Dependency Parsing

Lecture 2

Overview

- Nivre's Arc-Eager / Arc-Standard Algorithm
- Covington's Parsing Strategy
- Pseudo-projective Parsing
- Java ML Libraries
  - OpenNLP MaxEnt
  - Mallet
  - Liblinear

Arc-Standard Algorithm

- Two stacks:
  - Stack with tokens that still have to be processed (**Input Stack**)
  - Stack with tokens that already have been processed (**Processed Stack**)
- One set:
  - Set of predicted dependency pairs
- Initial configuration:
  - **Processed Stack** with “0“ on top of it. **Input Stack** with the whole input on it.
- Terminal configuration:
  - Empty **Input Stack**

Arc-Standard Parsing Algorithm

- **Leftarc**

- Makes the top token of the **input stack** the head of the top token of the **processed stack**
- Pops the top token from the **processed stack**

- **Rightarc**

*if the top token of the **processed stack** already has been attached to all of its dependents to the right* :

- Makes it the head of the top token of the **input stack**
- Pops the top token from the **input stack**
- Moves the top token of the **processed stack** on top of the **input stack**

- **Shift**

- Moves the top token of the **input stack** on top of the **processed stack**

Input

1	A	DT	_	_
2	hearing	NN	_	_
3	on	IN	_	_
4	the	DT	_	_
5	issue	NN	_	_
6	is	VBZ	_	_
7	scheduled	VBN	_	_
8	today	NN	_	_
9	.	.	_	_

Arc-Standard Parsing Example

[ ]

[0] [9, 8, 7, 6, 5, 4, 3, 2, 1]

Shift

0 A1 hearing2 on3 the4 issue5 is6 scheduled7 today8 .9

Arc-Standard Parsing Example

[ ]

[0, 1] [9, 8, 7, 6, 5, 4, 3, 2]

Leftarc

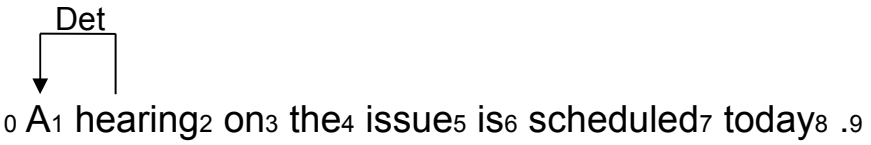
0 A1 hearing2 on3 the4 issue5 is6 scheduled7 today8 .9

Arc-Standard Parsing Example

[(1,2)]

[0] [9, 8, 7, 6, 5, 4, 3, 2]

Shift



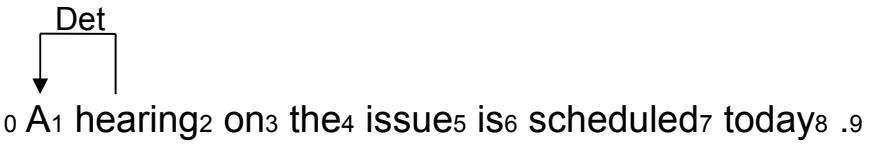
Arc-Standard Parsing Example

[(1,2)]

[0, 2]

[9, 8, 7, 6, 5, 4, 3]

Shift



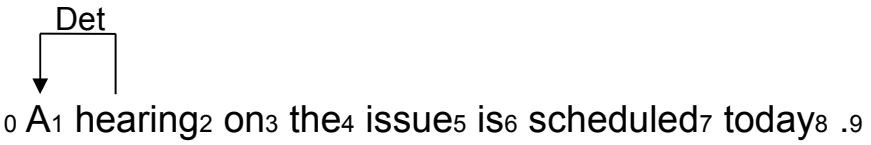
Arc-Standard Parsing Example

[(1,2)]

[0, 2, 3]

[9, 8, 7, 6, 5, 4]

Shift



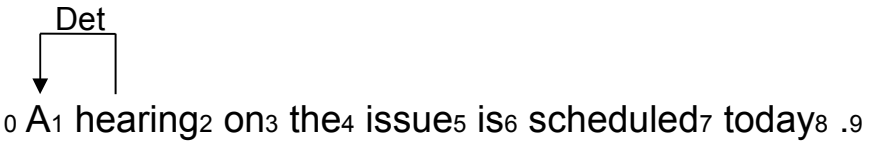
Arc-Standard Parsing Example

[(1,2)]

[0, 2, 3, 4]

[9, 8, 7, 6, 5]

Leftarc



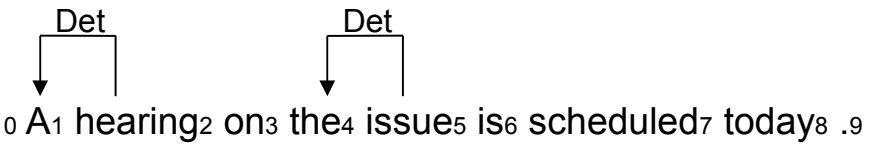
Arc-Standard Parsing Example

[(1,2), (4,5)]

[0, 2, 3]

[9, 8, 7, 6, 5]

Rightarc



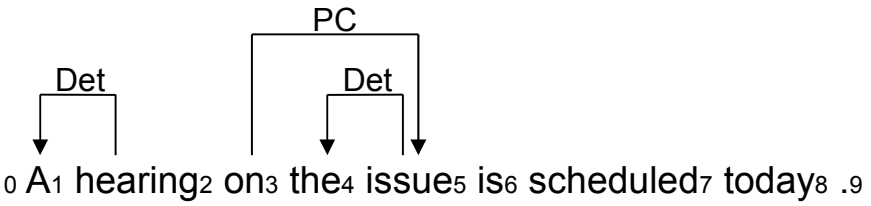
Arc-Standard Parsing Example

[(1,2), (4,5), (5,3)]

[0, 2]

[9, 8, 7, 6, 3]

Rightarc

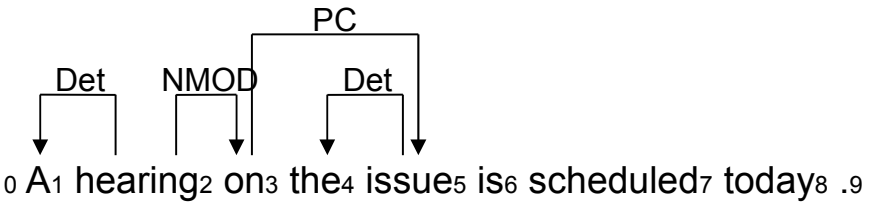


Arc-Standard Parsing Example

[(1,2), (4,5), (5,3), (3,2)]

[0] [9, 8, 7, 6, 2]

Shift



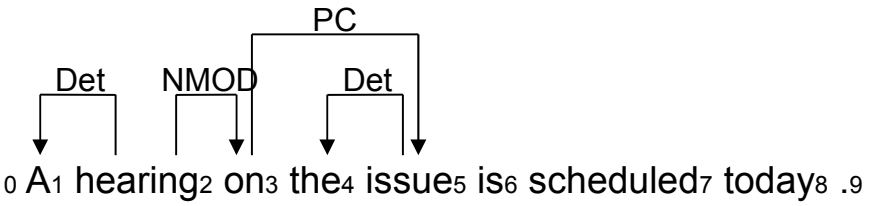
Arc-Standard Parsing Example

[(1,2), (4,5), (5,3), (3,2)]

[0, 2]

[9, 8, 7, 6]

Leftarc

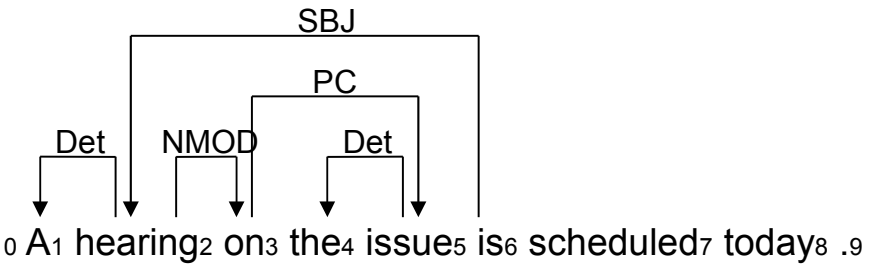


Arc-Standard Parsing Example

[(1,2), (4,5), (5,3), (3,2), (2,6)]

[0] [9, 8, 7, 6]

Leftarc

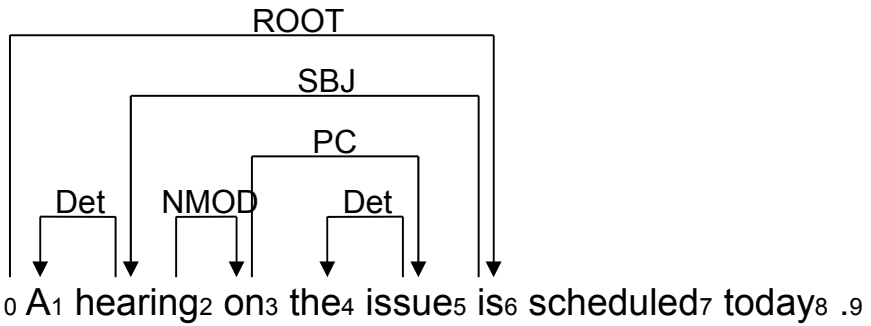


Arc-Standard Parsing Example

[(1,2), (4,5), (5,3), (3,2), (2,6), (6,0)]

[ ] [9, 8, 7, 6]

