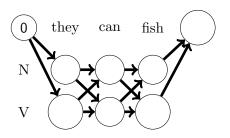
CS 4650/7650 Examples of Viterbi, Forward, and Backward algorithms

Jacob Eisenstein

September 19, 2013

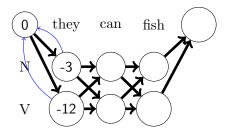
Transitions			
	N	V	END
N	-3	-1	-2
V	-1	-3	-2
START	-1	-2	

Emissions					
they can fish					
N	-2	-3	-3		
V	-10	-1	-3		



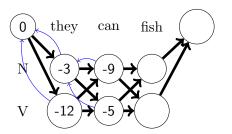
Transitions			
	N	V	END
N	-3	-1	-2
V	-1	-3	-2
START	-1	-2	

Emissions					
they can fish					
N	-2	-3	-3		
V	-10	-1	-3		



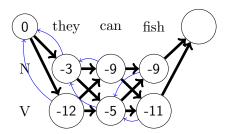
Transitions			
	N	V	END
N	-3	-1	-2
V	-1	-3	-2
START	-1	-2	

Emissions					
they can fish					
N	-2	-3	-3		
V	-10	-1	-3		



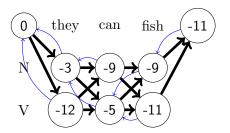
Transitions			
	N	V	END
N	-3	-1	-2
V	-1	-3	-2
START	-1	-2	

Emissions					
they can fish					
N	-2	-3	-3		
V	-10	-1	-3		



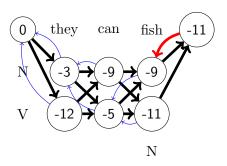
Transitions			
	N	V	END
N	-3	-1	-2
V	-1	-3	-2
START	-1	-2	

Emissions					
they can fish					
N	-2	-3	-3		
V	-10	-1	-3		



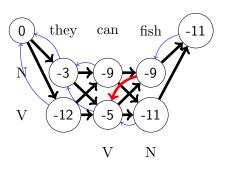
Transitions			
	N	V	END
N	-3	-1	-2
V	-1	-3	-2
START	-1	-2	

Emissions					
they can fish					
N	-2	-3	-3		
V	-10	-1	-3		



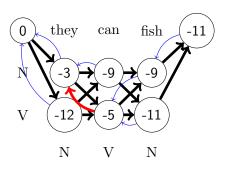
Transitions							
N V END							
N	-3	-1	-2				
V	-1	-3	-2				
START -1 -2							

Emissions						
	they can fish					
N	-2	-3	-3			
V	V -10 -1 -3					



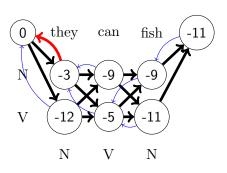
Transitions						
N V END						
N	-3	-1	-2			
V	-1	-3	-2			
START -1 -2						

Emissions						
they can fish						
N	-2	-3	-3			
V	/ -10 -1 -3					



Transitions						
N V END						
N	-3	-1	-2			
V	-1	-3	-2			
START -1 -2						

Emissions						
	they can fish					
N	-2	-3	-3			
V	V -10 -1 -3					



Now let's add a tag \boldsymbol{M} for modal verbs.

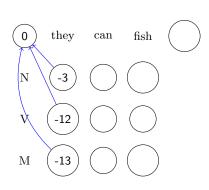
Transition						
N V M END						
N	-3	-1	-2	-2		
V	-1	-2	-5	-2		
M	-10	0	-3	-10		
Start	-1	-2	-3			

	Emission					
	they can fish					
N	-2	-3	-3			
V	-10	-2	-3			
М	-10	-1	-10			

0	they	can	fish	
N				
V				
M				

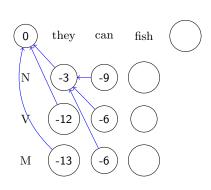
Transition					
	N	V	М	END	
N	-3	-1	-2	-2	
V	-1	-2	-5	-2	
M	-10	0	-3	-10	
Start	-1	-2	-3		

