HTK Tutorial

DT2118
Speech and Speaker Recognition

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Outline

Outline

HTK, What is it?

- A toolkit for Hidden Markov Modeling
- General purpose, but optimized for Speech Recognition
- Flexible and complete (active development)
- Good documentation (HTKBook)
- Free, but not distributable (special license)
- works on Unix (Linux), Windows, Mac OS X

Short History

`http://htk.eng.cam.ac.uk/docs/history.shtml`

- 1989 first developed by Steve Young at Cambridge Univ.
- 1992 sold by Lynxvale (Cambridge Univ.)
- 1993 Entropic Research Lab. took over
- 1999 Microsoft bought Entropic and licensed HTK back to Cambridge Univ.

How to get it?

From the net:

1. sign up and download from `http://htk.eng.cam.ac.uk`
2. unzip and follow instructions in `README`

On our computers at CSC/KTH:

```
module use /afs/nada.kth.se/dept/tmh/hacks/modules
module add htk
```

or

```
module initadd htk
```

...and start a new shell

Commands

Cluster	HInit	HParse	HVite	LLink
HBuild	HLEd	HQuant	LAdapt	LMerge
HCompV	HList	HRest	LBuild	LNewMap
HCopy	HLMCopy	HResults	LFoF	LNorm
HDMan	HLRescore	HSGen	LGCopy	LPlex
HERest	HLStats	HSLab	LGList	LSubset
HHEd	HMMIRest	HSmooth	LGPrep	

Additional requirements

- familiarity with Unix-like shell
  - `cd`, `ls`, `pwd`, `mkdir`, `cp`, `foreach`...
- text processing tools:
  - `perl`!
  - `grep`, `gawk`, `tr`, `sed`, `find`, `cat`, `wc`...
- lots of patience
- the **HTK Book**

Outline

Usage example (HList)

```
> HList

USAGE: HList [options] file ...

 Option                                                  Default

 -d       Coerce observation to VQ symbols               off
 -e N     End at sample N                                0
 -h       Print source header info                       off
 -i N     Set items per line to N                        10
 -n N     Set num streams to N                           1
 -o       Print observation structure                    off
 -p       Playback audio                                 off
 -r       Write raw output                               off
 -s N     Start at sample N                              0
 -t       Print target header info                       off
 -z       Suppress printing data                         on
 -A       Print command line arguments                   off
 -C cf    Set config file to cf                          default
 -D       Display configuration variables                off
...
```

Command line switches and options

```
> HList -e 1 -o -h feature_file

 Source: feature_file
  Sample Bytes:  26       Sample Kind:   MFCC_0
  Num Comps:     13       Sample Period: 10000.0 us
  Num Samples:   336      File Format:   HTK
------------------- Observation Structure --------------------
x:      MFCC-1  MFCC-2  MFCC-3  MFCC-4  MFCC-5  MFCC-6  MFCC-7
        MFCC-8  MFCC-9 MFCC-10 MFCC-11 MFCC-12      C0
------------------------ Samples: 0->1 -------------------------
0:    -14.314  -3.318  -6.263  -7.245   7.192   4.997   0.830
        3.293   5.428   6.831   5.819   5.606  40.734
1:    -13.591  -4.756  -6.037  -3.362   3.541   3.510   2.867
        0.812   0.630   5.285   1.054   8.375  40.778
---------------------------- END ----------------------------
```

Configuration file

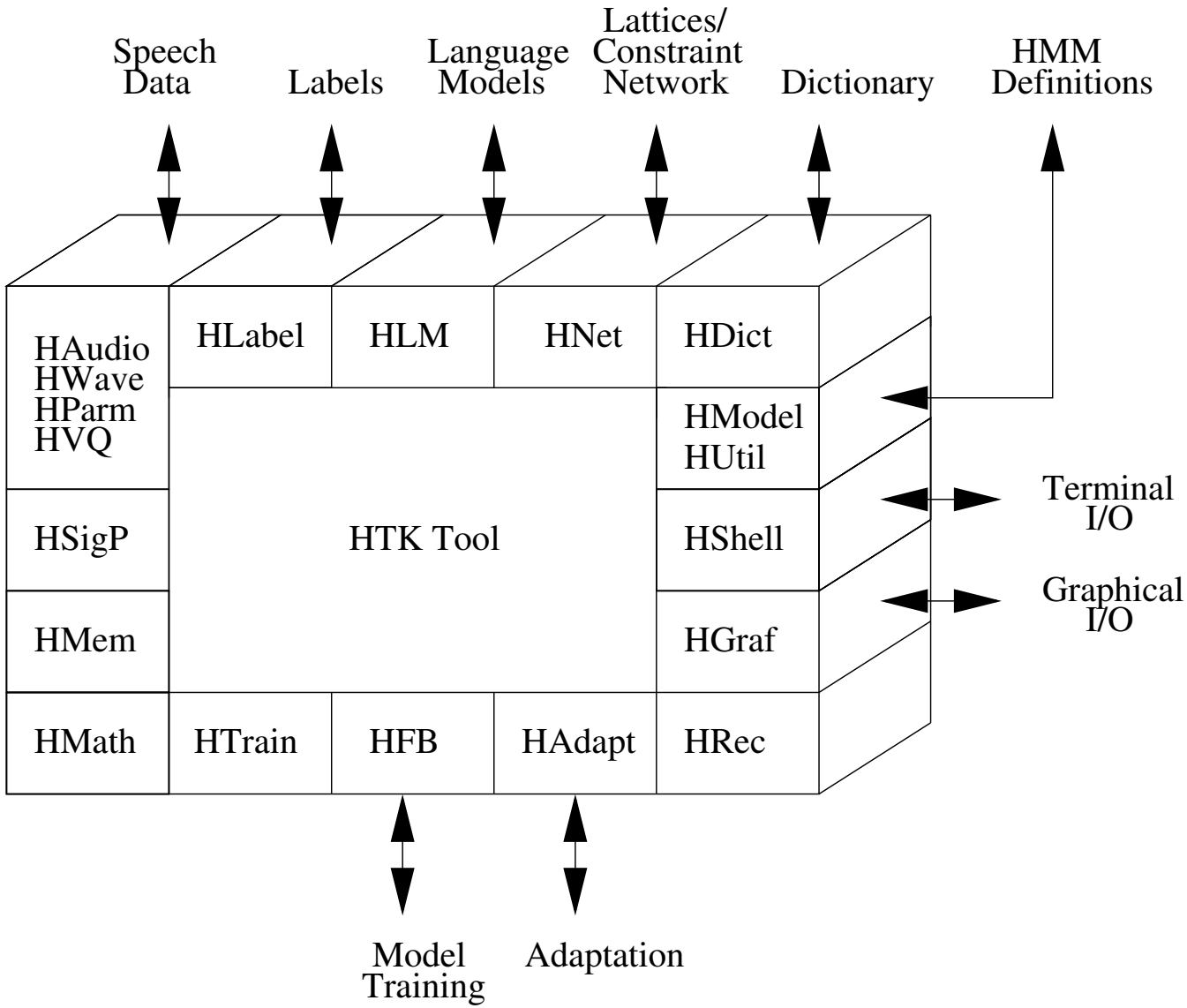
```
> cat config_file

SOURCEKIND = MFCC_0
TARGETKIND = MFCC_0_D_A

> HList -C config_file -e 0 -o -h feature_file

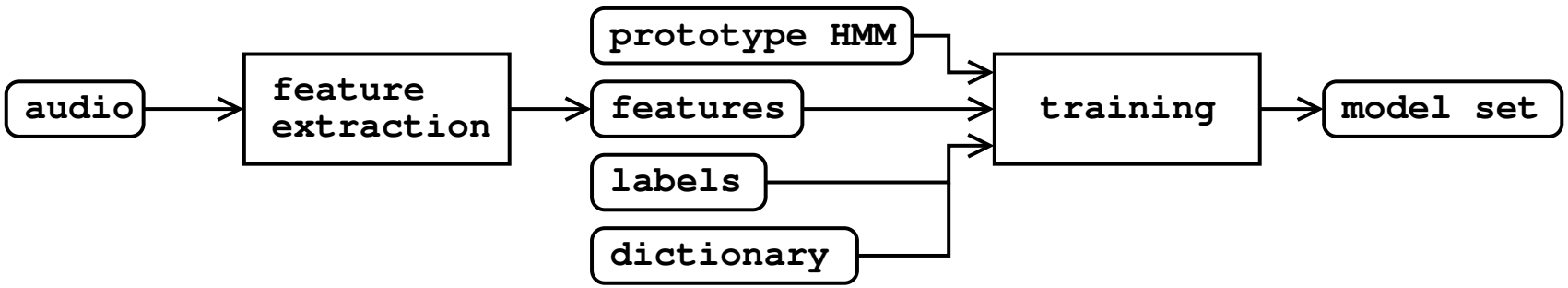
 Source: feature_file
  Sample Bytes:  26        Sample Kind:   MFCC_0
  Num Comps:     13        Sample Period: 10000.0 us
  Num Samples:   336       File Format:   HTK
-------------------- Observation Structure --------------------
x:      MFCC-1  MFCC-2  MFCC-3  MFCC-4  MFCC-5  MFCC-6  MFCC-7
        MFCC-8  MFCC-9 MFCC-10 MFCC-11 MFCC-12      C0   Del-1
         Del-2   Del-3   Del-4   Del-5   Del-6   Del-7   Del-8
         Del-9  Del-10  Del-11  Del-12   DelC0   Acc-1   Acc-2
         Acc-3   Acc-4   Acc-5   Acc-6   Acc-7   Acc-8   Acc-9
        Acc-10  Acc-11  Acc-12   AccC0
------------------------ Samples: 0->1 ------------------------
0:    -14.314  -3.318  -6.263  -7.245   7.192   4.997   0.830
        3.293   5.428   6.831   5.819   5.606  40.734  -0.107
       -0.180   0.731   1.134  -0.723  -0.676   1.083  -0.552
       -0.387  -0.592  -2.172  -0.030  -0.170   0.236   0.170
       -0.241  -0.226  -0.517  -0.244  -0.053   0.213  -0.029
        0.097   0.225  -0.294   0.051
--------------------------- END ---------------------------
```

