

0 Papa 1 ate 2 the 3 caviar 4 with 5 a 6 spoon 7

# Our Usual Example Grammar

ROOT  $\rightarrow$  S

S  $\rightarrow$  NP VP

NP  $\rightarrow$  Papa

NP  $\rightarrow$  Det N

N  $\rightarrow$  caviar

NP  $\rightarrow$  NP PP

N  $\rightarrow$  spoon

VP  $\rightarrow$  VP PP

V  $\rightarrow$  ate

VP  $\rightarrow$  V NP

P  $\rightarrow$  with

PP  $\rightarrow$  P NP

Det  $\rightarrow$  the

Det  $\rightarrow$  a

0
0 ROOT . S

initialize

*Remember this stands for (0, ROOT  $\rightarrow$  . S)*

0
0 ROOT . S
0 S . NP VP

**predict** the kind of S we are looking for

*Remember this stands for  $(0, S \rightarrow . NP VP)$*

0
0 ROOT . S
0 S . NP VP
0 NP . Det N
0 NP . NP PP
0 NP . Papa

**predict** the kind of NP we are looking for  
*(actually we'll look for 3 kinds: any of the 3 will do)*

0
0 ROOT . S
0 S . NP VP
0 NP . Det N
0 NP . NP PP
0 NP . Papa
0 Det . the
0 Det . a

**predict** the kind of Det we are looking for (*2 kinds*)

0
0 ROOT . S
0 S . NP VP
0 NP . Det N
0 NP . NP PP
0 NP . Papa
0 Det . the
0 Det . a

**predict** the kind of NP we're looking for  
*but we were already looking for these so  
don't add duplicate goals! Note that this happened  
when we were processing a left-recursive rule.*

0	Papa	1
0 ROOT . S	0 NP Papa .	
0 S . NP VP		
0 NP . Det N		
0 NP . NP PP		
0 NP . Papa		
0 Det . the		
0 Det . a		

**scan:** the desired word is in the input!

0 Papa 1	
0 ROOT . S	0 NP Papa .
0 S . NP VP	
0 NP . Det N	
0 NP . NP PP	
0 NP . Papa	
0 Det . the	
0 Det . a	

scan: failure



0 Papa 1	
0 ROOT . S	0 NP Papa .
0 S . NP VP	
0 NP . Det N	
0 NP . NP PP	
0 NP . Papa	
0 Det . the	
0 Det . a	

scan: failure

0	Papa	1
0 ROOT . S	0 NP Papa .	
0 S . NP VP	0 S NP . VP	
0 NP . Det N	0 NP NP . PP	
0 NP . NP PP		
0 NP . Papa		
0 Det . the		
0 Det . a		

**attach** the newly created NP  
 (which starts at 0) to its **customers**  
 (incomplete constituents that *end* at 0  
 and have NP after the dot)

0	Papa	1
0 ROOT . S	0 NP Papa .	
0 S . NP VP	0 S NP . VP	
0 NP . Det N	0 NP NP . PP	
0 NP . NP PP	1 VP . V NP	
0 NP . Papa	1 VP . VP PP	
0 Det . the		
0 Det . a		

predict

0      Papa      1	
0 ROOT . S	0 NP Papa .
0 S . NP VP	0 S NP . VP
0 NP . Det N	0 NP NP . PP
0 NP . NP PP	1 VP . V NP
0 NP . Papa	1 VP . VP PP
0 Det . the	1 PP . P NP
0 Det . a	

predict

0      Papa      1	
0 ROOT . S	0 NP Papa .
0 S . NP VP	0 S NP . VP
0 NP . Det N	0 NP NP . PP
0 NP . NP PP	1 VP . V NP
0 NP . Papa	1 VP . VP PP
0 Det . the	1 PP . P NP
0 Det . a	1 V . ate

predict

0	Papa	1
0 ROOT . S	0 NP Papa .	
0 S . NP VP	0 S NP . VP	
0 NP . Det N	0 NP NP . PP	
0 NP . NP PP	1 VP . V NP	
0 NP . Papa	1 VP . VP PP	
0 Det . the	1 PP . P NP	
0 Det . a	1 V . ate	

predict

0      Papa      1	
0 ROOT . S	0 NP Papa .
0 S . NP VP	0 S NP . VP
0 NP . Det N	0 NP NP . PP
0 NP . NP PP	1 VP . V NP
0 NP . Papa	1 VP . VP PP
0 Det . the	1 PP . P NP
0 Det . a	1 V . ate
	1 P . with

predict

0	Papa	1	ate	2
0 ROOT . S	0 NP Papa .	1 V ate .		
0 S . NP VP	0 S NP . VP			
0 NP . Det N	0 NP NP . PP			
0 NP . NP PP	1 VP . V NP			
0 NP . Papa	1 VP . VP PP			
0 Det . the	1 PP . P NP	scan: su		
0 Det . a	1 V . ate			
	1 P . with			