	Emission					
	they can fish					
N	-2	-3	-3			
V	-10	-2	-3			
М	-10	-1	-10			



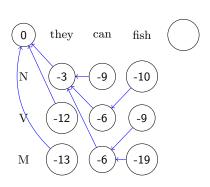
Transition				
	N	V	М	END
N	-3	-1	-2	-2
V	-1	-2	-5	-2
М	-10	0	-3	-10
Start	-1	-2	-3	

	Emission				
	they can fish				
N	-2	-3	-3		
V	-10	-2	-3		
M	-10	-1	-10		



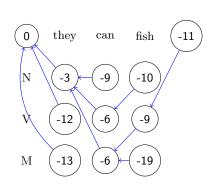
Transition				
	N	V	М	END
N	-3	-1	-2	-2
V	-1	-2	-5	-2
М	-10	0	-3	-10
Start	-1	-2	-3	

Emission						
	they can fish					
N	-2	-3	-3			
V	-10	-2	-3			
М	-10	-1	-10			



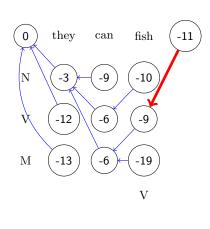
Transition				
	N	V	М	END
N	-3	-1	-2	-2
V	-1	-2	-5	-2
М	-10	0	-3	-10
Start	-1	-2	-3	

Emission						
	they can fish					
N	-2	-3	-3			
V	-10	-2	-3			
М	-10	-1	-10			



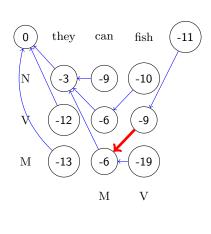
Transition				
	N	V	М	END
N	-3	-1	-2	-2
V	-1	-2	-5	-2
М	-10	0	-3	-10
Start	-1	-2	-3	

	Emission					
	they can fish					
N	-2	-3	-3			
V	-10	-2	-3			
М	-10	-1	-10			



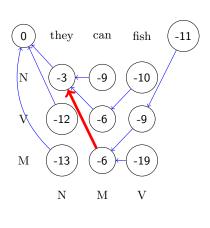
Transition				
	N	V	М	END
N	-3	-1	-2	-2
V	-1	-2	-5	-2
М	-10	0	-3	-10
Start	-1	-2	-3	

	Emission				
	they	can	fish		
N	-2	-3	-3		
V	-10	-2	-3		
М	-10	-1	-10		



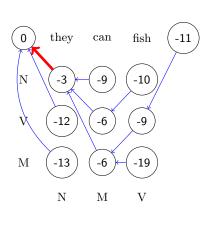
Transition				
	N	V	М	END
N	-3	-1	-2	-2
V	-1	-2	-5	-2
М	-10	0	-3	-10
Start	-1	-2	-3	

	Emission				
	they	fish			
N	-2	-3	-3		
V	-10	-2	-3		
M	-10	-1	-10		



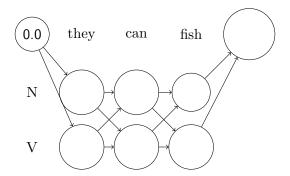
	Iransition				
	N	V	М	END	
N	-3	-1	-2	-2	
V	-1	-2	-5	-2	
M	-10	0	-3	-10	
Start	-1	-2	-3		

	Emission					
	they can fish					
N	-2	-3	-3			
V	-10	-2	-3			
M	-10	-1	-10			



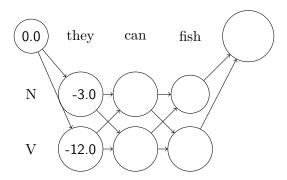
Iransitions					
	Ν	V	END		
N	-3	-1	-2		
V	-1	-3	-2		
START	-1	-2			