Software Architecture

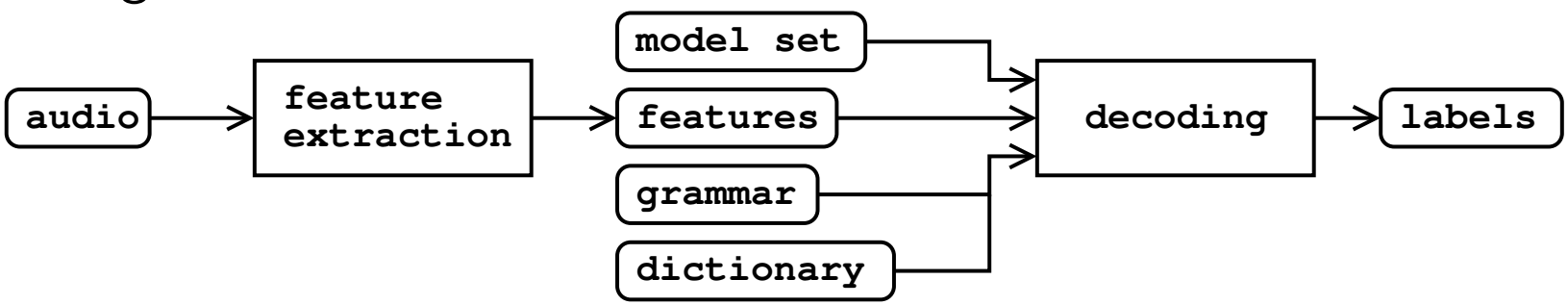


ASR Overview

Training



Recognition



The HTK tools

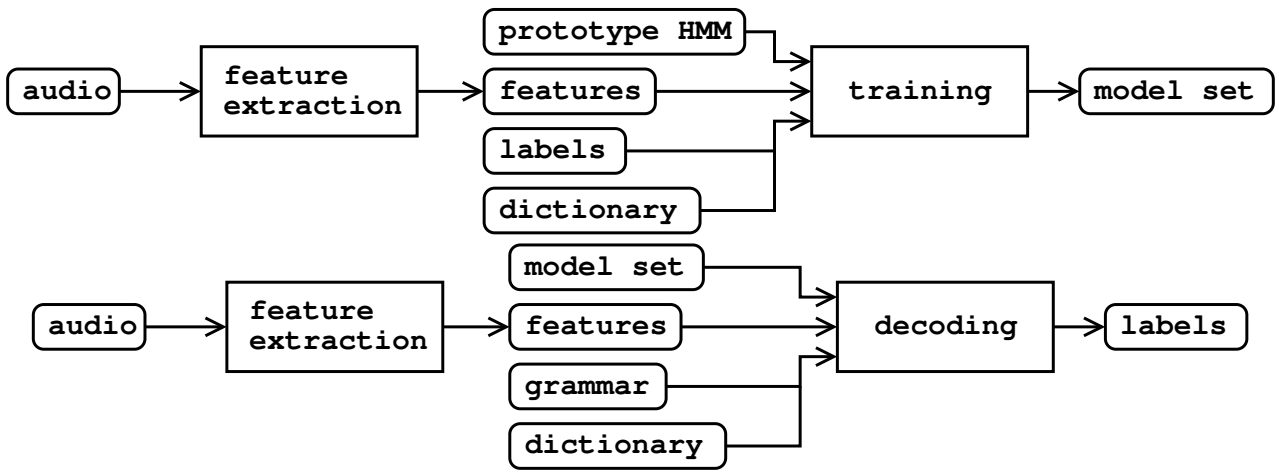
- data manipulation tools:
  `HCopy HQuant HLEd HHEd HDMan HBuild HParse`
- data visualization tools:
  `HSLab HList HSGen`
- training tools:
  `Cluster HCompV HInit HRest HERest HSmooth HMMIRest`
- recognition and evaluation tools:
  `HVite HResults HLRescore`
- statistical language modeling tools:
  `HLStats HLMCopy LAdapt LBuild LFoF LGCopy LGList LGPrep LLink LMerge LNewMap LNorm LPlex LSubset`

