# DT2118
# Speech and Speaker Recognition
## HTK Tutorial

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Notes

## Outline





Notes

## 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



Notes

## 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.



Notes

## 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



Notes

## 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
```



Notes

## 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**



Notes

## 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
...
```



Notes

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



Notes

## Configuration file

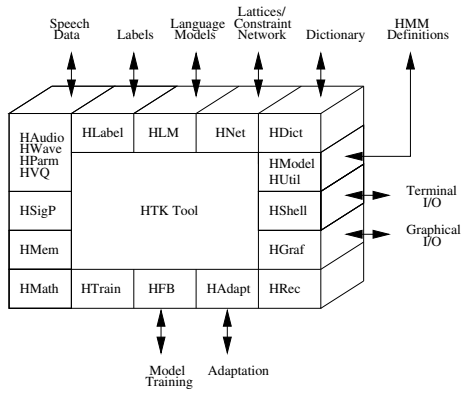
```
> cat config_file
SOURCEKIND = MFCC_0
TARGETKIND = MFCC_0_D_A
> HList -C config_file -e 0 -o -h feature_file

 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 ------------------------------
```



Notes

## Software Architecture

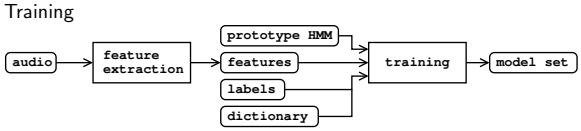




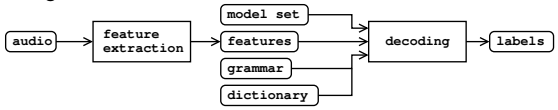

Notes

## ASR Overview

Training




Recognition






Notes

## 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

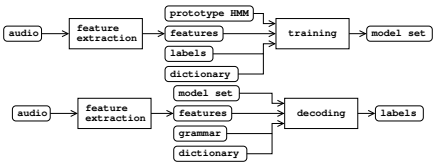


Notes

## 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 |






Notes

## File manipulation tools

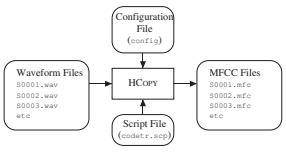
- HCopy: converts from/to various data formats (audio, **features**).
- HQuant: quantizes speech (audio).
- HLEd: edits label and **master label files**.
- HDMan: edits **dictionary files**.
- HHEd: edits model and **master macro files**.
- HBuild: converts language models in different formats (more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



Notes

## 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
```



Notes

## 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>
.
```



Notes

## 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



Notes

## 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
.
```



Notes

## 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
```

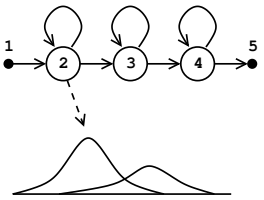


Notes

## 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>
```

HMM definition (~h)



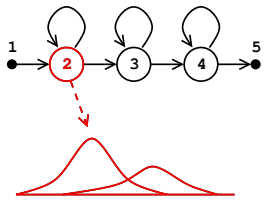

Notes



## 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>
```

State definition (~s)



