# HTK Tutorial

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# Outline

- Introduction
- Data formats and manipulation
- Data visualization
- Training
- Recognition

# Introduction

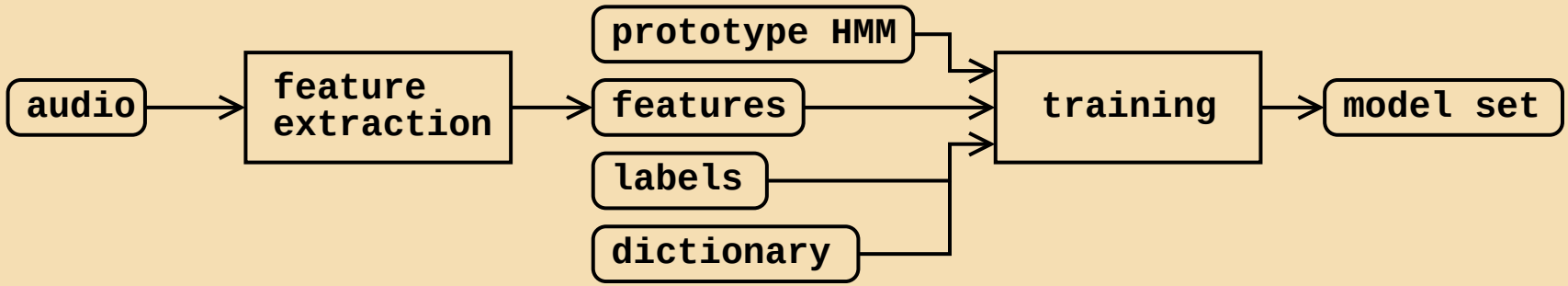
## What is it?

- toolkit for Hidden Markov Modeling
- general purpose, but...
- optimized for Speech Recognition
- very flexible and complete (always updated)
- very good documentation

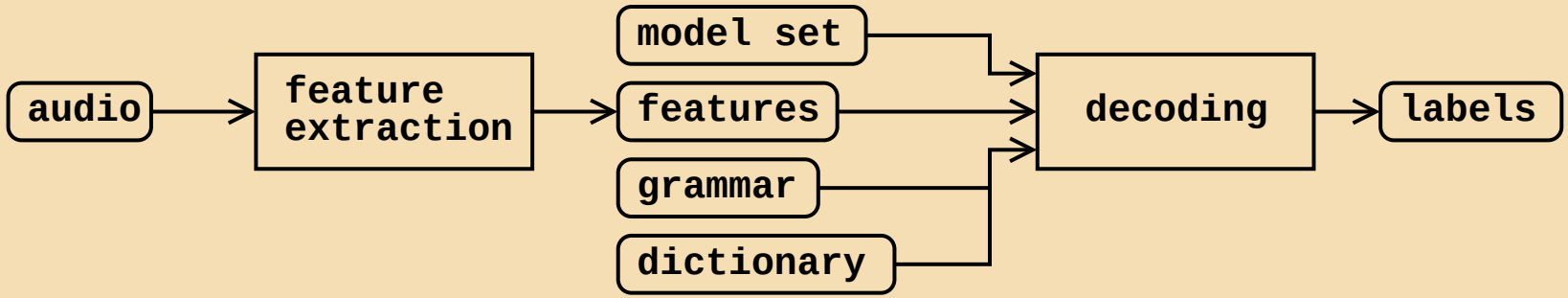
# Introduction

## ASR overview

Training




Recognition



# Introduction

## things that you should have before you start

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

# Introduction

## the HTK tools

data manipulation tools:

`HCopy` `HQuant` `HLEd` `HHEd` `HDMan` `HBuild`

data visualization tools:

`HSLab` `HList` `HSGen`

training tools:

`HCompV` `HInit` `HRest` `HERest` `HEAdapt` `HSmooth`

recognition tools:

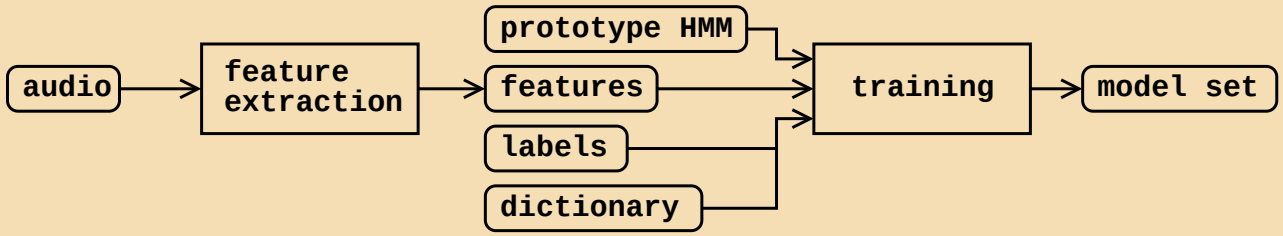
`HLStats` `HParse` `HVite` `HResults`

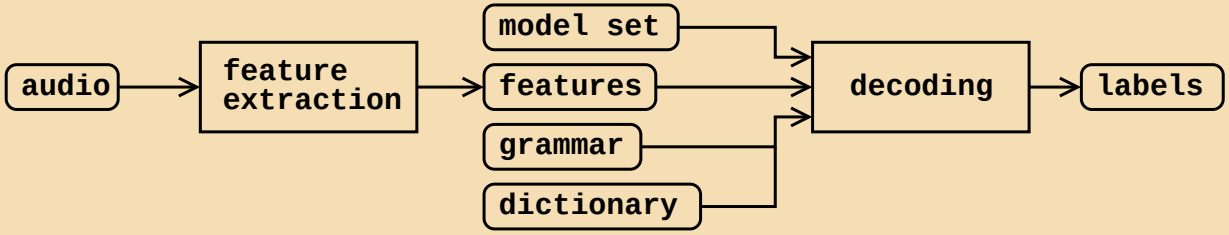
# Introduction

## 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 |



# Introduction

## 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
...
```

# Introduction

## 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 ----------------------------
```

# Introduction
## 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 ----------------------------
```

# Data formats and manipulation

## 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).

# Data formats and manipulation

## 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
```

# Data formats and manipulation

## 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

# Data formats and manipulation

## 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>
.
```

# Data formats and manipulation

## 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
.
```

# Data formats and manipulation

## dictionary (HDMan)

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

```
> cat lex.dic
förra    f oe r a sp
sju      S uh: a sp
```

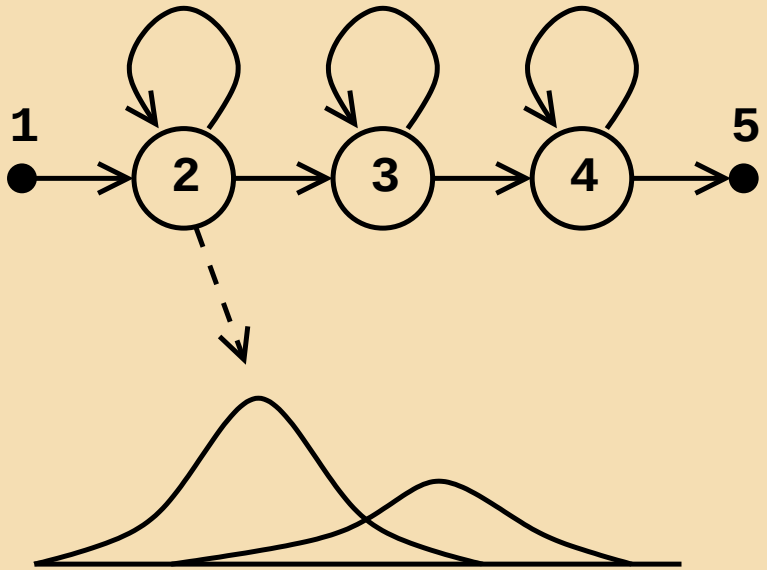
```
> cat lex2.dic
<sil>    [] sil
förra    f oe r a sp
sju      0.3 S uh: a sp
sju      0.7 S uh: sp
```