Outline

The HTK data formats

data formats:

audio:	many common formats plus HTK	binary
features:	HTK	binary
labels:	HTK (single or *Master Label* files)	text
models:	HTK (single or *Master Macro* files)	text or binary
other:	HTK	text



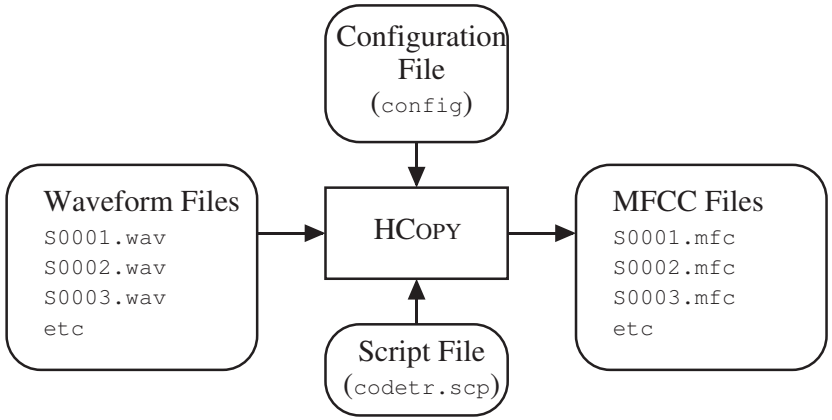
File manipulation tools

- `HCopy`: converts from/to various data formats (audio, **features**).
- `HQuant`: quantizes speech (audio).
- `HLEd`: edits label and **master label files**.
- `HDMan`: edits **dictionary files**.
- `HHEd`: edits model and **master macro files**.
- `HBuild`: converts language models in different formats (more in recognition section).

Computing feature files (HCopy)

```
> cat config_file
```

```
# Feature configuration
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
# input file format (headerless 8 kHz 16 bit linear PCM)
SOURCEKIND = WAVEFORM
SOURCEFORMAT = NOHEAD
SOURCERATE = 1250
```




```
> HCopy -C config_file audio_file1 param_file1 audio_file2 ...
> HCopy -C config_file -S file_list
```

Label file example 1

```
> cat aligned.mlf

#!MLF!#
"*/a10001a1.rec"
        0  6400000 sil    <sil>
 6400000  8600000 f      förra
 8600000 10400000 oe
10400000 11700000 r
11700000 14100000 a
14100000 14100000 sp
14100000 29800001 sil    <sil>
.
"*/a10001i1.rec"
        0  2600000 sil    <sil>
 2600000  4900000 S      sju
 4900000  8300000 uh:
 8300000  8600000 a
 8600000  8600000 sp
 8600000 21600000 sil    <sil>
.
```

Label files

```
#!MLF!#
"filename1"
  [start1 [end1]]    label1 [score]    {auxlabel [auxscore]}    [comment]
  [start2 [end2]]    label2 [score]    {auxlabel [auxscore]}    [comment]
  ...
  [startN [endN]]    labelN [score]    {auxlabel [auxscore]}    [comment]
.
"filename2"
  ...
.
```

- `[.]` = optional (0 or 1);
- `{.}` = possible repetition (0, 1, 2...)
- time stamps are in 100ns units (!?): 10ms = 100.000

Label file example 2 (HLEd)

```
> HLEd -l '*' -d lex.dic -i phones.mlf words2phones.led words.mlf
```

```
> cat words.mlf

#!MLF!#
"*/a10001a1.rec"
förra
.
"*/a10001i1.rec"
sju
.
```

```
> cat words2phones.led

EX
IS sil sil
```

```
> cat phones.mlf

#!MLF!#
"*/a10001a1.rec"
sil
f
oe
r
a
sp
sil
.
"*/a10001i1.rec"
sil
S
uh:
a
sp
sil
.
```

Dictionary (HDMan)

```
WORD [OUTSYM] PRONPROB P1 P2 P3 P4 ...
```

```
> cat lex.dic

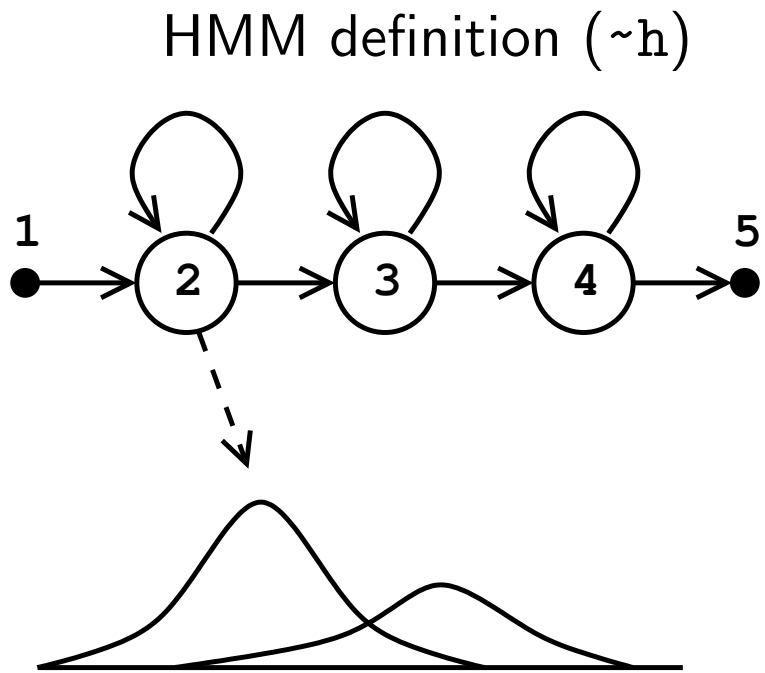
förra    f oe r a sp
sju      S uh: a sp
```

```
> cat lex2.dic

<sil>    [] sil
förra    f oe r a sp
sju      0.3 S uh: a sp
sju      0.7 S uh: sp
```