Shift

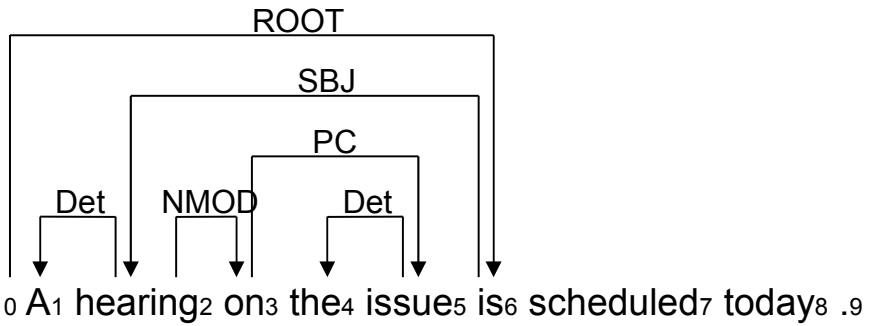


Arc-Standard Parsing Example

[(1,2), (4,5), (5,3), (3,2), (2,6), (6,0)]

[6] [9, 8, 7]

Shift

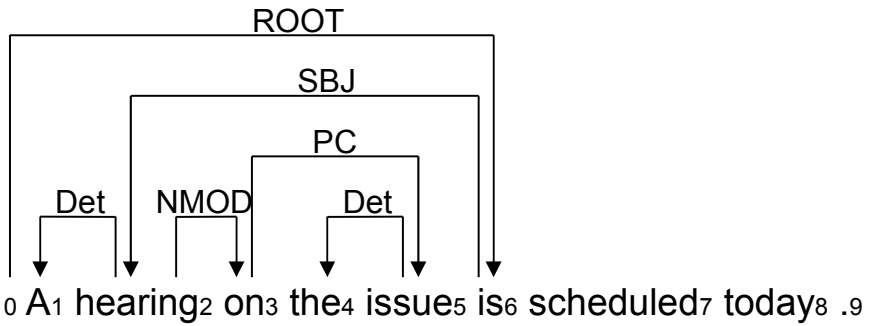


Arc-Standard Parsing Example

[(1,2), (4,5), (5,3), (3,2), (2,6), (6,0)]

[6, 7] [9, 8]

Rightarc

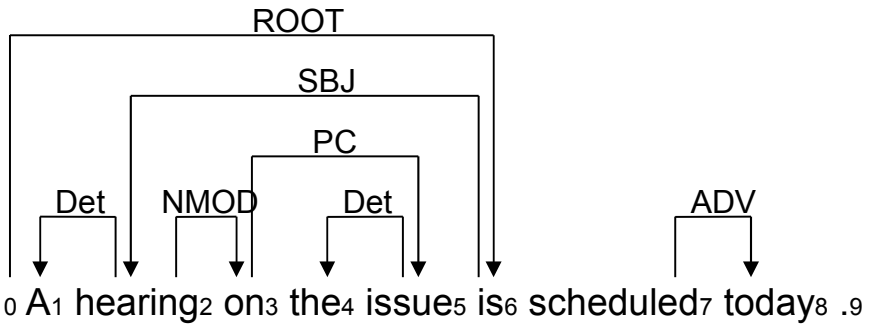


Arc-Standard Parsing Example

[(1,2), (4,5), (5,3), (3,2), (2,6), (6,0), (8,7)]

[6] [9, 7]

Rightarc

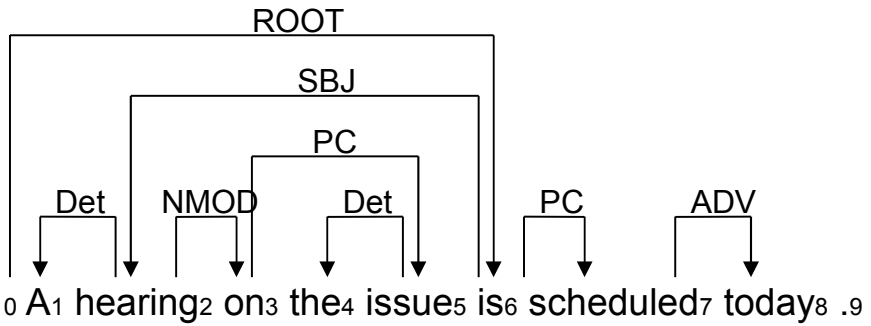


Arc-Standard Parsing Example

[(1,2), (4,5), (5,3), (3,2), (2,6), (6,0), (8,7), (7,6)]

[ ] [9, 6]

Shift

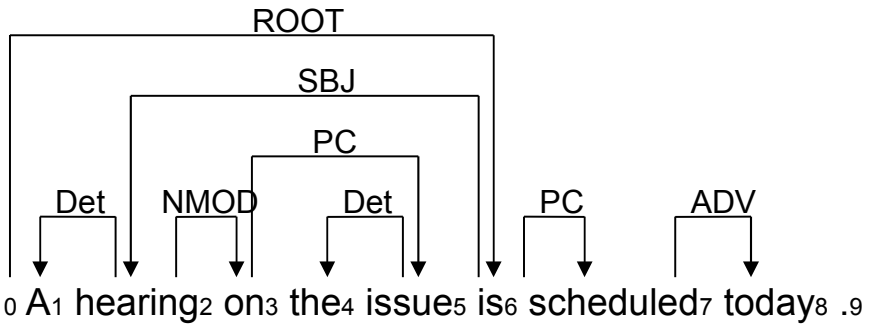


Arc-Standard Parsing Example

[(1,2), (4,5), (5,3), (3,2), (2,6), (6,0), (8,7), (7,6)]

[6] [9]

Rightarc

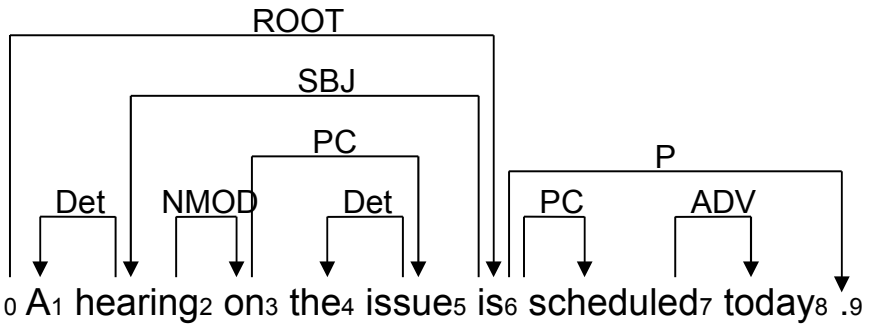


Arc-Standard Parsing Example

[(1,2), (4,5), (5,3), (3,2), (2,6), (6,0), (8,7), (7,6), (9,6)]

[ ] [6]

Shift

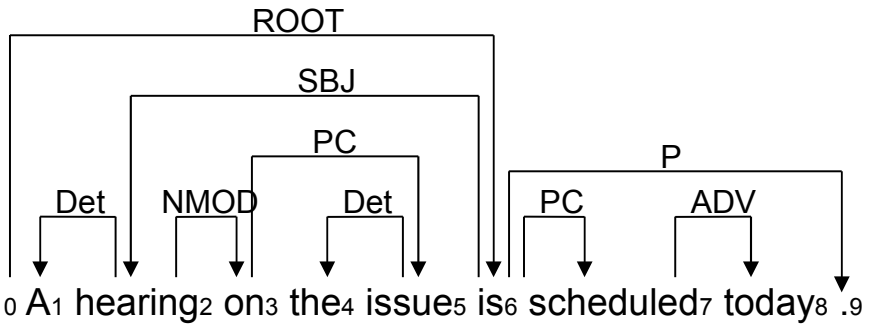


Arc-Standard Parsing Example

[(1,2), (4,5), (5,3), (3,2), (2,6), (6,0), (8,7), (7,6), (9,6)]

[6] [ ]

Shift



Output

1	A	DT	2	DET
2	hearing	NN	6	SBJ
3	on	IN	2	NMOD
4	the	DT	5	DET
5	issue	NN	3	OC
6	is	VBZ	0	ROOT
7	scheduled	VBN	6	PC
8	today	NN	7	ADV
9	.	.	6	P

Fundamental Parsing Algorithm

- Go through all words in the sentence and for every word *j* try to combine it with the words *1*..*j-1*
- Dependents of any given word are more likely to be near it than far away, therefore work backwards through *j-1*, *j-2* etc, rather than forwards from *1* to *2*, *3* etc.
- Don‘t consider not permissible pairs (don‘t look for a parent if a word already has one, pairs which introduce cycles etc.)

Fundamental Parsing Algorithm Operations

- Given the current word j and a word i < j there are three operations:

- **Link(i, j)**

- Creates a dependency pair with j being the head of i

- **Link(j, i)**

- Creates a dependency pair with i being the head of j

- **Shift**

- Rejects the current pair and moves on

Input

1	She	PRP	_	_
2	was	VBD	_	_
3	the	DT	_	_
4	first	JJ	_	_
5	woman	NN	_	_
6	to	TO	_	_
7	be	VB	_	_
8	appointed	VBN	_	_
9	FCC	NNP	_	_
10	general	JJ	_	_
11	counsel	NN	_	_
12	.	.	_	_