# Data formats and manipulation

## HMM definition files (HHEd) 1/5

```
~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>
```

HMM definition (~h)

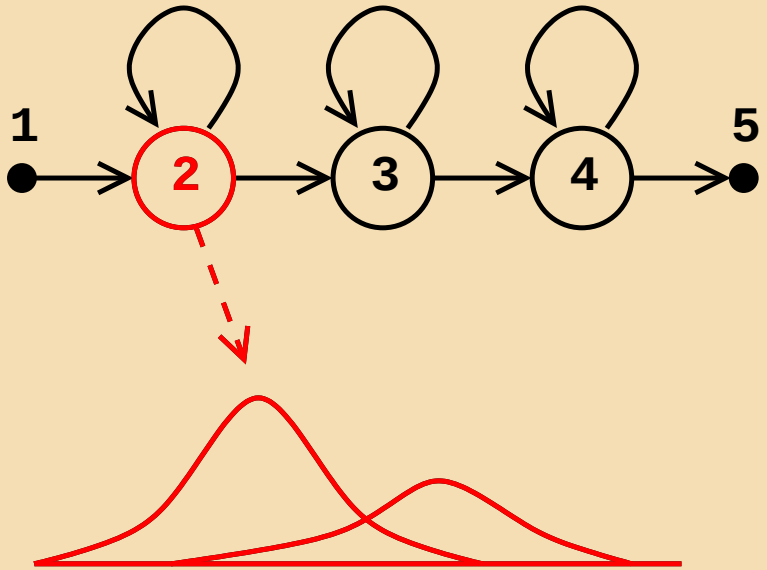


# Data formats and manipulation

## HMM definition files (HHEd) 2/5

```
~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>
```

State definition (~s)