HMM definition files (HHEd)

```
~h "hmm_name"
<BEGINHMM>
  <NUMSTATES> 5
  <STATE> 2
    <NUMMIXES> 2
    <MIXTURE> 1 0.8
      <MEAN> 4
        0.1 0.0 0.7 0.3
      <VARIANCE> 4
        0.2 0.1 0.1 0.1
    <MIXTURE> 2 0.2
      <MEAN> 4
        0.2 0.3 0.4 0.0
      <VARIANCE> 4
        0.1 0.1 0.1 0.2
  <STATE> 3
    ~s "state_name"
  <STATE> 4
    <NUMMIXES> 2
    <MIXTURE> 1 0.7
      ~m "mix_name"
    <MIXTURE> 2 0.3
      <MEAN> 4
        ~u "mean_name"
      <VARIANCE> 4
        ~v "variance_name"
  <TRANSP>
    ~t "transition_name"
<ENDHMM>
```



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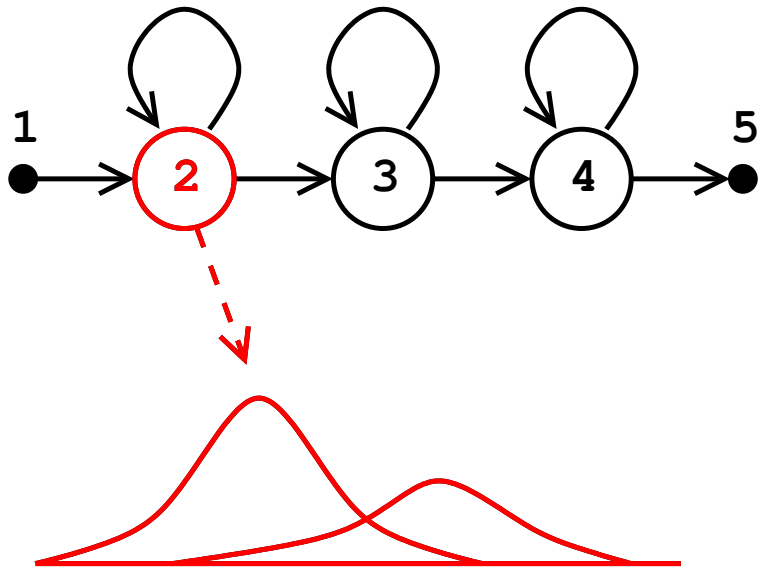
<BEGINHMM>
  <NUMSTATES> 5
  <STATE> 2
    <NUMMIXES> 2
    <MIXTURE> 1 0.8
      <MEAN> 4
        0.1 0.0 0.7 0.3
      <VARIANCE> 4
        0.2 0.1 0.1 0.1
    <MIXTURE> 2 0.2
      <MEAN> 4
        0.2 0.3 0.4 0.0
      <VARIANCE> 4
        0.1 0.1 0.1 0.2
  <STATE> 3
    ~s "state_name"
  <STATE> 4
    <NUMMIXES> 2
    <MIXTURE> 1 0.7
      ~m "mix_name"
    <MIXTURE> 2 0.3
      <MEAN> 4
        ~u "mean_name"
      <VARIANCE> 4
        ~v "variance_name"
  <TRANSP>
    ~t "transition_name"
<ENDHMM>
```

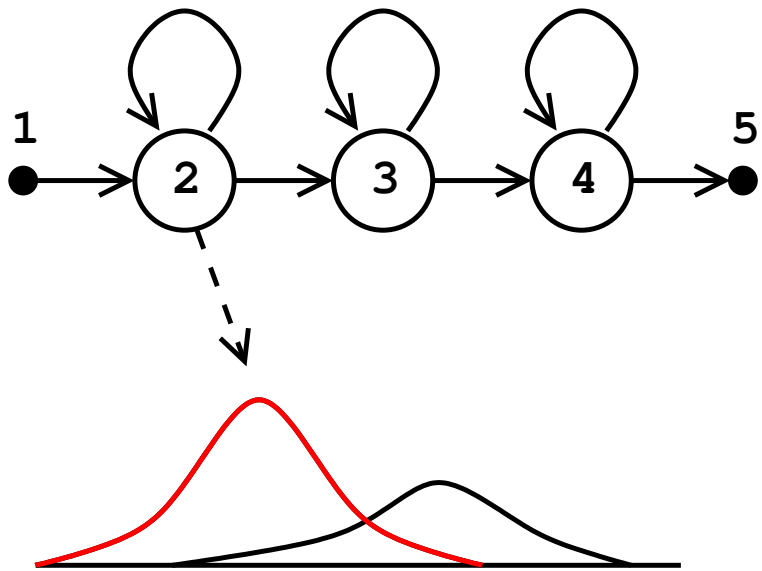
State definition (~s)



HMM definition files (HHEd)

```
~h "hmm_name"
<BEGINHMM>
  <NUMSTATES> 5
  <STATE> 2
    <NUMMIXES> 2
    <MIXTURE> 1 0.8
      <MEAN> 4
        0.1 0.0 0.7 0.3
      <VARIANCE> 4
        0.2 0.1 0.1 0.1
    <MIXTURE> 2 0.2
      <MEAN> 4
        0.2 0.3 0.4 0.0
      <VARIANCE> 4
        0.1 0.1 0.1 0.2
  <STATE> 3
    ~s "state_name"
  <STATE> 4
    <NUMMIXES> 2
    <MIXTURE> 1 0.7
      ~m "mix_name"
    <MIXTURE> 2 0.3
      <MEAN> 4
        ~u "mean_name"
      <VARIANCE> 4
        ~v "variance_name"
  <TRANSP>
    ~t "transition_name"
<ENDHMM>
```

Gaussian mixture component definition (~m)

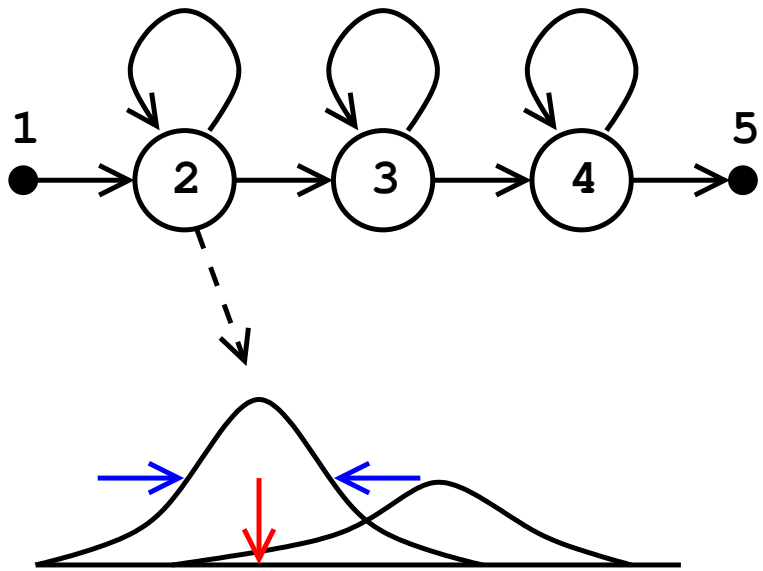


HMM definition files (HHEd)