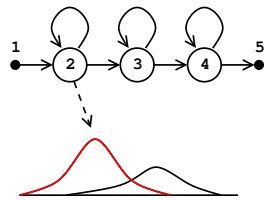

Notes



## 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)



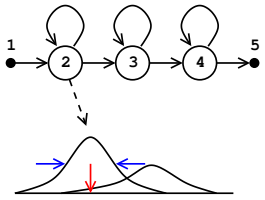

Notes



## 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)

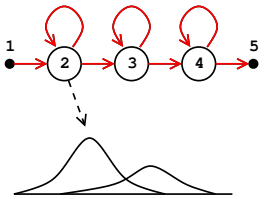



Notes

## 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)



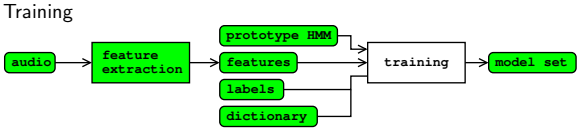




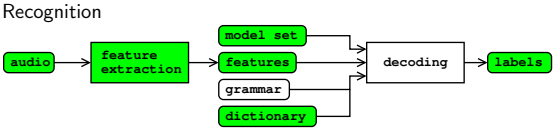

Notes

## What do we know so far?

Training




Recognition






Notes

## Training: different levels of supervision

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



Notes

## 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.



Notes

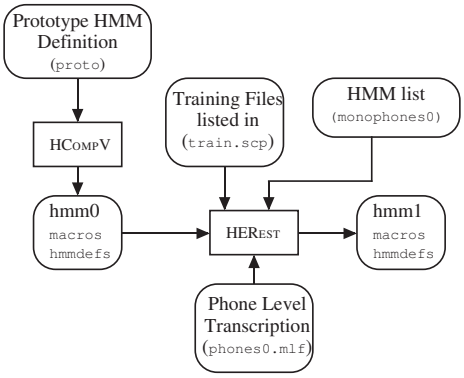
## Traning tools

- `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.

Notes



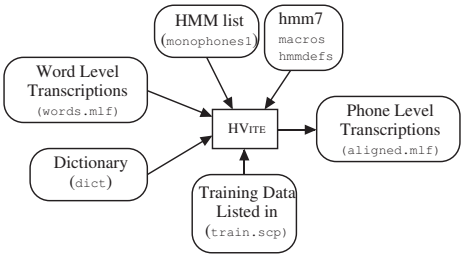
## Training with no time-aligned phonetic transcriptions




Notes



## Generating time-aligned phonetic transcriptions




Notes



## Training with time-aligned phonetic transcriptions

Instead of `HCompV -> HERest`

`HInit -> HRest -> HERest`

Notes

## 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.

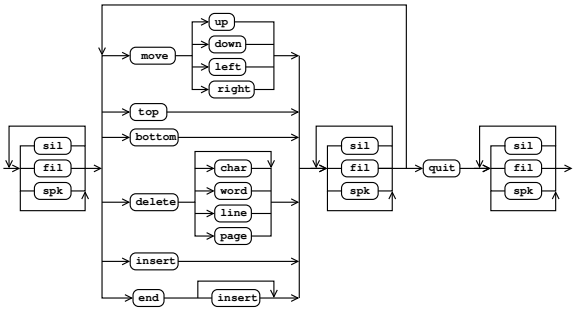
evaluation

- `HResults`: evaluates recognition results.



Notes

## Grammar definition (`HParse`)






Notes

## 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})
```

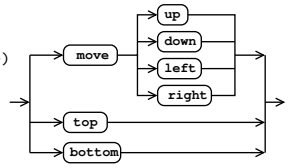
- `[.]` optional (zero or one)
- `{.}` zero or more
- `(.)` block
- `<.>` loop
- `<<.>>` context dep. loop
- `.|.` alternative



Notes

## 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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- `.|.` alternative



Notes

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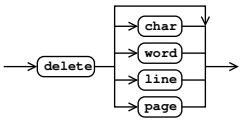
```
> cat grammar.bnf
$dir  = up | down | left | right;
$mcmd = move $dir | top | bottom;
$item = char | word | line | page;
$dcmd = delete [$item];
$icmd = insert;
$ecmd = end [insert];
$cmd  = $mcmd | $dcmd | $icmd | $ecmd;
$noise     = sil | fil | spk;
({$noise} < $cmd $noise > quit {$noise})
```



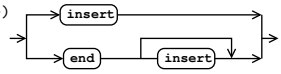

- [.] optional (zero or one)
- {.} zero or more
- (.) block
- <.> loop
- <<.>> context dep. loop
- .|. alternative



Notes

## 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
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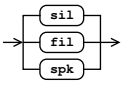
- <.> loop
- <<.>> context dep. loop
- .|. alternative



Notes

## 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})
```



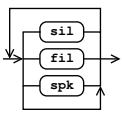

- [.] optional (zero or one)
- {.} zero or more
- (.) block
- <.> loop
- <<.>> context dep. loop
- .|. alternative



Notes

## 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



Notes

## 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
```



Notes

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



Notes

## 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
```



Notes

Notes