Fundamental Parsing Algorithm Example

[ ]

j: 1

i: 0

{l1=0.016, **shift**=0.9832}

0 She1 was2 the3 first4 woman5 to6 be7 appointed8 FCC9 general10 counsel11 .12

Fundamental Parsing Algorithm Example

[ ]

j: 2

i: 1

{**l2**=0.8848, l1=0.0083, shift=0.1069}

0 She1 was2 the3 first4 woman5 to6 be7 appointed8 FCC9 general10 counsel11 .12

Fundamental Parsing Algorithm Example

[(1,2)]

j: 2

i: 0

{**I1**=0.6437, shift=0.2547}

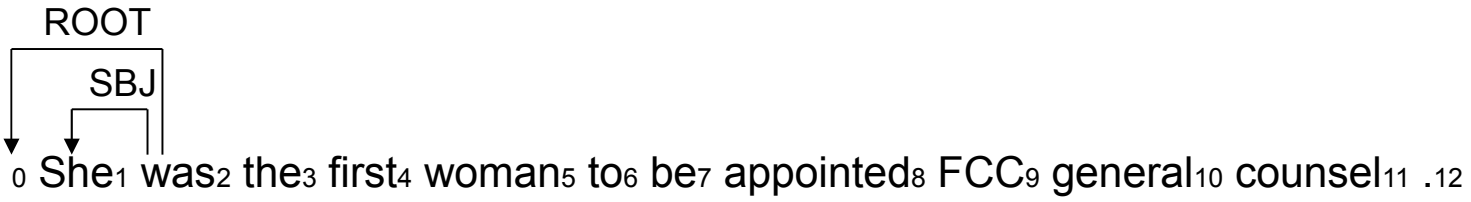
Fundamental Parsing Algorithm Example

[(1,2), (2,0)]

j: 3

i: 2

{**I1**=0.6437, shift=0.2547}



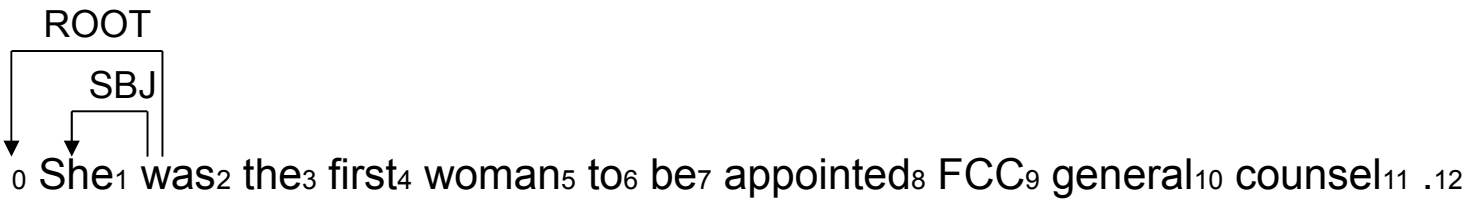
Fundamental Parsing Algorithm Example

[(1,2), (2,0)]

j: 4

i: 3

{l2=0.0224, l1=0.0, **shift**=0.9776}



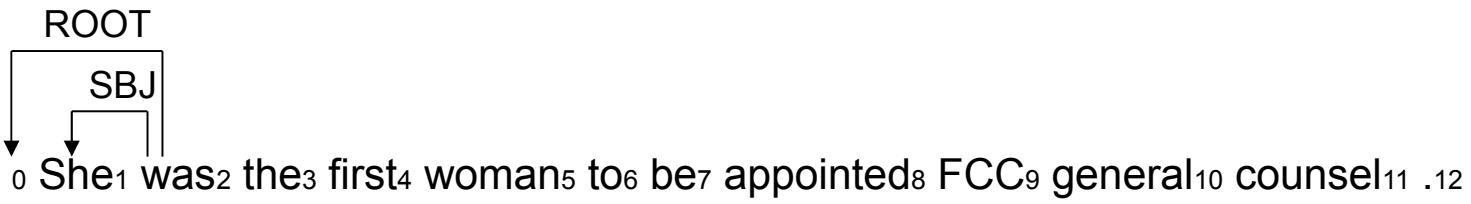
Fundamental Parsing Algorithm Example

[(1,2), (2,0)]

j: 4

i: 2

{l1=0.0745, **shift**=0.9247}



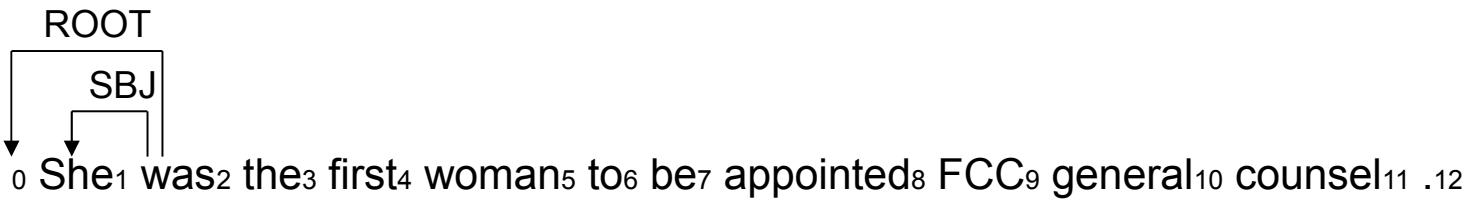
Fundamental Parsing Algorithm Example

[(1,2), (2,0)]

j: 5

i: 4

{**l2**=0.8812, l1=0.013, shift=0.1058}



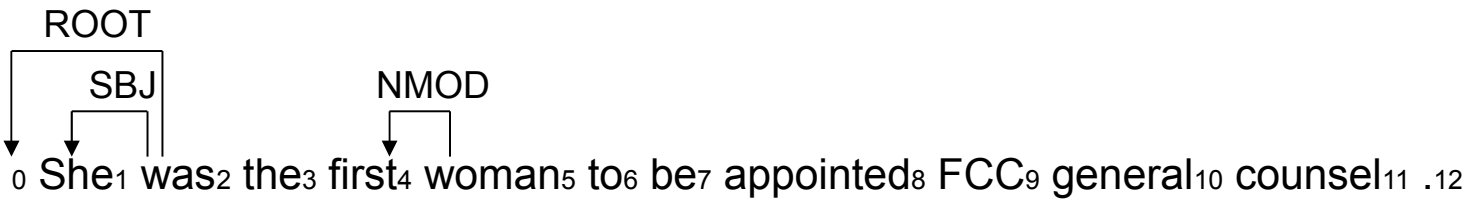
Fundamental Parsing Algorithm Example

[(1,2), (2,0), (5,4)]

j: 5

i: 3

{**l2**=0.8812, l1=0.013, shift=0.1058}



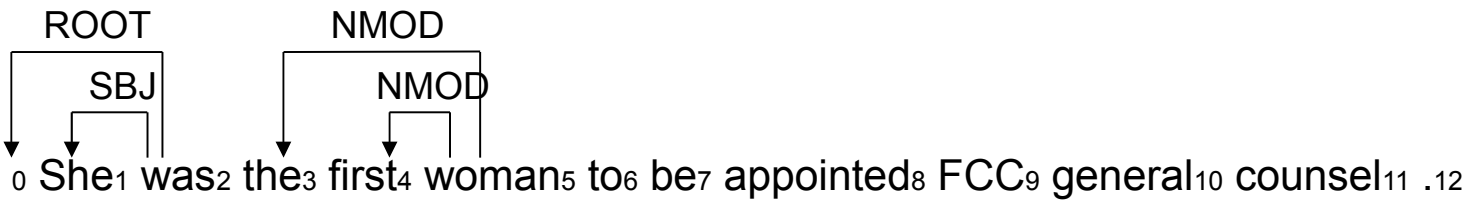
Fundamental Parsing Algorithm Example

[(1,2), (2,0), (5,4), (5,3)]

j: 5

i: 2

{**l1**=0.8364, shift=0.1415}



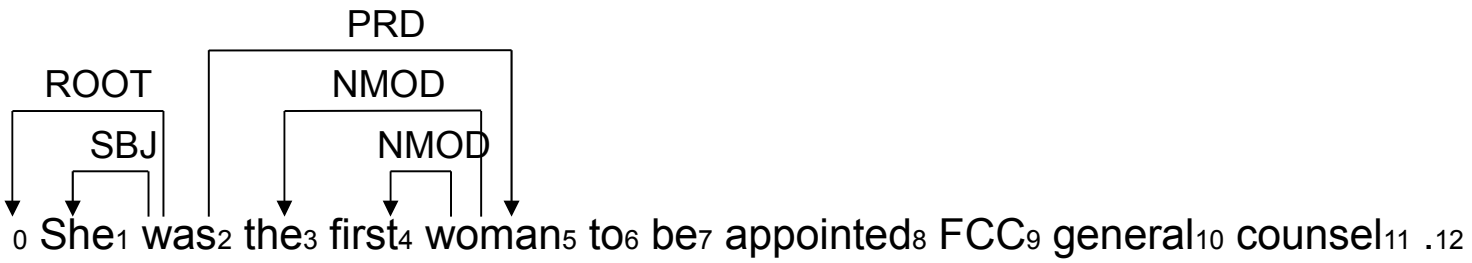
Fundamental Parsing Algorithm Example

[(1,2), (2,0), (5,4), (5,3), (2,5)]

j: 6

i: 5

{**l1**=0.6597, shift=0.2593}



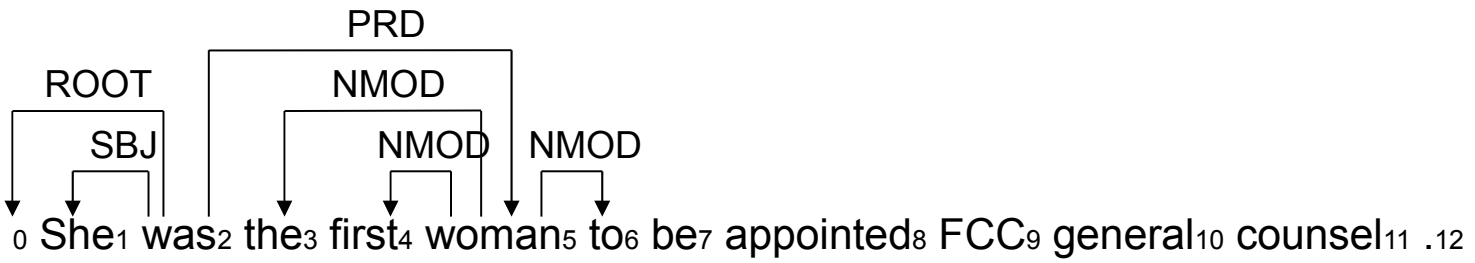
Fundamental Parsing Algorithm Example

[(1,2), (2,0), (5,4), (5,3), (2,5), (6,5)]