**scan: success!**



[illegible]

0	Papa	1	ate	2
0 ROOT . S	0 NP Papa .	1 V ate .		
0 S . NP VP	0 S NP . VP	1 VP V . NP		
0 NP . Det N	0 NP NP . PP			
0 NP . NP PP	1 VP . V NP			
0 NP . Papa	1 VP . VP PP			
0 Det . the	1 PP . P NP			
0 Det . a	1 V . ate			
	1 P . with			

attach

0	Papa	1	ate	2
0 ROOT . S	0 NP Papa .	1 V ate .		
0 S . NP VP	0 S NP . VP	1 VP V . NP		
0 NP . Det N	0 NP NP . PP	2 NP . Det N		
0 NP . NP PP	1 VP . V NP	2 NP . NP PP		
0 NP . Papa	1 VP . VP PP	2 NP . Papa		
0 Det . the	1 PP . P NP			
0 Det . a	1 V . ate			
	1 P . with			

predict

0	Papa	1	ate	2
0 ROOT . S	0 NP Papa .	1 V ate .		
0 S . NP VP	0 S NP . VP	1 VP V . NP		
0 NP . Det N	0 NP NP . PP	2 NP . Det N		
0 NP . NP PP	1 VP . V NP	2 NP . NP PP		
0 NP . Papa	1 VP . VP PP	2 NP . Papa		
0 Det . the	1 PP . P NP	2 Det . the		
0 Det . a	1 V . ate	2 Det . a		
	1 P . with			

**predict** *(these next few steps should look familiar)*

0	Papa	1	ate	2
0 ROOT . S	0 NP Papa .	1 V ate .		
0 S . NP VP	0 S NP . VP	1 VP V . NP		
0 NP . Det N	0 NP NP . PP	2 NP . Det N		
0 NP . NP PP	1 VP . V NP	2 NP . NP PP		
0 NP . Papa	1 VP . VP PP	2 NP . Papa		
0 Det . the	1 PP . P NP	2 Det . the		
0 Det . a	1 V . ate	2 Det . a		
	1 P . with			

predict

0	Papa	1	ate	2
0 ROOT . S	0 NP Papa .	1 V ate .		
0 S . NP VP	0 S NP . VP	1 VP V . NP		
0 NP . Det N	0 NP NP . PP	2 NP . Det N		
0 NP . NP PP	1 VP . V NP	2 NP . NP PP		
0 NP . Papa	1 VP . VP PP	2 NP . Papa		
0 Det . the	1 PP . P NP	2 Det . the		
0 Det . a	1 V . ate	2 Det . a		
	1 P . with			

**scan** (*this time we fail since Papa is not the next word*)

0	Papa	1	ate	2	the	3
0 ROOT . S	0 NP Papa .	1 V ate .	2 Det the .			
0 S . NP VP	0 S NP . VP	1 VP V . NP				
0 NP . Det N	0 NP NP . PP	2 NP . Det N				
0 NP . NP PP	1 VP . V NP	2 NP . NP PP				
0 NP . Papa	1 VP . VP PP	2 NP . Papa				
0 Det . the	1 PP . P NP	2 Det . the				
0 Det . a	1 V . ate	2 Det . a				
	1 P . with					

scan: success!













0	Papa	1	ate	2	the	3	caviar	4
0 ROOT . S	0 NP Papa .	1 V ate .	2 Det the .	3 N caviar .				
0 S . NP VP	0 S NP . VP	1 VP V . NP	2 NP Det . N	2 NP Det N .				
0 NP . Det N	0 NP NP . PP	2 NP . Det N	3 N . caviar					
0 NP . NP PP	1 VP . V NP	2 NP . NP PP	3 N . spoon					
0 NP . Papa	1 VP . VP PP	2 NP . Papa						
0 Det . the	1 PP . P NP	2 Det . the						
0 Det . a	1 V . ate	2 Det . a						
	1 P . with							

attach

0	Papa	1	ate	2	the	3	caviar	4
0 ROOT . S	0 NP Papa .	1 V ate .	2 Det the .	3 N caviar .				
0 S . NP VP	0 S NP . VP	1 VP V . NP	2 NP Det . N	2 NP Det N .				
0 NP . Det N	0 NP NP . PP	2 NP . Det N	3 N . caviar	1 VP V NP .				
0 NP . NP PP	1 VP . V NP	2 NP . NP PP	3 N . spoon	2 NP NP . PP				
0 NP . Papa	1 VP . VP PP	2 NP . Papa						
0 Det . the	1 PP . P NP	2 Det . the						
0 Det . a	1 V . ate	2 Det . a						
	1 P . with							