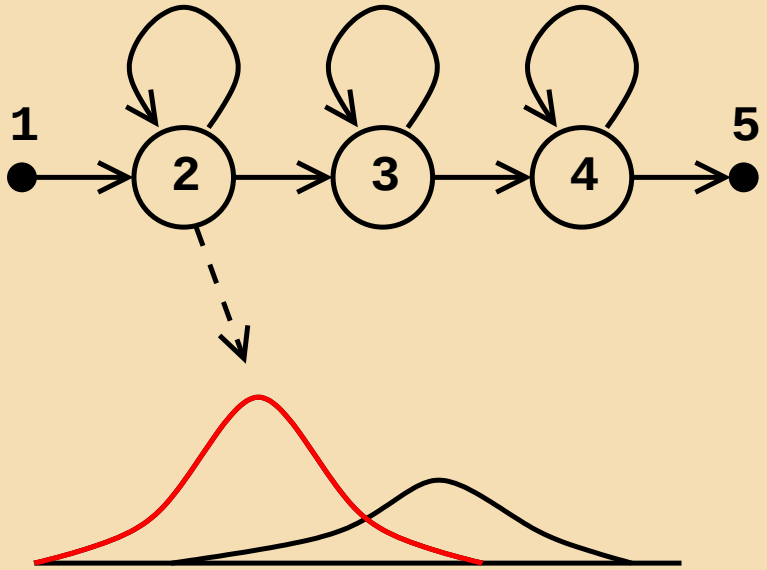


# Data formats and manipulation

## HMM definition files (HHEd) 3/5

```
~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)



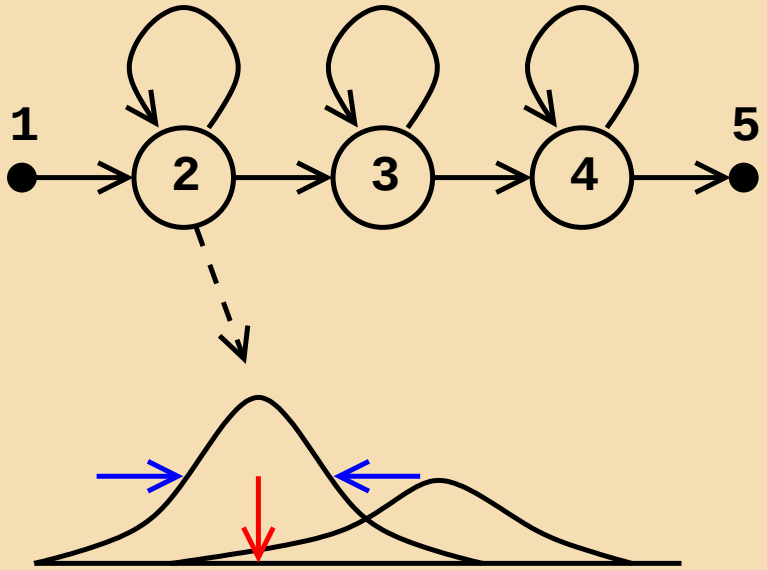
# Data formats and manipulation

## HMM definition files (HHEd) 4/5

```
~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)