j: 7

i: 6

{**l1**=0.9699, shift=0.0286}



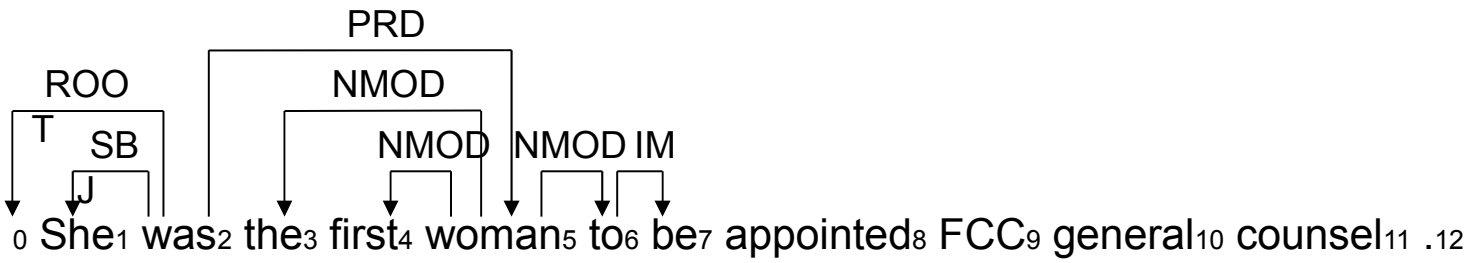
Fundamental Parsing Algorithm Example

[(1,2), (2,0), (5,4), (5,3), (2,5), (6,5), (7,6)]

j: 8

i: 7

{**I1**=0.4813, shift=0.5179}



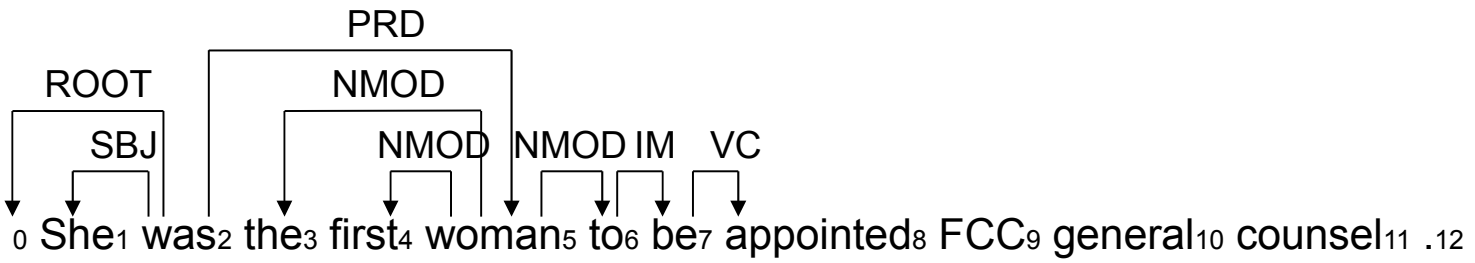
Fundamental Parsing Algorithm Example

[(1,2), (2,0), (5,4), (5,3), (2,5), (6,5), (7,6), (8,7)]

j: 9

i: 8

{l1=0.0987, **shift**=0.8476}



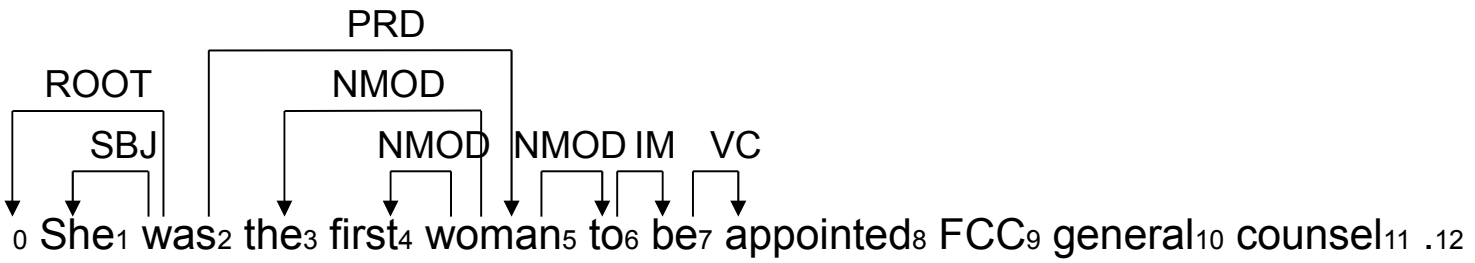
Fundamental Parsing Algorithm Example

[(1,2), (2,0), (5,4), (5,3), (2,5), (6,5), (7,6), (8,7)]

j: 9

i: 7

{l1=0.0404, **shift**=0.9589}



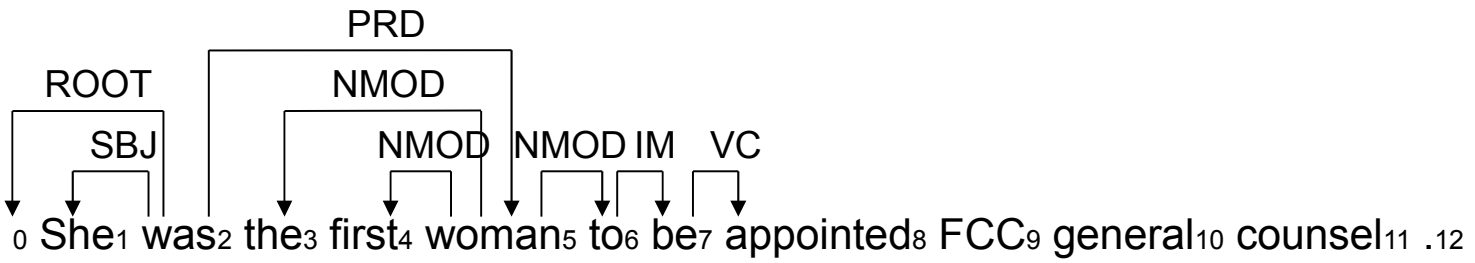
Fundamental Parsing Algorithm Example

[(1,2), (2,0), (5,4), (5,3), (2,5), (6,5), (7,6), (8,7)]

j: 9

i: 6

{l1=0.0099, **shift**=0.9894}



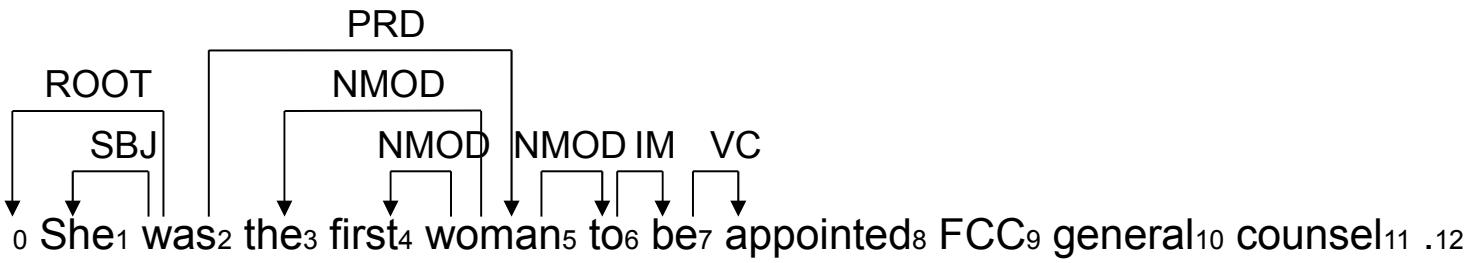
Fundamental Parsing Algorithm Example

[(1,2), (2,0), (5,4), (5,3), (2,5), (6,5), (7,6), (8,7)]

j: 9

i: 5

{l1=0.0054, **shift**=0.977}



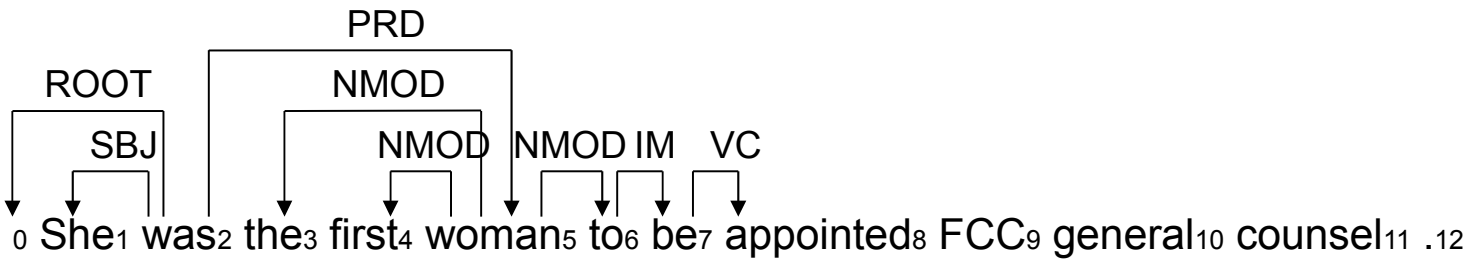
Fundamental Parsing Algorithm Example

[(1,2), (2,0), (5,4), (5,3), (2,5), (6,5), (7,6), (8,7)]

j: 9

i: 2

{l1=0.0371, **shift**=0.9576}



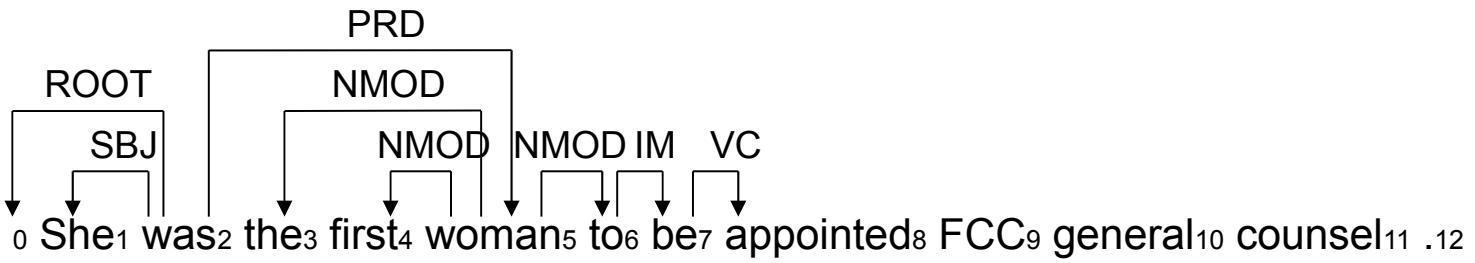
Fundamental Parsing Algorithm Example

[(1,2), (2,0), (5,4), (5,3), (2,5), (6,5), (7,6), (8,7)]