```
~h "hmm_name"
<BEGINHMM>
  <NUMSTATES> 5
  <STATE> 2
    <NUMMIXES> 2
    <MIXTURE> 1 0.8
      <MEAN> 4
        0.1 0.0 0.7 0.3
      <VARIANCE> 4
        0.2 0.1 0.1 0.1
    <MIXTURE> 2 0.2
      <MEAN> 4
        0.2 0.3 0.4 0.0
      <VARIANCE> 4
        0.1 0.1 0.1 0.2
  <STATE> 3
    ~s "state_name"
  <STATE> 4
    <NUMMIXES> 2
    <MIXTURE> 1 0.7
      ~m "mix_name"
    <MIXTURE> 2 0.3
      <MEAN> 4
        ~u "mean_name"
      <VARIANCE> 4
        ~v "variance_name"
  <TRANSP>
    ~t "transition_name"
<ENDHMM>
```

Mean vector definition (~u)

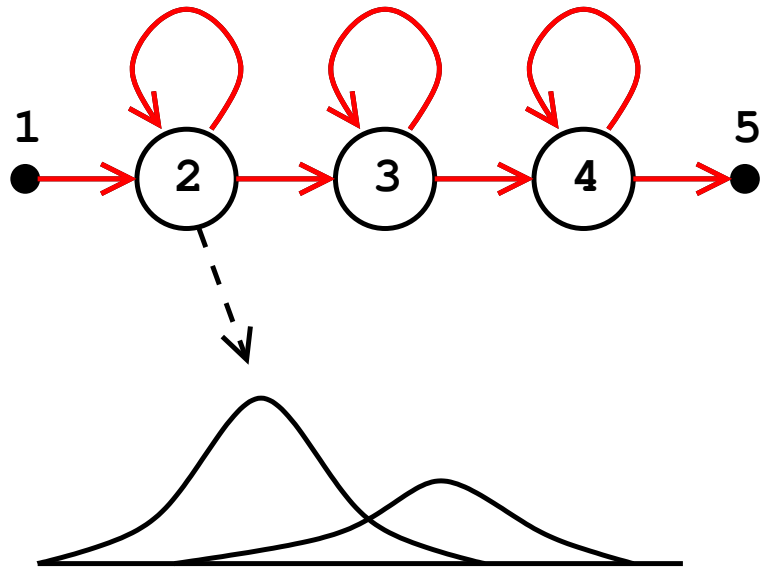
Diagonal variance vector definition (~v)



HMM definition files (HHEd)

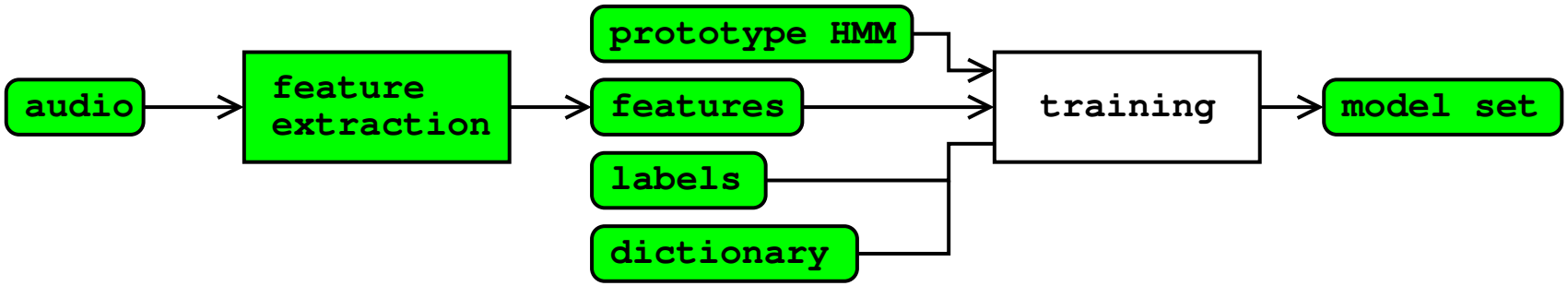
```
~h "hmm_name"
<BEGINHMM>
  <NUMSTATES> 5
  <STATE> 2
    <NUMMIXES> 2
    <MIXTURE> 1 0.8
      <MEAN> 4
        0.1 0.0 0.7 0.3
      <VARIANCE> 4
        0.2 0.1 0.1 0.1
    <MIXTURE> 2 0.2
      <MEAN> 4
        0.2 0.3 0.4 0.0
      <VARIANCE> 4
        0.1 0.1 0.1 0.2
  <STATE> 3
    ~s "state_name"
  <STATE> 4
    <NUMMIXES> 2
    <MIXTURE> 1 0.7
      ~m "mix_name"
    <MIXTURE> 2 0.3
      <MEAN> 4
        ~u "mean_name"
      <VARIANCE> 4
        ~v "variance_name"
  <TRANSP>
    ~t "transition_name"
<ENDHMM>
```

Transition matrix definition (~t)

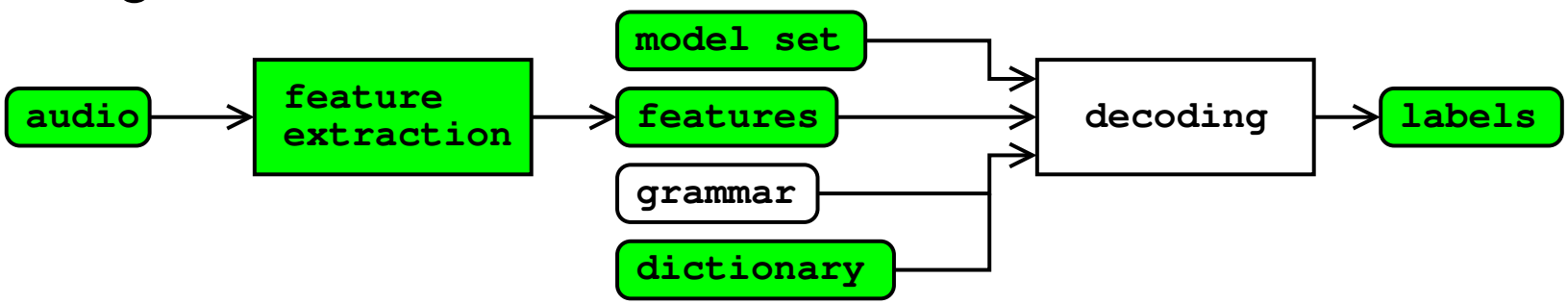


What do we know so far?

Training



Recognition



Outline

Training: different levels of supervision

- sentence
- words
- phonemes
- states
- Gaussian mixture component

Model initialization

Initialization procedure depends on the information avaliable at that time.

- `HCompV`: computes the overall mean and variance.
  Input: a prototype HMM.
- `HInit`: Viterbi segmentation + parameter estimation. For mixture distribution uses K-means.

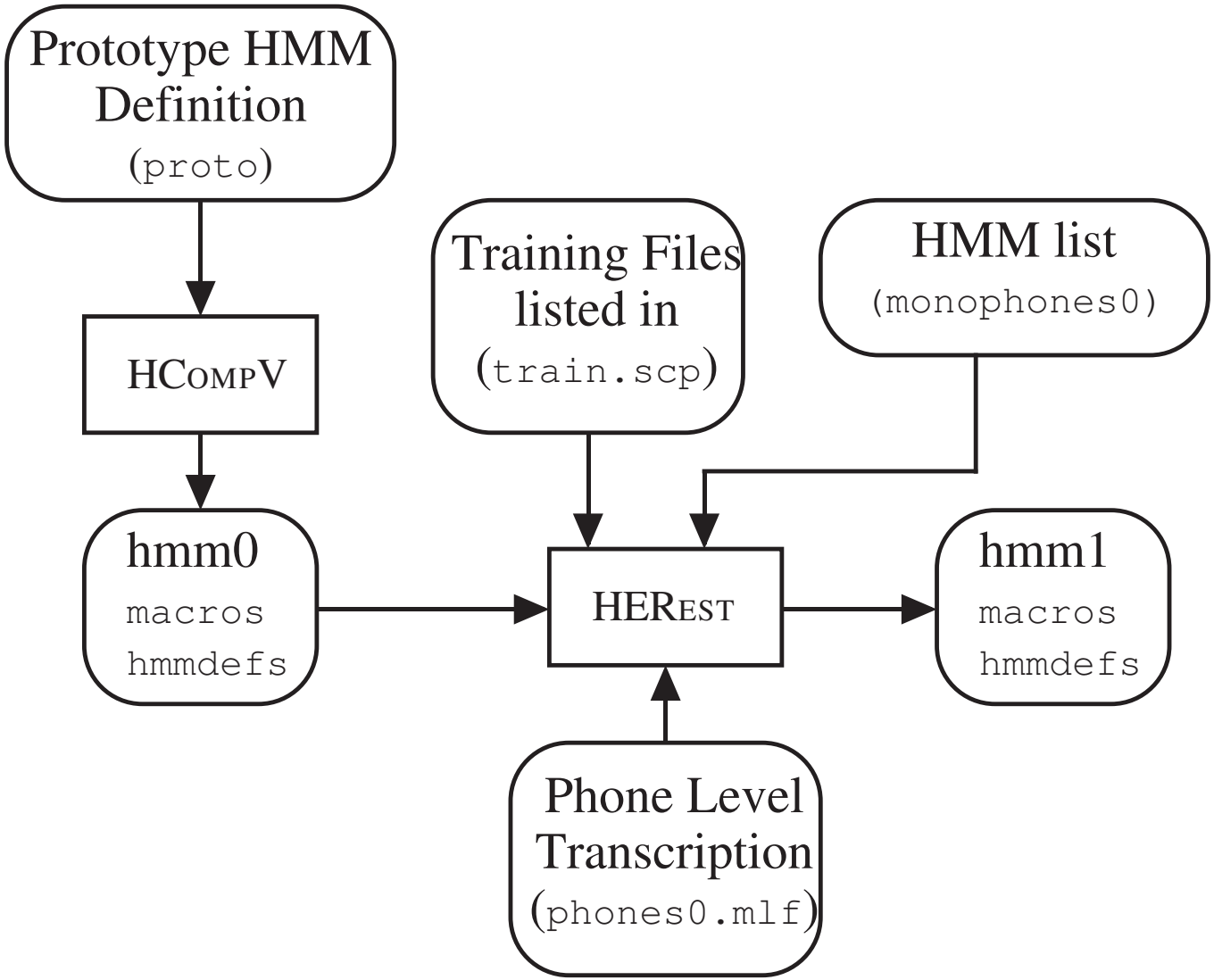
  Input: a prototype HMM, time aligned transcriptions.

Traning tools

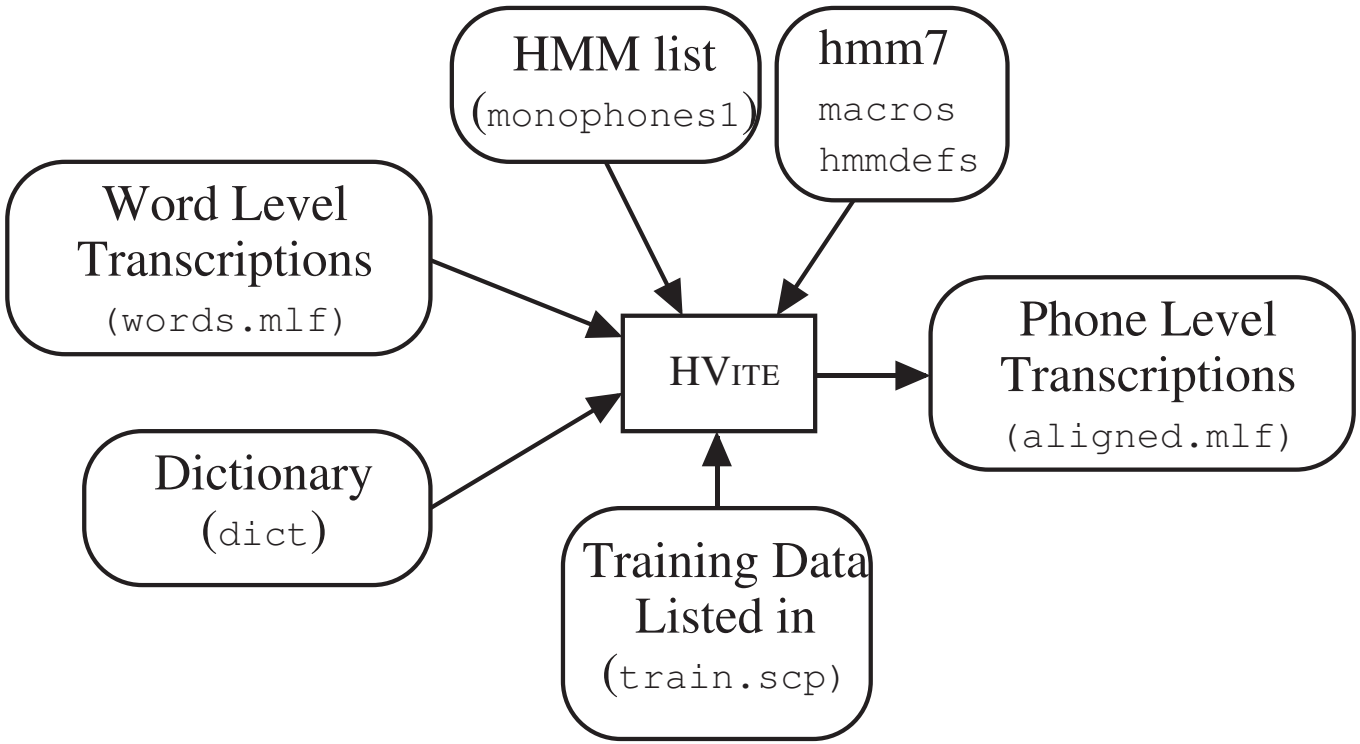
- `HRest`: Baum-Welch re-estimation.

  Input: an initialized model set, time aligned transcriptions.
- `HERest`: performs *embedded* Baum-Welch training.
  Input: an initialized model set, timeless transcriptions.
- `HEAdapt`: performs adaptation on a limited set of data.
- `HSmooth`: smoots a set of context-dependent models according to the context-independent counterpart.

Training with no time-aligned phonetic transcriptions



Generating time-aligned phonetic transcriptions



Training with time-aligned phonetic transcriptions

Instead of `HCompV -> HERest`

`HInit -> HRest -> HERest`

Outline

Recognition tools

grammar generation

- `HLStats`: creates bigram from training data.
- `HParse`: parses a user defined grammar to produce a *lattice*.

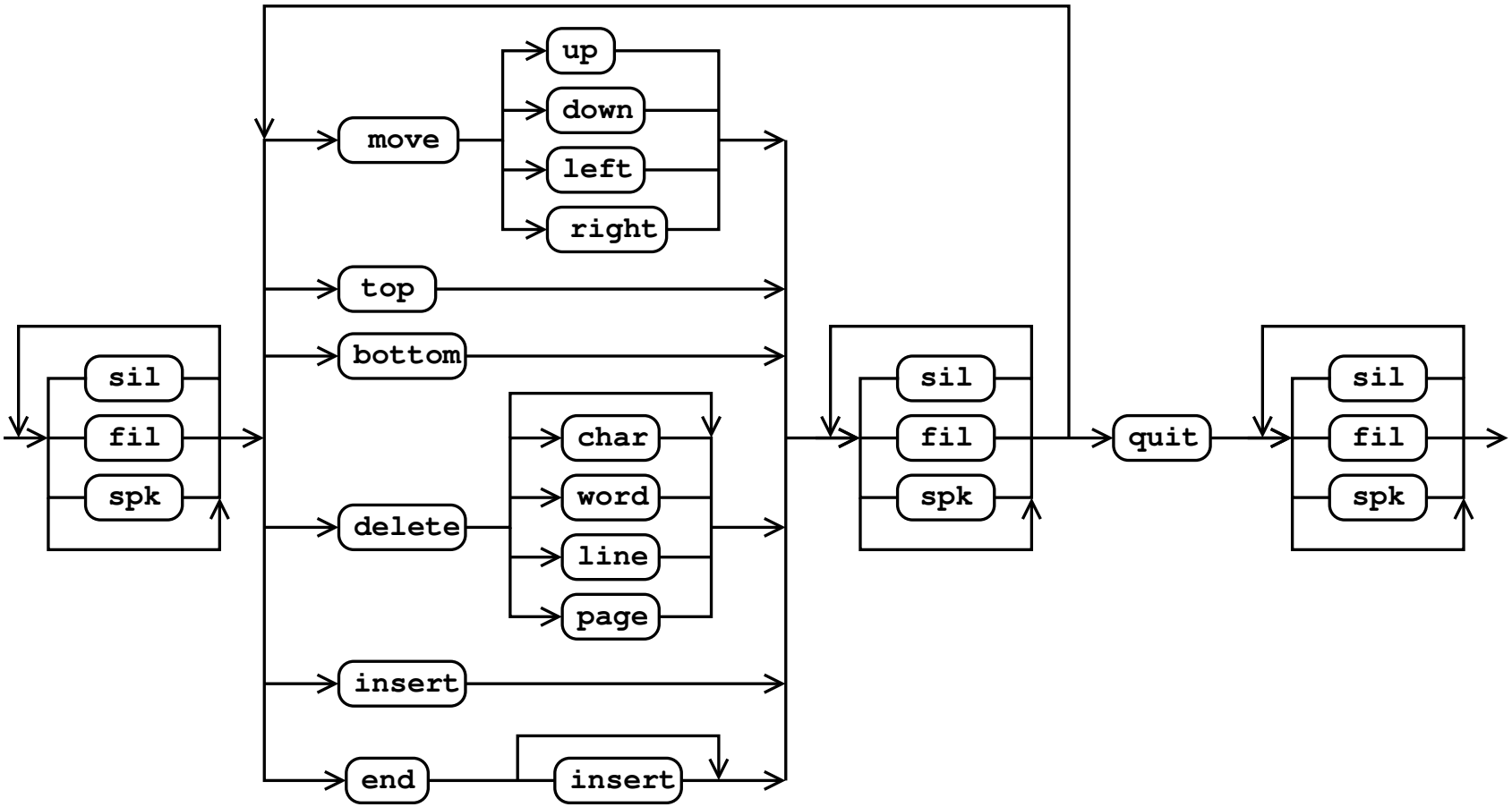
decoding

- `HVite`: performs Viterbi decoding.

evaluation

- `HResults`: evaluates recognition results.

Grammar definition (HParse)



Grammar definition (HParse)

