Language Understanding Systems

Sequence Labeling with FSM & LM

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Outline

1. Sequence Labeling
2. POS-Tagging
3. Exercise
4. Solution

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Section 1

Sequence Labeling

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Sequence Labeling: *Definition*

Classification

Assignment of a categorical **label** to a **new observation** based on the categories in the **training data**.

Sequence Labeling

Assignment of a categorical **label** to each member of a **sequence** of observed values

- Can be treated as a set of independent **classification** tasks, one per member of the sequence;
- Performance is generally improved by making the optimal label for a given element **dependent on the choices of nearby elements**;

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Sequence Labeling: *NLP Tasks*

- Part-of-Speech Tagging
- Chunking
- Named Entity Recognition
- Semantic Role Labeling
- Frame Net Parsing
- Dependency Parsing
- Discourse Parsing
- **Spoken Language Understanding**
- ...

Sequence Labeling: *NLP Tasks*

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Section 2

POS-Tagging

Part-of-Speech Tagging

POS-Tags: Noun, Verb, etc.

the/DT cat/NN is/VBZ fat/JJ

The general setting:

- Create 'training' and 'testing' corpora by POS-tagging a certain amount of text by hand
- 'Train' POS-tagging model to extract generalizations from the annotated corpus
- Use the trained POS-tagger too annotate new texts

Markov Model Tagging

Given word sequence $w_1, ..., w_n$ find the most probable tag sequence $t_1, ..., t_n$

$$t_1, ..., t_n = \arg\max_{t_1,...,t_n} P(t_1, ..., t_n | w_1, ..., w_n) \tag{1}$$

Bayes's Law:

$$t_1, ..., t_n = \arg\max_{t_1,...,t_n} \frac{P(w_1, ..., w_n | t_1, ..., t_n) P(t_1, ..., t_n)}{P(w_1, ..., w_n)} \tag{2}$$

Probability of a word sequence is the same for all tags, thus:

$$t_1, ..., t_n = \arg\max_{t_1,...,t_n} P(w_1, ..., w_n | t_1, ..., t_n) P(t_1, ..., t_n) \tag{3}$$

Simplifying Assumptions

- Probability of a word only depends on its own tag, not tags of other words in sentence:

$$P(w_1, ..., w_n | t_1, ..., t_n) \approx P(w_1|t_1)P(w_2|t_2)...P(w_n|t_n) \quad (4)$$

- The (first-order) Markov assumption (bigram):

$$P(t_1, ..., t_n) \approx P(t_1|t_0)P(t_2|t_1)...P(t_n|t_{n-1}) \quad (5)$$

- Second-order Markov assumption would correspond to trigram model

Simplifying Assumptions

$$t_1, ..., t_n = \arg\max_{t_1,...,t_n} P(t_1, ..., t_n | w_1, ..., w_n) \tag{6}$$

$$t_1, ..., t_n = \arg\max_{t_1,...,t_n} \prod_{i=1}^{n} P(w_i|t_i) P(t_i|t_{i-1}) \tag{7}$$

- $P(w_i|t_i)$ – probability of seeing current word given the current tag
- $P(t_i|t_{i-1})$ – probability of seeing the current tag given the tag we just saw

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Training from Data

- $$P(w_i|t_i) = \frac{C(t_i, w_i)}{C(t_i)} \tag{8}$$
- $$P(t_i|t_{i-1}) = \frac{C(t_{i-1}, t_i)}{C(t_{i-1})} \tag{9}$$

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Section 3

Exercise

Unigram POS-Tagger

Develop simple **unigram**-based **POS-Tagger**

$$t_1, ..., t_n = \arg\max_{t_1,...,t_n} \prod_{i=1}^{n} P(w_i|t_i)P(t_i) \tag{10}$$

$$P(w_1|t_1) * P(w_2|t_2) * ... * P(w_n|t_n) \tag{11}$$

Data

train.pos.txt

- Create lexicon
- Create transducer & compile it using OpenFST
- Take care of *unknown words*: all tags are equally probable
- POS-tag the test set: test.txt

Ngram POS-Tagger

Extend the unigram POS-Tagger to

$$t_1, ..., t_n = \arg\max_{t_1,...,t_n} \prod_{i=1}^{n} P(w_i|t_i)P(t_i|t_{i-1}) \tag{12}$$

Data

train.pos.txt

- Create lexicon
- Create *LM* using OpenGRM
- POS-tag the test set: test.txt

Section 4

Solution

Calculating $P(w_i|t_i) = \frac{C(t_i, w_i)}{C(t_i)}$

Create count file for $C(t_i)$, from 2 column tab-separated token-per-line format: 1st column - tokens, 2nd column POS-tags

```
cat $data | cut -f 2 |\ # get 2nd column
sed '/^ *$/d' |\        # remove empty lines
sort | uniq -c |\       # unique list of POS with counts
sed 's/^ *//g' |\       # remove leading spaces
awk '{OFS="\t"; print $2,$1}' # swap columns
                              # & use tab for separator
```