j: 10

i: 9

{l2=0.1853, l1=0.0035, **shift**=0.8112}



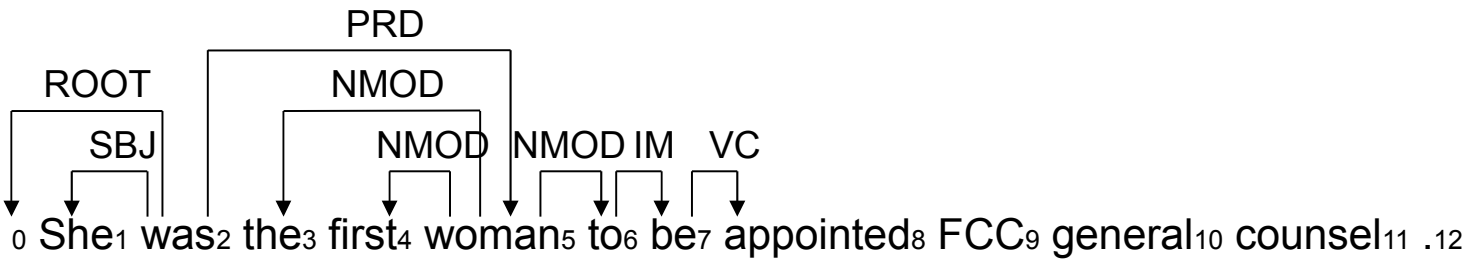
Fundamental Parsing Algorithm Example

[(1,2), (2,0), (5,4), (5,3), (2,5), (6,5), (7,6), (8,7)]

j: 10

i: 8

{l1=0.0344, **shift**=0.9581}



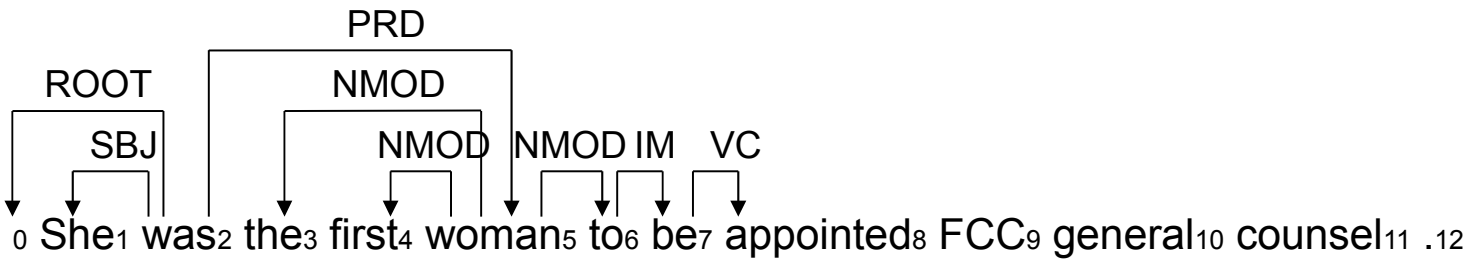
Fundamental Parsing Algorithm Example

[(1,2), (2,0), (5,4), (5,3), (2,5), (6,5), (7,6), (8,7)]

j: 10

i: 7

{l1=0.0115, **shift**=0.9884}



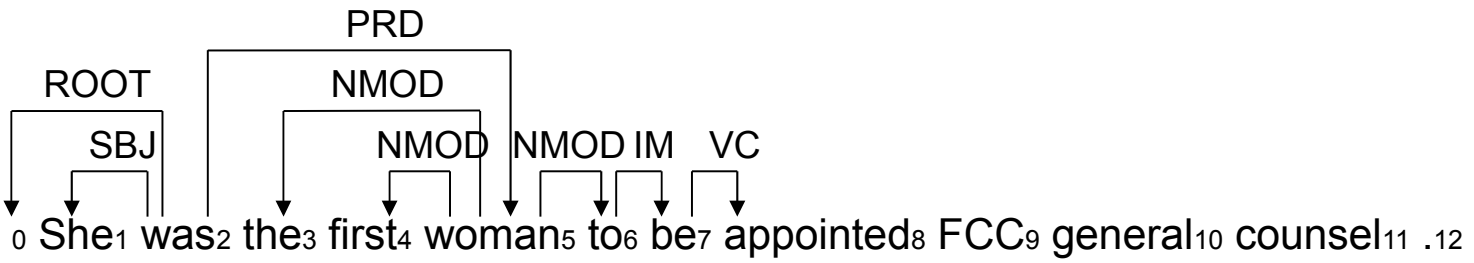
Fundamental Parsing Algorithm Example

[(1,2), (2,0), (5,4), (5,3), (2,5), (6,5), (7,6), (8,7)]

j: 10

i: 6

{l1=0.0072, **shift**=0.9924}



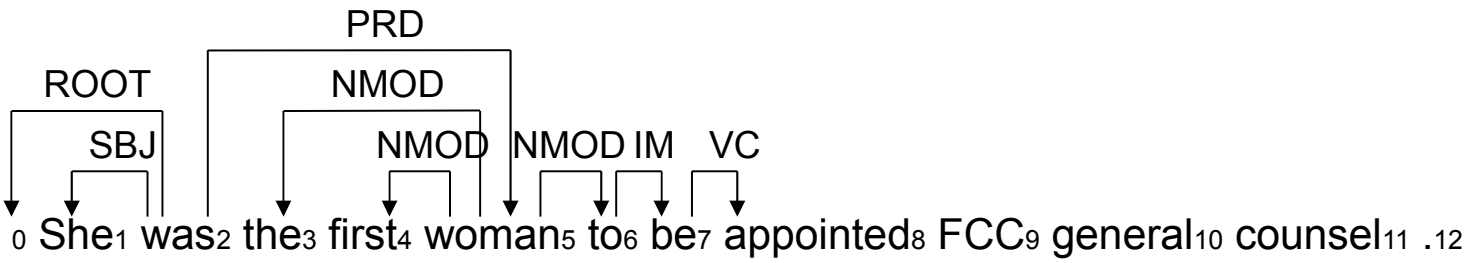
Fundamental Parsing Algorithm Example

[(1,2), (2,0), (5,4), (5,3), (2,5), (6,5), (7,6), (8,7)]

j: 10

i: 5

{l1=0.0039, **shift**=0.9858}



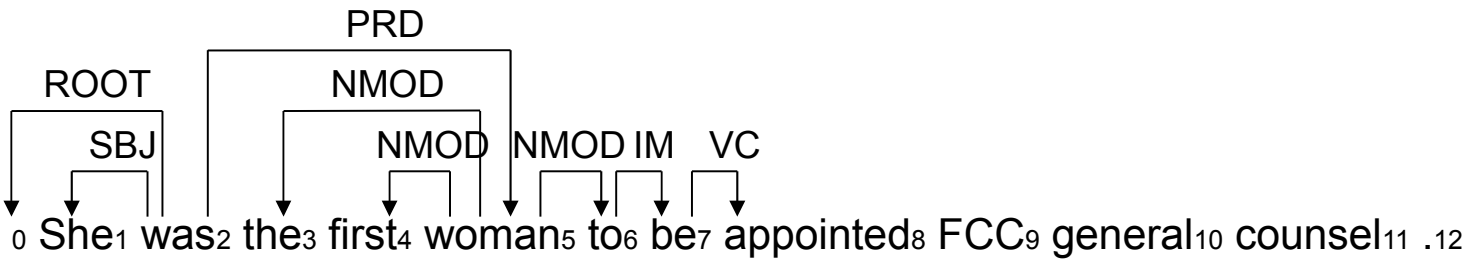
Fundamental Parsing Algorithm Example

[(1,2), (2,0), (5,4), (5,3), (2,5), (6,5), (7,6), (8,7)]

j: 10

i: 2

{l1=0.0272, **shift**=0.9697}



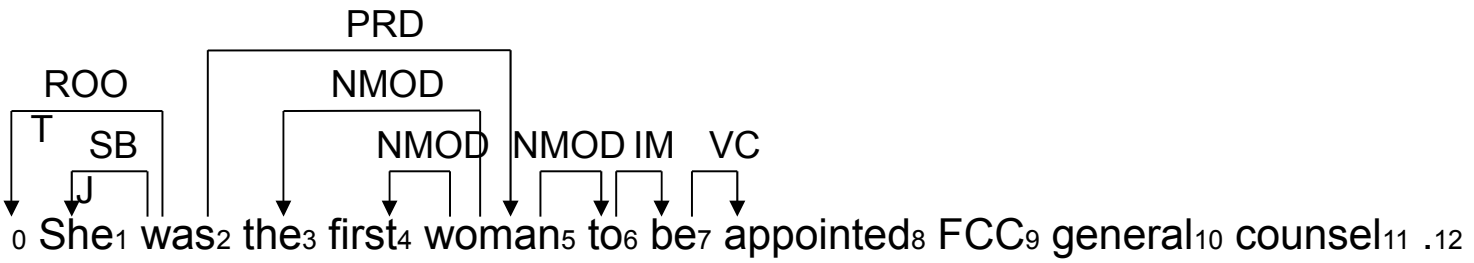
Fundamental Parsing Algorithm Example

[(1,2), (2,0), (5,4), (5,3), (2,5), (6,5), (7,6), (8,7)]