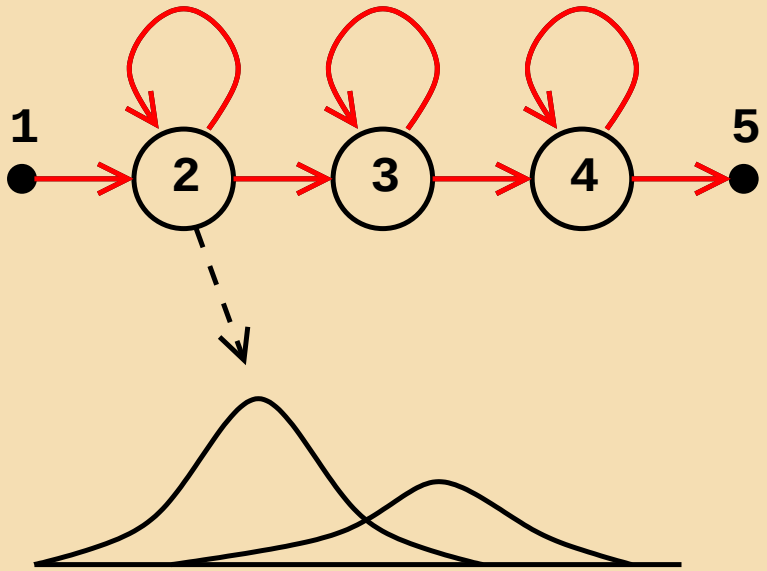


# Data formats and manipulation

## HMM definition files (HHEd) 5/5

```
~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)



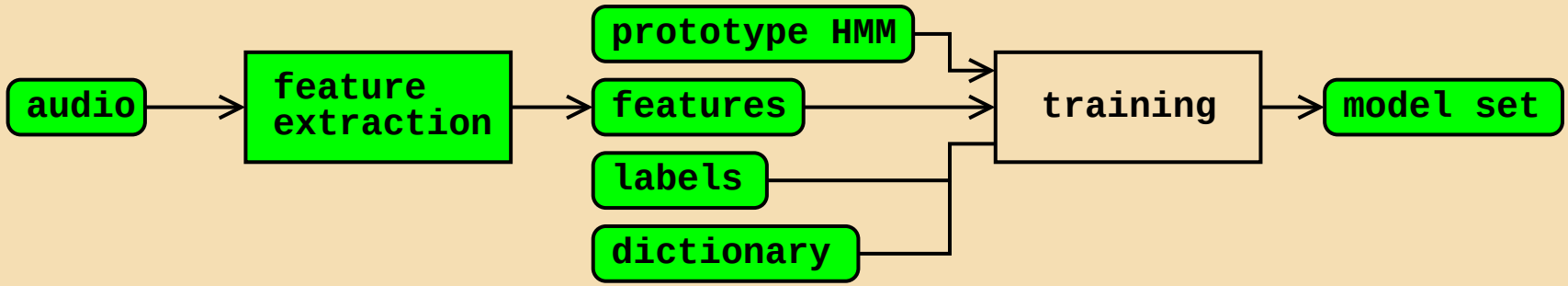
# Data visualization

- `HSLab`: graphical tool to label speech (use `WaveSurfer` instead).
- `HList`: gives information about audio and feature files.
- `HSGen`: generates random sentences out of a regular grammar.

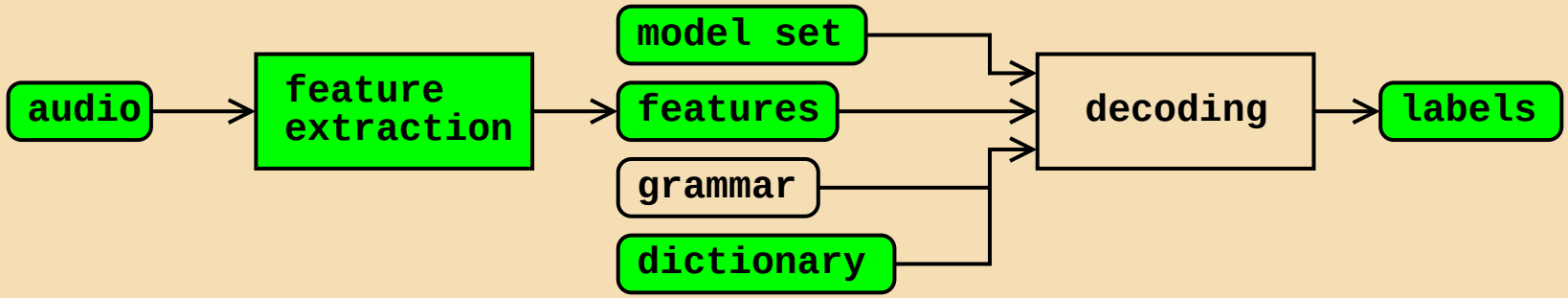
# Intermezzo

## what do we know so far?

Training




Recognition



# Traning tools

## 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

## training and adaptation

- `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.

# Traning tools

## training example: RefRec

first pass:

prototype HMM → `HCompV` → cloning → `HERest` →
realignment (`HVite`) → `HERest` → increase MC (`HHEd`) →
`HERest` → realignment (`HVite`)

second pass:

prototype HMM + aligned transcriptions → `HInit` →
`HRest` → `HERest` → increase MC (`HHEd`) → `HERest`

# Recognition tools

grammar generation

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

decoding

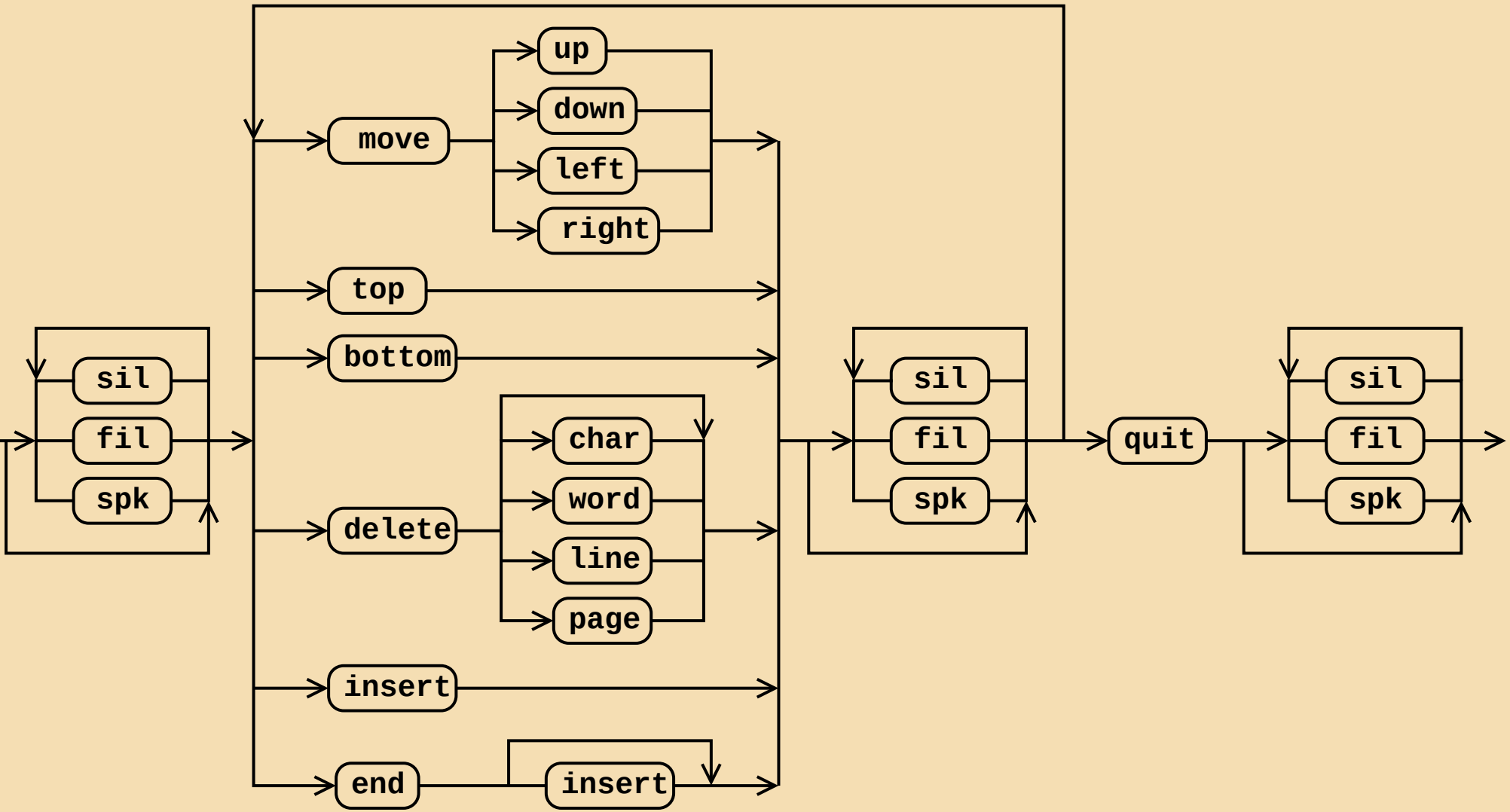
- `HVite`: performs Viterbi decoding.

evaluation

- `HResults`: evaluates recognition results.

# Recognition tools

## grammar definition (HParse)



# Recognition tools

## 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 more
- (.) block
- <.> loop
- <<.>> context dep. loop
- .|. alternative

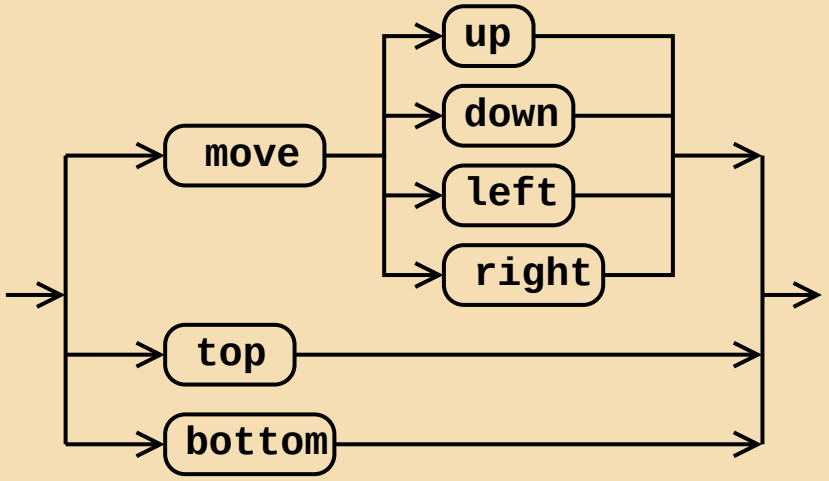
# Recognition tools

## 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})
```

