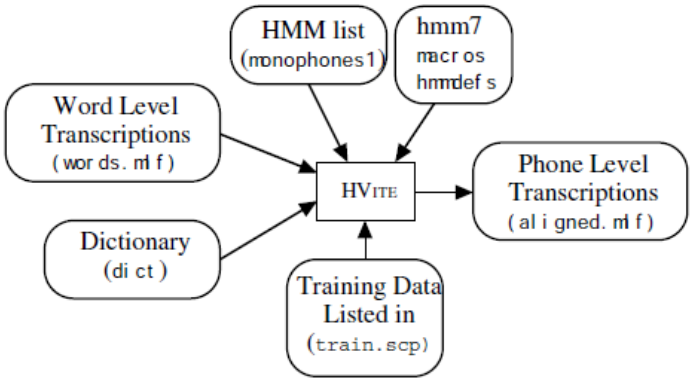


Fig. 3.11 Step 8

Creating Tied-State Triphones

Introduction

- The last step of model building is to transform the monophone HMMs into context-dependent triphone HMMs, which is done in two steps
  - First, convert monophone transcriptions into triphone transcriptions, create a new set of triphones (by copying monophones), and reestimating
  - Second, tie similar acoustic states (to ensure robust estimation)

Step 9 – Making Triphones from Monophones

- Generate triphones transcriptions for training data

```
HLEd -n triphones1 -l '*' -i wintri.mlf mktri.led aligned.mlf
```

  - 'mktri.led': edit script explaining how to handle pauses (p. 38)
  - 'wintri.mlf': word-internal triphone transcriptions (output)
  - 'triphones1': list of triphones (output)

– Generate context-dependent triphones by cloning monophones

```
HHEd -B -H hmm9/macros -H hmm9/hmmdefs -M hmm10 mktri.hed
monophones1
```

- ‘mktri.hed’: edit script describing the procedure for HHEd (p. 39)

– Reestimate (twice) the triphone set with HERest

```
HERest -B -C config -I wintri.mlf -t 250.0 150.0 1000.0 -s
stats -S train.scp -H hmm11/macros -H hmm11/hmmdefs -M hmm12
triphones1
```

- ‘stats’: state occupation statistics (output), to be used during the state-clustering process (step 10)

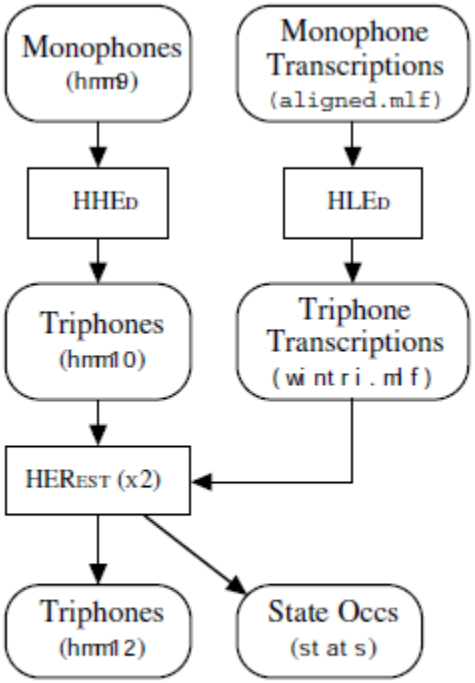


Fig. 3.13 Step 9

Step 10 – Making Tied-State Triphones

- The last step in model building is to tie states within triphone sets in order to share data and make robust parameter estimates

- Here we use a method based on decision trees, which is based on asking questions about the left and right context of each triphone

```
HHEd -B -H hmm12/macros -H hmm12/hmmdefs -M hmm13 tree.hed
triphones1 > log
```

  - 'tree.hed': edit script describing which context to examine and what results to save in output files (p. 41)