**attach**  
(again!)

0	Papa	1	ate	2	the	3	caviar	4
0 ROOT . S	0 NP Papa .	1 V ate .	2 Det the .	3 N caviar .				
0 S . NP VP	0 S NP . VP	1 VP V . NP	2 NP Det . N	2 NP Det N .				
0 NP . Det N	0 NP NP . PP	2 NP . Det N	3 N . caviar	1 VP V NP .				
0 NP . NP PP	1 VP . V NP	2 NP . NP PP	3 N . spoon	2 NP NP . PP				
0 NP . Papa	1 VP . VP PP	2 NP . Papa		0 S NP VP .				
0 Det . the	1 PP . P NP	2 Det . the		1 VP VP . PP				
0 Det . a	1 V . ate	2 Det . a						
	1 P . with							

**attach**  
(again!)





0	Papa	1	ate	2	the	3	caviar	4
0 ROOT . S	0 NP Papa .	1 V ate .	2 Det the .	3 N caviar .				
0 S . NP VP	0 S NP . VP	1 VP V . NP	2 NP Det . N	2 NP Det N .				
0 NP . Det N	0 NP NP . PP	2 NP . Det N	3 N . caviar	1 VP V NP .				
0 NP . NP PP	1 VP . V NP	2 NP . NP PP	3 N . spoon	2 NP NP . PP				
0 NP . Papa	1 VP . VP PP	2 NP . Papa		0 S NP VP .				
0 Det . the	1 PP . P NP	2 Det . the		1 VP VP . PP				
0 Det . a	1 V . ate	2 Det . a		4 PP . P NP				
	1 P . with			0 ROOT S .				

**attach**  
(again!)











































0	Papa	1	ate	2	the	3	caviar	4	with a spoon	7
0 ROOT . S	0 NP Papa .	1 V ate .	2 Det the .	3 N caviar .	...	6 N spoon .				
0 S . NP VP	0 S NP . VP	1 VP V . NP	2 NP Det . N	2 NP Det N .		5 NP Det N .				
0 NP . Det N	0 NP NP . PP	2 NP . Det N	3 N . caviar	1 VP V NP .		4 PP P NP .				
0 NP . NP PP	1 VP . V NP	2 NP . NP PP	3 N . spoon	2 NP NP . PP		5 NP NP . PP				
0 NP . Papa	1 VP . VP PP	2 NP . Papa		0 S NP VP .		2 NP NP PP .				
0 Det . the	1 PP . P NP	2 Det . the		1 VP VP . PP		1 VP VP PP .				
0 Det . a	1 V . ate	2 Det . a		4 PP . P NP		7 PP . P NP				
	1 P . with			0 ROOT S .		1 VP V NP .				
				4 P . with		2 NP NP . PP				

0	Papa	1	ate	2	the	3	caviar	4	with a spoon	7
0 ROOT . S	0 NP Papa .	1 V ate .	2 Det the .	3 N caviar .	...	6 N spoon .				
0 S . NP VP	0 S NP . VP	1 VP V . NP	2 NP Det . N	2 NP Det N .		5 NP Det N .				
0 NP . Det N	0 NP NP . PP	2 NP . Det N	3 N . caviar	1 VP V NP .		4 PP P NP .				
0 NP . NP PP	1 VP . V NP	2 NP . NP PP	3 N . spoon	2 NP NP . PP		5 NP NP . PP				
0 NP . Papa	1 VP . VP PP	2 NP . Papa		0 S NP VP .		2 NP NP PP .				
0 Det . the	1 PP . P NP	2 Det . the		1 VP VP . PP		1 VP VP PP .				
0 Det . a	1 V . ate	2 Det . a		4 PP . P NP		7 PP . P NP				
	1 P . with			0 ROOT S .		1 VP V NP .				
				4 P . with		2 NP NP . PP				
						0 S NP VP .				
						1 VP VP . PP				