```
> cat grammar.bnf
$dir  = up | down | left | right;
$mcmd = move $dir | top | bottom;
$item = char | word | line | page;
$dcmd = delete [$item];
$icmd = insert;
$ecmd = end [insert];
$cmd  = $mcmd | $dcmd | $icmd | $ecmd;
$noise     = sil | fil | spk;
({$noise} < $cmd $noise > quit {$noise})
```

- `[.]` optional (zero or one)
- `{.}` zero or more
- `(.)` block
- `<.>` loop
- `<<.>>` context dep. loop
- `.|.` alternative

Grammar definition (HParse)

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> cat grammar.bnf
$dir  = up | down | left | right;
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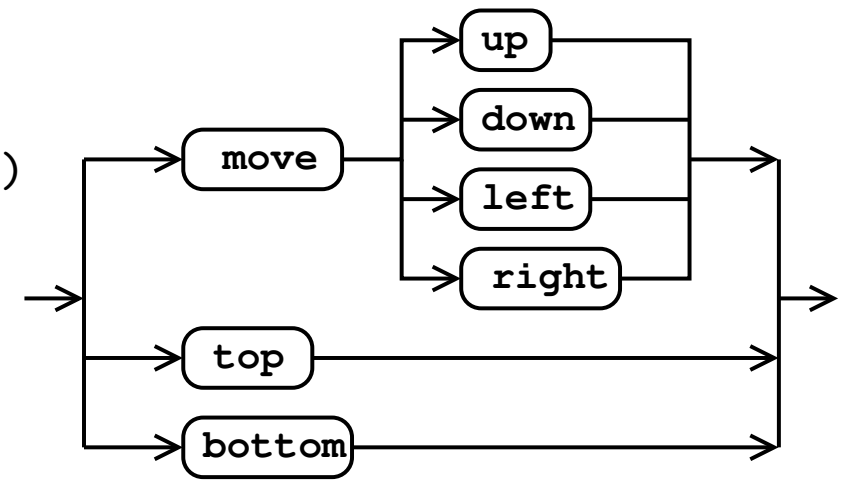
$cmd  = $mcmd | $dcmd | $icmd | $ecmd;
$noise     = sil | fil | spk;
({$noise} < $cmd $noise > quit {$noise})
```