– Prior to executing HHEd, we will need to generate a list of all possible triphones on the entire dictionary, not just those on the training set (this is needed for recognition purposes)

```
HDMan -b sp -n fulllist -g global.ded -l flog beep-tri beep
```

- ‘global.ded’: global command TC (p. 42)
- ‘fulllist’: full list of all triphones (output)
- ‘beep-tri’: triphone transcription of all words in grammar (output)
- ‘tiedlist’: list of all tied states (output)
- ‘trees’: list of all trees (output)

– Repeat HERest twice more, generating directories ‘hmm14’ and ‘hmm15’

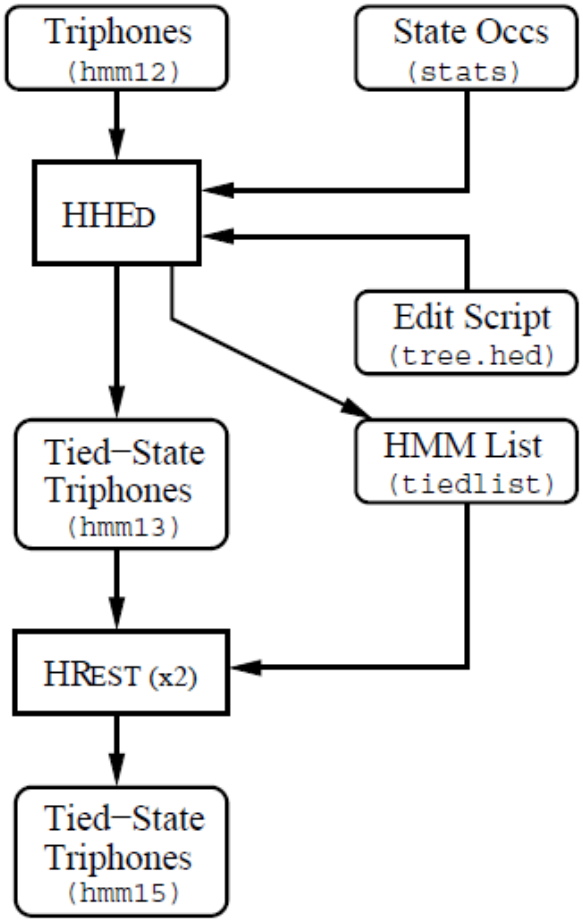


Fig. 3.14 Step 10

Recognizer evaluation

Step 11 – Recognizing the Test Data

– First, run the recognizer on test data

```
HVite -C config -H hmm15/macros -H hmm15/hmmdefs -S test.scp -
l '*' -i recout.mlf -w wdnet -p 0.0 -s 5.0 dict tiedlist
```

- ‘config’: configuration file to allow word-internal expansion (p. 43)
- ‘test.scp’: list of test files (MFC)
- ‘recout.mlf’: transcription output

– Finally, compare recognizer output against ground truth

```
HResults -I testref.mlf tiedlist recout.mlf
```

- ‘testref.mlf’: word-level transcription for each test file (ground truth)

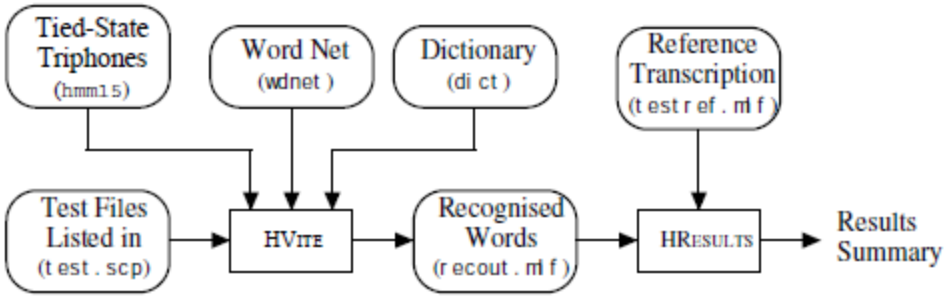


Fig. 3.15 Step 11