Emissions					
they can fish					
N	-2	-3	-3		
V	-10	-1	-3		



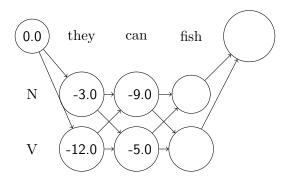
Iransitions					
	Ν	V	END		
N	-3	-1	-2		
V	-1	-3	-2		
START	-1	-2			

Emissions					
they can fish					
N	-2	-3	-3		
V	-10	-1	-3		



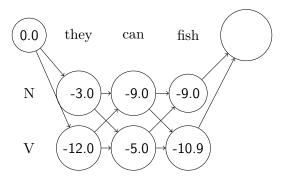
Transitions					
	Ν	V	END		
N	-3	-1	-2		
V	-1	-3	-2		
START	-1	-2			

Emissions					
they can fish					
N	-2	-3	-3		
V	-10	-1	-3		



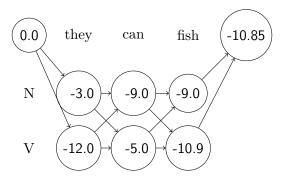
Transitions					
	N	V	END		
N	-3	-1	-2		
V	-1	-3	-2		
START	-1	-2			

Emissions				
they can fish				
N	-2	-3	-3	
V	-10	-1	-3	



	Transitions					
		N	V	END		
N		-3	-1	-2		
V		-1	-3	-2		
S	ΓART	-1	-2			

Emissions				
they can fish				
N	-2	-3	-3	
V	-10	-1	-3	



Example: backward algorithm

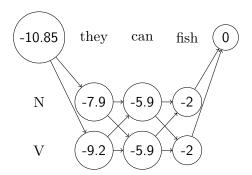
ır	iransitions					
	N	V	END			
N	-3	-1	-2			
V	-1	-3	-2			
START	-1	-2				

Emissions						
	they can fish					
N	-2	-3	-3			
V	-10	-1	-3			

Example: backward algorithm

Iransitions				
N	V	END		
-3	-1	-2		
-1	-3	-2		
-1	-2			
	-3 -1 -1	N V -3 -1 -1 -3		

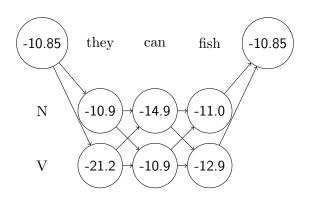
Emissions					
they can fish					
N	-2	-3	-3		
V	-10	-1	-3		



Example: marginal probabilities

	N	V	END
N	-3	-1	-2
V	-1	-3	-2
START	-1	-2	

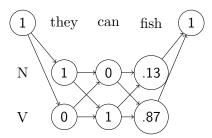
Emissions					
they can fish					
N	-2	-3	-3		
V	-10	-1	-3		



Example: marginal probabilities

	Ν	V	END
N	-3	-1	-2
V	-1	-3	-2
START	-1	-2	

Emissions					
they can fish					
N	-2	-3	-3		
V	-10	-1	-3		



Example: marginal probabilities

Transition weights						
(log-probabilities)						
	N V END					
N	-2	-1	-2			
V	-2	-3	-2			
START	-1	-2				

Emission weights
(log-probabilities)
they can fish

N -2 -3 -3
V -6 -1 -2

$$\begin{split} \log P(they/N \; can/V \; fish/V) &= -1 - 2 - 1 - 1 - 3 - 2 - 2 = -12 \\ \log P(they/N \; can/V \; fish/N) &= -1 - 2 - 1 - 1 - 2 - 3 - 2 = -12 \\ \log P(they/V \; ...) &\approx -\infty \\ \log \sum_{y} \exp P(y_1, y_2 = V, y_3, x_{1:3}) &= \log(e^{-12} + e^{-12} + e^{-\infty} + e^{-\infty}) \\ &= -11.3 = f_2(V) + b_2(V) \end{split}$$