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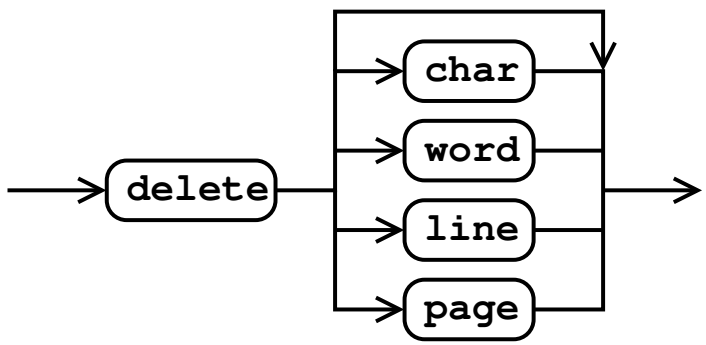
$icmd = insert;
$ecmd = end [insert];
$cmd  = $mcmd | $dcmd | $icmd | $ecmd;
$noise     = sil | fil | spk;
({$noise} < $cmd $noise > quit {$noise})
```



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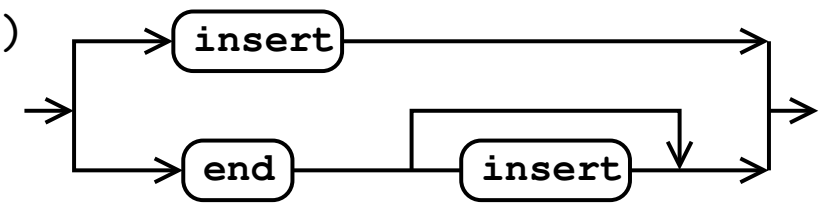
$dir  = up | down | left | right;
$mcmd = move $dir | top | bottom;
$item = char | word | line | page;
$dcmd = delete [$item];
$icmd = insert;
$ecmd = end [insert];
$cmd  = $mcmd | $dcmd | $icmd | $ecmd;
$noise     = sil | fil | spk;
({$noise} < $cmd $noise > quit {$noise})
```



