

1. Accuracy and runtime of CRF model

(1) Viterbi

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Viterbi decoding took 42.636644 seconds  
Labeled F1: 79.00, precision: 4329/5016 = 86.30, recall: 4329/5943 = 72.84
```

(2) Beam

k = 1

```
Beam decoding took 13.048968 seconds  
Labeled F1: 72.81, precision: 3949/4905 = 80.51, recall: 3949/5943 = 66.45
```

k = 2

```
Beam decoding took 16.921504 seconds  
Labeled F1: 75.03, precision: 4101/4989 = 82.20, recall: 4101/5943 = 69.01
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k = 3

```
Beam decoding took 21.727504 seconds  
Labeled F1: 75.79, precision: 4148/5003 = 82.91, recall: 4148/5943 = 69.80
```

k = 4

```
Beam decoding took 23.993286 seconds  
Labeled F1: 78.20, precision: 4284/5013 = 85.46, recall: 4284/5943 = 72.08
```

2. The accuracy would be slightly lower than the Viterbi algorithm method, but the runtime would be much faster. (The smaller the beam size is, the faster the program execute)

	Viterbi algorithm	Beam search algorithm			
		k = 1	k = 2	k = 3	k = 4
accuracy	79.58	72.81	75.03	75.79	78.20
runtime	42.63 sec	13.04 sec	16.92sec	21.72 sec	23.99 sec

3. The time complexity of the Viterbi algorithm is $O(TN^2)$, for T equal to the length of the time series, and N equal to the size of state. In the beam search algorithm, it reduces the size of the state to K (For $K \ll N$) which makes the runtime much faster. If there are some language models with a huge number of states, a beam search algorithm would be a good choice by losing some accuracy.