The last step is optional, but convenient. Redirect output to some file, e.g. *POS.counts*

Calculating $P(w_i|t_i) = \frac{C(t_i,w_i)}{C(t_i)}$

Similarly, create count file for $C(t_i, w_i)$, from 2 column tab-separated token-per-line format: 1st column - tokens, 2nd column POS-tags

```
cat $data |\          # we need both columns
sed '/^ *$/d' |\      # remove empty lines
sort | uniq -c |\     # unique list of word-POS counts
sed 's/^ *//g' |\     # remove leading spaces
awk '{OFS="\t"; print $2,$3,$1}' # swap columns
                                 # & use tab for separator
```

The last step is optional, but convenient. Redirect output to some file, e.g. *TOK_POS.counts*

Calculating $P(w_i|t_i) = \frac{C(t_i,w_i)}{C(t_i)}$

Calculate probabilities $P(w_i|t_i)$ using both count files

```
while read token pos count
do
    # get pos counts
    poscount=$(grep "^$pos\t" POS.counts | cut -f 2)
    # calculate probability
    prob=$(echo "$count / $poscount" | bc -l)
    # print token, pos-tag & probability
    echo -e "$token\t$pos\t$prob"
done < TOK_POS.counts
```

Redirect output to some file, e.g. *TOK_POS.probs*

Note: Some POS-tags end with $, which is 'end-of-line' symbol in RegEx. This might lead to errors. Using grep as above gets the desired behavior.

[**Advice**: Use proper scripting language]

Building Transducer

- Create lexicon file that contains both words and POS-tags.
- Since word probabilities depends only on tokens, single state transducer is enough.
- Either add `0 0` in-front of every line in TOK_POS.probs, or modify the code to do so.

```
...
    # -e to interpret \t
    # -n to not print new line
    echo -en "0\t0\t"
    # print token, pos-tag & probability
    echo -e "$token\t$pos\t$prob"
...
```

- Then add the final state '0' as

```
echo '0' >> TOK_POS.probs
```

- Compile using `fstcompile`

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Issues to Solve

- By default FST wights are *costs* – the lower the better; *probability* – the higher the better.
- Unknown words & their $P(w_i|t_i)$

Weights

Instead of raw probabilities use negative log probabilities $x = -ln(x)$:

```
prob=$(echo "-l($count / $poscount)" | bc -l)
```

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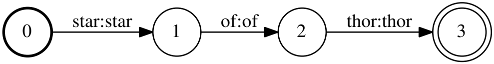
Issues to Solve: Unknown words

- All tags have equal probability to generate an unknown word (or an unknown word has equal probability for all tags).
- We have 38 tags.
- Conditional probabilities must sum to 1.
- Thus: $P(< unk > |t_i) = 1/38$
- Build another transducer for unknown words, compile it, and make a union with the other word transducer.

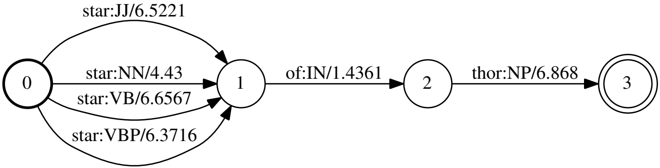
```
prob=$(echo "-l(1/38)" | bc -l)
while read pos count
do
   echo -e "0\t0\t<unk>\t$pos\t$prob"
done < POS.counts
echo "0"
```

Tagging

1. Represent input sentence "star of thor" as FSA/FST:



2. Compose it with our tagger to get



3. use `fstshortestpath` to get the 'best' tag sequence (NN,IN,NP)

Second Term: $P(t_i|t_{i-1})$

Convert token-per-line format into POS-tag sentence-per-line format

```
cat $data | cut -f 2 |\ # get 2nd column
# replace empty line with some special symbol (#)
sed 's/^ *$/#/g' |\
tr '\n' ' ' |\          # replace '\n' with space
tr '#' '\n' |\          # replace '#' with '\n'
sed 's/^ *//g;s/ *$//g' # clean redundant spaces
```

Train Language model on this data

```
farcompilestrings --symbols=lex.txt
                  --unknown_symbol='<unk>'
                  $data > data.far
ngramcount --order=3
           --require_symbols=false
           data.far > pos.cnt
ngrammake --method=witten_bell pos.cnt > pos.lm
```

Using All Together

Compose sentence FSA, POS-tagger FST and the POS-LM in a sequence:

$sent_{FSA/FST} \circ tagger_{FST} \circ pos.lm_{FSA/FST}$

```
fstcompose sent.fsa pos-tagger.fst |\
fstcompose - pos.lm |\
fstrmepsilon |\
fstshortestpath
```