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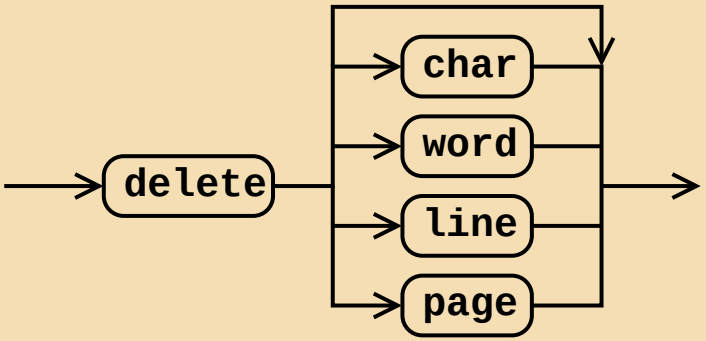
$dcmd = delete [$item];
$icmd = insert;
$ecmd = end [insert];
$cmd  = $mcmd | $dcmd | $icmd | $ecmd;
$noise     = sil | fil | spk;
({$noise} < $cmd {$noise} > quit {$noise})
```

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# Recognition tools

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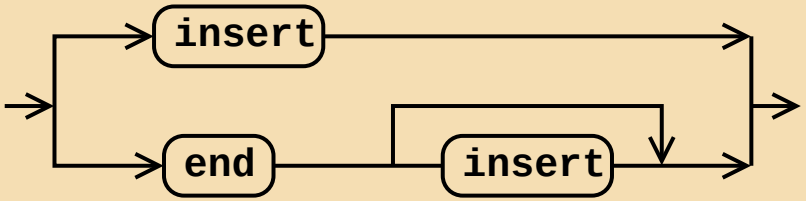
$item = char | word | line | page;
$dcmd = delete [$item];
$icmd = insert;
$ecmd = end [insert];
$cmd  = $mcmd | $dcmd | $icmd | $ecmd;
$noise     = sil | fil | spk;
({$noise} < $cmd {$noise} > quit {$noise})
```