j: 11

i: 10

{**l2**=0.971, l1=0.0143, shift=0.0147}



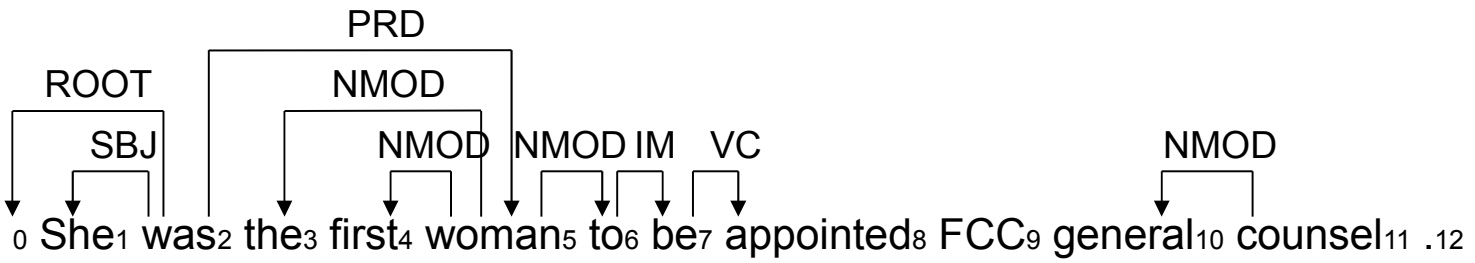
Fundamental Parsing Algorithm Example

[(1,2), (2,0), (5,4), (5,3), (2,5), (6,5), (7,6), (8,7), (10,11)]

j: 11

i: 9

{**l2**=0.9516, l1=0.023, shift=0.0255}



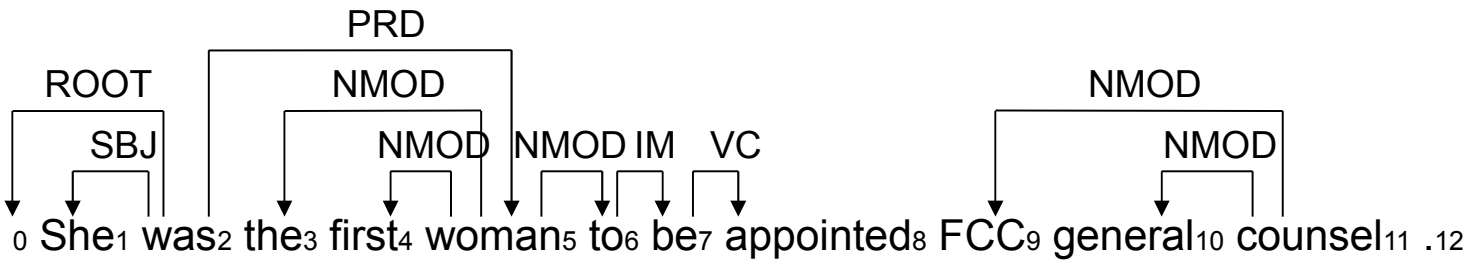
Fundamental Parsing Algorithm Example

[(1,2), (2,0), (5,4), (5,3), (2,5), (6,5), (7,6), (8,7), (10,11), (9,11)]

j: 11

i: 8

{**I1**=0.7512, shift=0.1036}



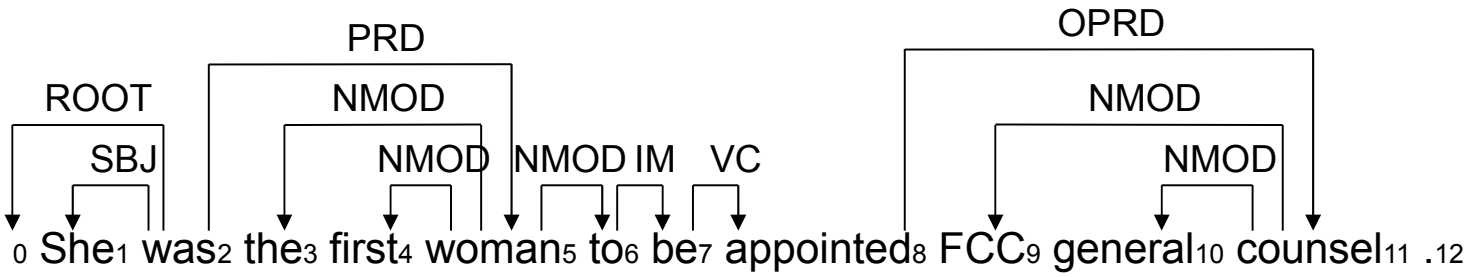
Fundamental Parsing Algorithm Example

[(1,2), (2,0), (5,4), (5,3), (2,5), (6,5), (7,6), (8,7), (10,11), (9,11), (11,8)]

j: 12

i: 11

{l1=0.1134, **shift**=0.8858}



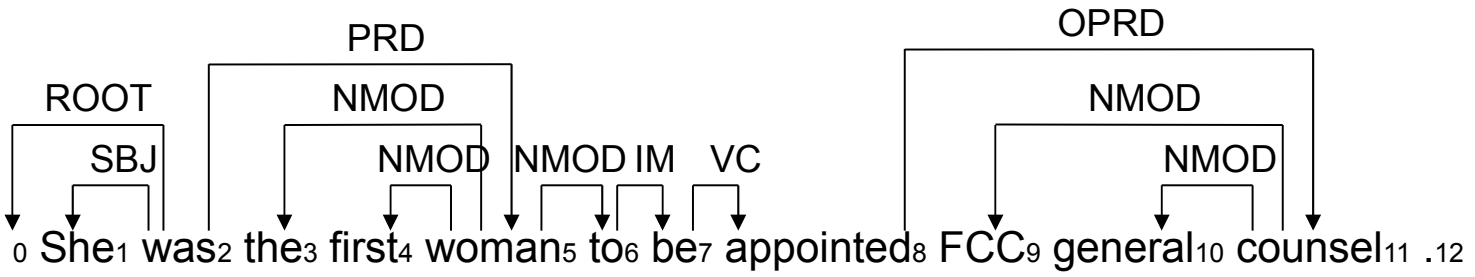
Fundamental Parsing Algorithm Example

[(1,2), (2,0), (5,4), (5,3), (2,5), (6,5), (7,6), (8,7), (10,11), (9,11), (11,8)]

j: 12

i: 8

{l1=0.2228, **shift**=0.7771}



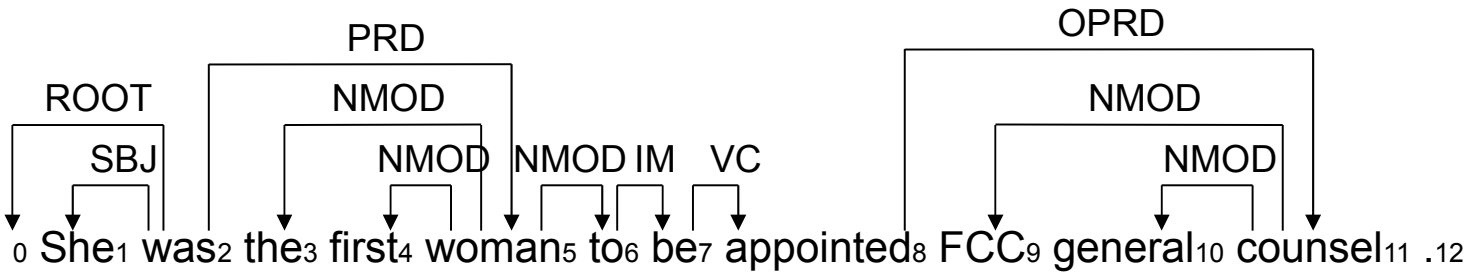
Fundamental Parsing Algorithm Example

[(1,2), (2,0), (5,4), (5,3), (2,5), (6,5), (7,6), (8,7), (10,11), (9,11), (11,8)]

j: 12

i: 7

{l1=0.2711, **shift**=0.7289}

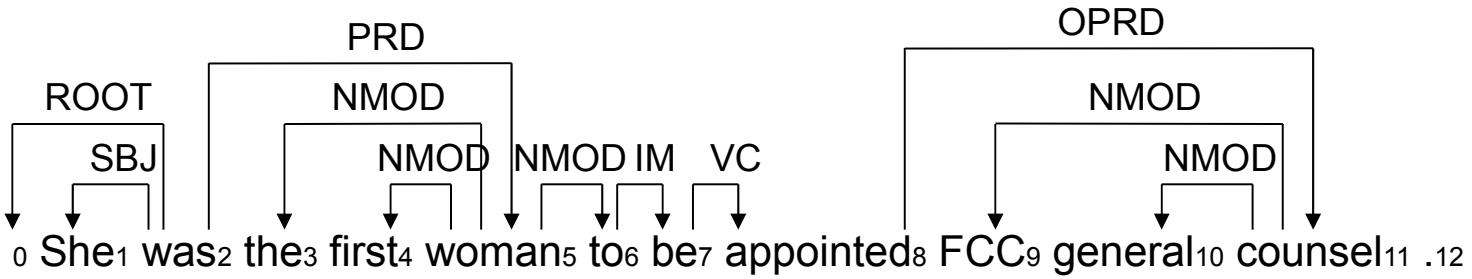


Fundamental Parsing Algorithm Example

[(1,2), (2,0), (5,4), (5,3), (2,5), (6,5), (7,6), (8,7), (10,11), (9,11), (11,8)]