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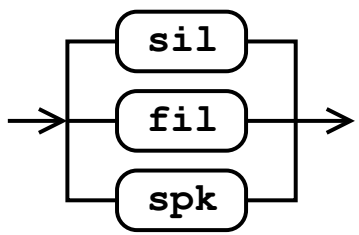
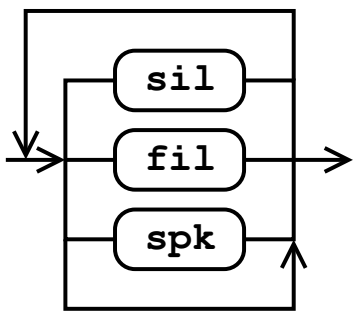
$item = char | word | line | page;
$dcmd = delete [$item];
$icmd = insert;
$ecmd = end [insert];
$cmd  = $mcmd | $dcmd | $icmd | $ecmd;
$noise     = sil | fil | spk;
({$noise} < $cmd $noise > quit {$noise})
```



- [.] optional (zero or one)
- {.} zero or more
- (.) block
- <.> loop
- <<.>> context dep. loop
- .|. alternative

Grammar definition (HParse)

```
> cat grammar.bnf
$dir  = up | down | left | right;
$mcmd = move $dir | top | bottom;
$item = char | word | line | page;
$dcmd = delete [$item];
$icmd = insert;
$ecmd = end [insert];
$cmd  = $mcmd | $dcmd | $icmd | $ecmd;
$noise     = sil | fil | spk;
({$noise} < $cmd $noise > quit {$noise})
```



- `[.]` optional (zero or one)
- `{.}` zero or more
- `(.)` block
- `<.>` loop
- `<<.>>` context dep. loop
- `.|.` alternative

Grammar parsing (HParse) and recognition (HVite)

Parse grammar

```
> HParse grammar.bnf grammar.slf
```

Run recognition on file(s)

```
> HVite -C offline.cfg -H mono_32_2.mmf -w grammar.slf
        -y lab dict.txt phones.lis audio_file.wav
```

Run recognition live

```
> HVite -C live.cfg -H mono_32_2.mmf -w grammar.slf
        -y lab dict.txt phones.lis
```

Evaluation (HResults)

```
> HResults -I reference.mlf ... word.lst recognized.mlf

====================== HTK Results Analysis =======================
  Date: Thu Jan 18 16:17:53 2001
  Ref : nworkdir_train/testset.mlf
  Rec : nresults_train/mono_32_2/rec.mlf
------------------------ Overall Results --------------------------
SENT: %Correct=74.07 [H=994, S=348, N=1342]
WORD: %Corr=94.69, Acc=94.37 [H=9202, D=196, S=320, I=31, N=9718]
-------------------------------------------------------------------
```

N = total number, I = insertions, S = substitutions, D = deletions

correct: $H = N - S - D$

%correct: $\%Corr = H/N$ **accuracy**: $Acc = \frac{H-I}{N} = \frac{N-S-D-I}{N}$

HResults: Confusion Matrix

```
------------------------ Confusion Matrix -------------------------
       A    E    F    F    N    N    S    T    T
       T    T    E    Y    I    O    E    R    V
       T    T    M    R    O    L    X    E    A
       A              A         L
                                                 Del [ %c / %e]
ATTA   5    0    0    0    0    0    0    0    0    0
 ETT   0    4    0    0    0    0    0    0    0    0
 FEM   0    0    4    0    0    0    0    0    0    0
FYRA   4    0    0    2    0    1    0    0    0    0 [28.6/12.5]
 NIO   0    0    0    0    2    4    0    0    0    0 [33.3/10.0]
NOLL   0    0    0    0    0    2    0    0    0    0
 SEX   0    0    0    0    0    0    6    0    0    0
 SJU   0    1    0    0    0    0    0    0    0    0 [ 0.0/2.5]
 TRE   0    3    0    0    0    0    0    0    0    0 [ 0.0/7.5]
 TVA   0    0    0    0    0    0    0    0    2    0
Ins    2    1    1    0    0    0    0    1    0
```