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# Recognition tools

## grammar definition (HParse)

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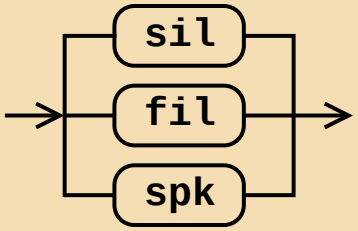
$dir  = up | down | left | right;
$mcmd = move $dir | top | bottom;
$item = char | word | line | page;
$dcmd = delete [$item];
$icmd = insert;
$ecmd = end [insert];
$cmd  = $mcmd | $dcmd | $icmd | $ecmd;
$noise     = sil | fil | spk;
({$noise} < $cmd {$noise} > quit {$noise})
```

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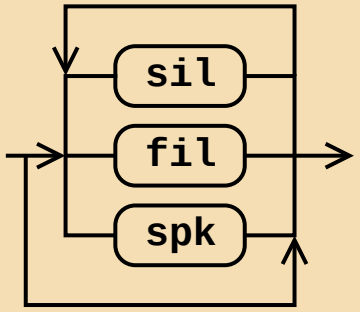
- .|. alternative

# Recognition tools

## 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 more
- (.) block
- <.> loop
- <<.>> context dep. loop
- .|. alternative

# Recognition tools

## 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
```

# Recognition tools

## 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**: $Acc = \frac{H-I}{N} = \frac{N-S-D-I}{N}$