j: 12
i: 6

{l1=0.1105, **shift**=0.8895}

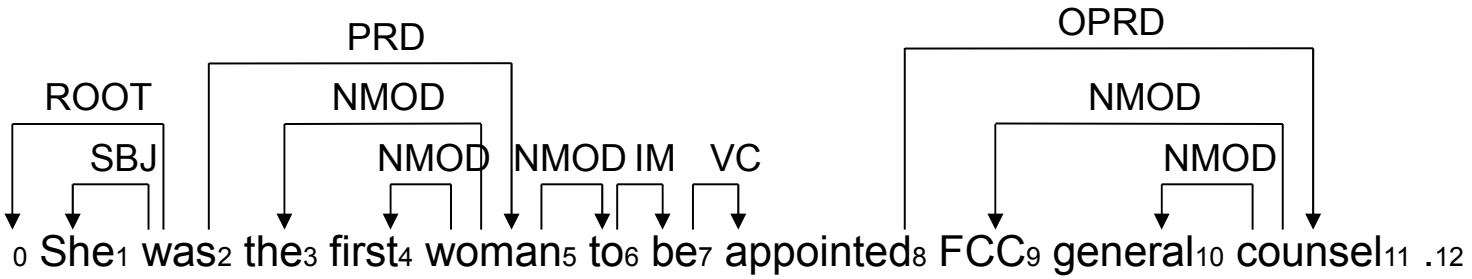


Fundamental Parsing Algorithm Example

[(1,2), (2,0), (5,4), (5,3), (2,5), (6,5), (7,6), (8,7), (10,11), (9,11), (11,8)]

j: 12
i: 5

{l1=0.0583, **shift**=0.9415}

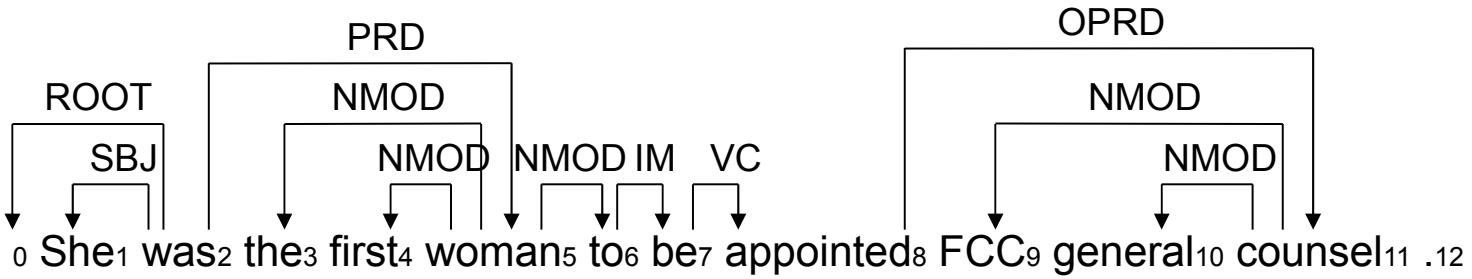


Fundamental Parsing Algorithm Example

[(1,2), (2,0), (5,4), (5,3), (2,5), (6,5), (7,6), (8,7), (10,11), (9,11), (11,8)]

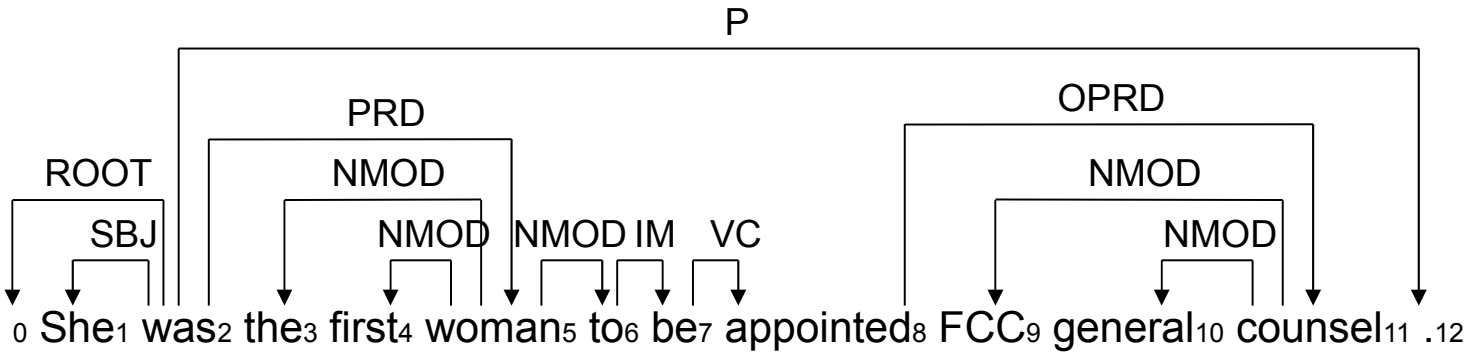
j: 12
i: 2

{**I1**=0.4616, shift=0.5383}



Fundamental Parsing Algorithm Example

[(1,2), (2,0), (5,4), (5,3), (2,5), (6,5), (7,6), (8,7), (10,11), (9,11), (11,8), (12, 2)]



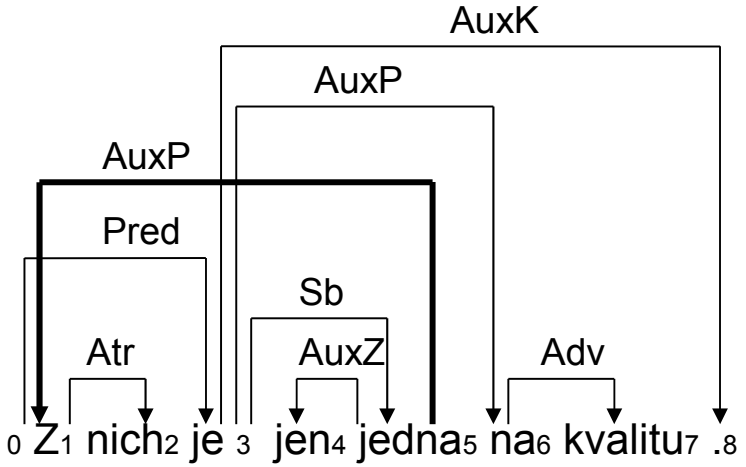
Output

1	She	PRP	2	SBJ
2	was	VBD	0	ROOT
3	the	DT	5	NMOD
4	first	JJ	5	NMOD
5	woman	NN	2	PRD
6	to	TO	5	NMOD
7	be	VB	6	IM
8	appointed	VBN	7	VC
9	FCC	NNP	11	NMOD
10	general	JJ	11	NMOD
11	counsel	NN	8	OPRD
12	.	.	2	P

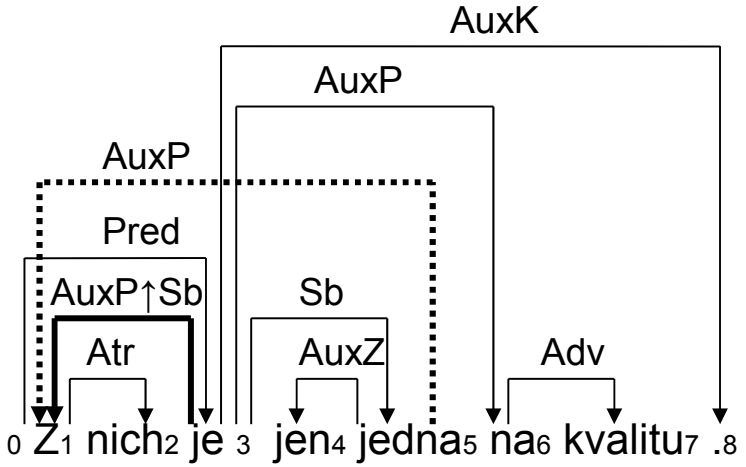
Pseudo-Projective Parsing

- Technique for projective parsers to create structures that can be transformed into non-projective structures
- Information about projectivity is encoded in arc labels

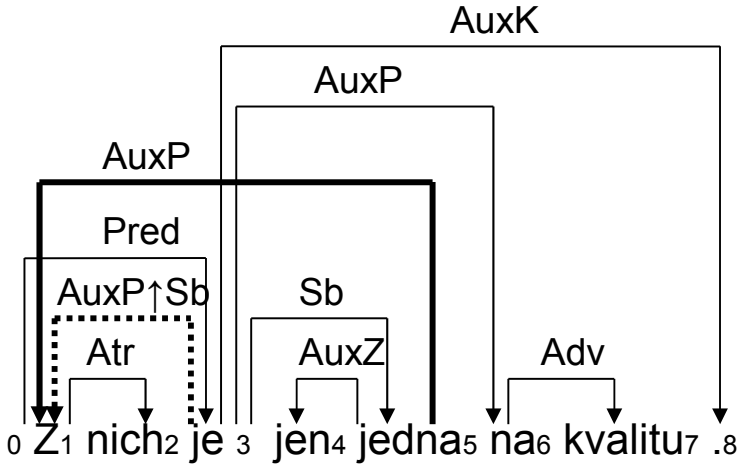
Pseudo-Projective Parsing Example



Pseudo-Projective Parsing Example



Pseudo-Projective Parsing Example



Machine Learning Libraries

- OpenNLP MaxEnt - http://maxent.sourceforge.net/howto.html
- Mallet Toolkit - http://mallet.cs.umass.edu/
- Liblinear - http://www.csie.ntu.edu.tw/~cjlin/liblinear/

OpenNLP

- OpenNLP – easiest tool, worst performance (accuracy and runtime)
- Two main classes: CreateModel and Predict
- Format:

  - training instance:

  Brendan N capitalized=true B-PER

  - classification instance:

  Richard N capitalized=true ?

  - classification result:

  B-PER[0.6441] I-PER[0.2060] 0[0.1499]

Example

Amerikaanse Adj B-MISC
tragikomische Adj O
film N O
van Prep O
Richard N B-PER
Benjamin N I-PER
uit Prep O
1996 Num O
met Prep O
Shirley N B-PER
MacLaine N I-PER
, Punc O
Ricki N B-PER
Lake N I-PER
, Punc O

Brendan N B-PER
Fraser N I-PER
, Punc O
Miguel N B-PER
Sandoval N I-PER
, Punc O
Loren N B-PER
Dean N I-PER
en Conj O
Peter N B-PER
Gerety N I-PER
. Punc O

Vorige Adj O
week N O
kondigde V O
minister N O
Aelvoet N B-PER
al Adv O
de Art O
invoering N O
van Prep O
Beltrace N B-MISC
(Punc O
Belgian N B-MISC
Tracability N I-MISC
) Punc O
aan Prep O
. Punc O

Vorige Adj ?
week N ?
kondigde V ?
minister N ?
Aelvoet N ?
al Adv ?
de Art ?
invoering N ?
van Prep ?
Beltrace N ?
(Punc ?
Belgian N ?
Tracability N ?
) Punc ?
aan Prep ?
. Punc ?

Mallet

- http://mallet.cs.umass.edu/mallet-tutorial.pdf
- Quite powerful, a little bit harder to use
- Important Classes:
  - Instance, InstanceList, Pipe
  - ClassifierTrainer, Classifier
  - Alphabet
  - Labeling
- Format: can be the same as with OpenNLP

Instances/Pipes/Alphabet

```
ArrayList<Pipe> pipeList = new ArrayList<Pipe>();

pipeList.add(new Target2Label());

pipeList.add(new CharSequence2TokenSequence());

pipeList.add(new TokenSequence2FeatureSequence());

pipeList.add(new FeatureSequence2FeatureVector());

Pipe pipe = new SerialPipes(pipeList);

InstanceList instances = new InstanceList(pipe);

FileInputStream in = new FileInputStream("input/ned.train");

InputStreamReader ir = new InputStreamReader(in,"UTF8");

BufferedReader fr = new BufferedReader(ir);

String line;

while ((line = fr.readLine())!= null) {

 if (line.length() > 0) {

String features = line.substring(0,line.lastIndexOf(" "));

String cl = line.substring(line.lastIndexOf(" ")+1);

Instance i = new Instance(features,cl,null,null);

instances.addThruPipe(i);

 }

}
```

Instance:

- Name - What is it called?
- **Data** - What is the input?
- **Target/Label** - What is the output?
- Source - What did it originally look like?

Pipes:

- Transform your input to internal representation
- Create alphabets

Alphabets:

- Allow efficient mappings
- Store features used during training
- Store possible class labels

Trainer/Classifier

```
MaxEntTrainer trainer =       new MaxEntTrainer();
Classifier classifier =    trainer.train(instances);
ObjectOutputStream oos = new ObjectOutputStream(new
FileOutputStream(classifierFile));
oos.writeObject(classifier);
oos.close();
```

```
ObjectInputStream serializedClassifier = new ObjectInputStream(new
FileInputStream(classifierFile));
Classifier classifier  = (Classifier)serializedClassifier.readObject();
FileInputStream in = new FileInputStream("input/ned.test");
InputStreamReader ir = new InputStreamReader(in,"UTF8");
BufferedReader fr = new BufferedReader(ir);
Pipe classifierPipe = classifier.getInstancePipe();
instances = new InstanceList(classifierPipe);
while ((line = fr.readLine())!= null) {
 if (line.length() > 0) {
    String features = line.substring(0,line.lastIndexOf(" "));
    String cl = line.substring(line.lastIndexOf(" ")+1);
    Instance i = new Instance(features,cl,null,null);
    instances.addThruPipe(i);
    System.out.println(classifier.classify(i).getLabeling().getBestLabel()+" "+cl);
 }
}
```

Liblinear

- Most powerful library, a little bit more effort to use
- You have to create and work with Alphabets yourself
- Format:

Amerikaanse Adj B-MISC	Amerikaanse=1 Adj=2 B-MISC=0	1:1 2:1 0
tragikomische Adj O	tragikomische=3 Adj=2 O=1	2:1 3:1 1
film N O	film=4 N=5 O=1	4:1 5:1 1
van Prep O	van=6 Prep=7 O=1	6:1 7:1 1

Models

```
private double    bias              = -1;
private Problem   prob              = null;
private Parameter param = new Parameter(SolverType.L1R_LR, 1, 0.01);
readProblem(trainingDataFile);
int l = this.prob.l;
int[] perm = new int[l];
GroupClassesReturn rv = groupClasses(this.prob, perm);
Model model = Linear.train(this.prob, this.param);
model.save(new File(modelFile));

Model.load(new File(modelFile));
```

groupClasses()

```
private static GroupClassesReturn groupClasses(Problem prob, int[] perm) {
     int l = prob.l;
     int max_nr_class = 16;
     int nr_class = 0;

     int[] label = new int[max_nr_class];
     int[] count = new int[max_nr_class];
     int[] data_label = new int[l];
     int i;

     for (i = 0; i < l; i++) {
         int this_label = prob.y[i];
         int j;
         for (j = 0; j < nr_class; j++) {
             if (this_label == label[j]) {
                 ++count[j];
                 break;
             }
         }
         data_label[i] = j;
         if (j == nr_class) {
             if (nr_class == max_nr_class) {
                 max_nr_class *= 2;
                 label = copyOf(label, max_nr_class);
                 count = copyOf(count, max_nr_class);
             }
             label[nr_class] = this_label;
             count[nr_class] = 1;
             ++nr_class;
         }
     }

     int[] start = new int[nr_class];
     start[0] = 0;
     for (i = 1; i < nr_class; i++)
         start[i] = start[i - 1] + count[i - 1];
     for (i = 0; i < l; i++) {
         perm[start[data_label[i]]] = i;
         ++start[data_label[i]];
     }
     start[0] = 0;
     for (i = 1; i < nr_class; i++)
         start[i] = start[i - 1] + count[i - 1];

     return new GroupClassesReturn(nr_class, label, start, count);
 }
```

readProblem()

```
public void readProblem(String filename) throws IOException, InvalidInputDataException {
            BufferedReader fp = new BufferedReader(new FileReader(filename));
            List<Integer> vy = new ArrayList<Integer>();
            List<FeatureNode[]> vx = new ArrayList<FeatureNode[]>();
            int max_index = 0;
        int lineNr = 0;

    try {
       while (true) {
            String line = fp.readLine();
            if (line == null) break;
              lineNr++;

                 StringTokenizer st = new StringTokenizer(line, " \t\n\r\f:");
                      String token = st.nextToken();

              try {
                    vy.add(liblinear.Linear.atoi(token));
                      } catch (NumberFormatException e) {
                     throw new InvalidInputDataException("invalid label: " + token, filename, lineNr, e);
                      }

                  int m = st.countTokens() / 2;
                 FeatureNode[] x;
                if (bias >= 0) {
                      x = new FeatureNode[m + 1];
             } else {
                         x = new FeatureNode[m];
               }
                int indexBefore = 0;
               for (int j = 0; j < m; j++) {

                         token = st.nextToken();
                    int index;
                          try {
                      index = liblinear.Linear.atoi(token);
                    } catch (NumberFormatException e) {
                        throw new InvalidInputDataException("invalid index: " + token, filename, lineNr, e);
                          }

                      // assert that indices are valid and sorted
                     if (index < 0) throw new InvalidInputDataException("invalid index: " + index, filename, lineNr);
                     if (index <= indexBefore) throw new InvalidInputDataException("indices must be sorted in ascending order", filename, lineNr);
                    indexBefore = index;

                   token = st.nextToken();
                      try {
                                double value = liblinear.Linear.atof(token);
                               x[j] = new FeatureNode(index, value);
                           } catch (NumberFormatException e) {
                          throw new InvalidInputDataException("invalid value: " + token, filename, lineNr);
                     }
             }
                if (m > 0) {
                    max_index = Math.max(max_index, x[m - 1].index);
              }

                 vx.add(x);
             }
            prob = constructProblem(vy, vx, max_index);
        }
        finally {
             fp.close();
         }
     }
```

Classification

```
String[] instance = integerRepresentation.split(" ");
FeatureNode[] predArray = new FeatureNode[instance.length-1];
double[] scoreArray = new double[alphabet.getNumberOfLabels()];
// calculating the score for each label
for (int i=1; i < instance.length; i++) {
     String[] fArray = instance[i].split(":");
     int fIndex = Integer.valueOf(fArray[0]);
     if (scoreArray.length != 2) {
          for (int k=0; k < scoreArray.length; k++) {
               double w = model.w[(fIndex-1)*scoreArray.length+k];
               scoreArray[k] += w;
          }
     }
     else {
          scoreArray[0] += model.w[fIndex-1];
          scoreArray[1] += (-1)*model.w[fIndex-1];
     }
     FeatureNode fn = new FeatureNode(fIndex,1);
     predArray[i-1] = fn;
}
predictedLabelIndex = -1;
double max = Double.NEGATIVE_INFINITY;
double[] probArray = new double[scoreArray.length];
// determining the index of the top scored label
for (int i=0; i < scoreArray.length; i++) {
     if (scoreArray[i] > max ) {
          max = scoreArray[i];
          predictedLabelIndex = i+1;
     }
}
// calculating probabilities out of the scores
double sum = 0.0;
for (int i=0; i < probArray.length; i++) {
     probArray[i] = Math.exp(scoreArray[i]-max);
     sum += probArray[i];
}
// normalization
for (int i=0; i < probArray.length; i++) {
     probArray[i] /= sum;
}
```

1:1 3:1 5:1 9:1

Alphabet(Labels) = {0,1,2}

0.5 1.5 -2.0
0.3 0.2 -0.5
0 1.0 -1.0
0.2 -0.1 -0.1

0.4
0.2
-0.3
-0.1

Corresponds to the
Classification slide from Lecture 1

CoNLL Format

1 – Index, 2 – Word Form, 3 – Lemma,
4 – POS(coarse), 5 – POS(fine), 6 – Morphology,
7 – Head, 8 – Dep type

1	Ms.	Ms.	NNP	NNP	_	2	TITLE
2	Haag	Haag	NNP	NNP	_	3	SBJ
3	plays	plays	VBZ	VBZ	_	0	ROOT
4	Elianti	Elianti	NNP	NNP	_	3	OBJ
5	.	.	.	.	_	3	P

Enjoy training your own dependency parser!