0	Papa	1	ate	2	the	3	caviar	4	with a spoon	7
0 ROOT . S	0 NP Papa .	1 V ate .	2 Det the .	3 N caviar .	...	6 N spoon .				
0 S . NP VP	0 S NP . VP	1 VP V . NP	2 NP Det . N	2 NP Det N .		5 NP Det N .				
0 NP . Det N	0 NP NP . PP	2 NP . Det N	3 N . caviar	1 VP V NP .		4 PP P NP .				
0 NP . NP PP	1 VP . V NP	2 NP . NP PP	3 N . spoon	2 NP NP . PP		5 NP NP . PP				
0 NP . Papa	1 VP . VP PP	2 NP . Papa		0 S NP VP .		2 NP NP PP .				
0 Det . the	1 PP . P NP	2 Det . the		1 VP VP . PP		1 VP VP PP .				
0 Det . a	1 V . ate	2 Det . a		4 PP . P NP		7 PP . P NP				
	1 P . with			0 ROOT S .		1 VP V NP .				
				4 P . with		2 NP NP . PP				
						0 S NP VP .				
						1 VP VP . PP				
						7 P . with				

0	Papa	1	ate	2	the	3	caviar	4	with a spoon	7
0 ROOT . S	0 NP Papa .	1 V ate .	2 Det the .	3 N caviar .	...	6 N spoon .				
0 S . NP VP	0 S NP . VP	1 VP V . NP	2 NP Det . N	2 NP Det N .		5 NP Det N .				
0 NP . Det N	0 NP NP . PP	2 NP . Det N	3 N . caviar	1 VP V NP .		4 PP P NP .				
0 NP . NP PP	1 VP . V NP	2 NP . NP PP	3 N . spoon	2 NP NP . PP		5 NP NP . PP				
0 NP . Papa	1 VP . VP PP	2 NP . Papa		0 S NP VP .		2 NP NP PP .				
0 Det . the	1 PP . P NP	2 Det . the		1 VP VP . PP		1 VP VP PP .				
0 Det . a	1 V . ate	2 Det . a		4 PP . P NP		7 PP . P NP				
	1 P . with			0 ROOT S .		1 VP V NP .				
				4 P . with		2 NP NP . PP				
						0 S NP VP .				
						1 VP VP . PP				
						7 P . with				



0	Papa	1	ate	2	the	3	caviar	4	with a spoon	7
0 ROOT . S	0 NP Papa .	1 V ate .	2 Det the .	3 N caviar .	...	6 N spoon .				
0 S . NP VP	0 S NP . VP	1 VP V . NP	2 NP Det . N	2 NP Det N .		5 NP Det N .				
0 NP . Det N	0 NP NP . PP	2 NP . Det N	3 N . caviar	1 VP V NP .		4 PP P NP .				
0 NP . NP PP	1 VP . V NP	2 NP . NP PP	3 N . spoon	2 NP NP . PP		5 NP NP . PP				
0 NP . Papa	1 VP . VP PP	2 NP . Papa		0 S NP VP .		2 NP NP PP .				
0 Det . the	1 PP . P NP	2 Det . the		1 VP VP . PP		1 VP VP PP .				
0 Det . a	1 V . ate	2 Det . a		4 PP . P NP		7 PP . P NP				
	1 P . with			0 ROOT S .		1 VP V NP .				
				4 P . with		2 NP NP . PP				
						0 S NP VP .				
						1 VP VP . PP				
						7 P . with				

0 Papa 1 ate 2 the 3 caviar 4 with a spoon 7					
0 ROOT . S	0 NP Papa .	1 V ate .	2 Det the .	3 N caviar .	... 6 N spoon .
0 S . NP VP	0 S NP . VP	1 VP V . NP	2 NP Det . N	2 NP Det N .	5 NP Det N .
0 NP . Det N	0 NP NP . PP	2 NP . Det N	3 N . caviar	1 VP V NP .	4 PP P NP .
0 NP . NP PP	1 VP . V NP	2 NP . NP PP	3 N . spoon	2 NP NP . PP	5 NP NP . PP
0 NP . Papa	1 VP . VP PP	2 NP . Papa		0 S NP VP .	2 NP NP PP .
0 Det . the	1 PP . P NP	2 Det . the		1 VP VP . PP	1 VP VP PP .
0 Det . a	1 V . ate	2 Det . a		4 PP . P NP	7 PP . P NP
	1 P . with			0 ROOT S .	1 VP V NP .
				4 P . with	2 NP NP . PP
					0 S NP VP .
					1 VP VP . PP
					7 P . with
					0 ROOT S .

0		Papa		1		ate		2		the		3		caviar		4		with a spoon		7	
0 ROOT . S		0 NP Papa .		1 V ate .		2 Det the .		3 N caviar .		...		6 N spoon .									
0 S . NP VP		0 S NP . VP		1 VP V . NP		2 NP Det . N		2 NP Det N .				5 NP Det N .									
0 NP . Det N		0 NP NP . PP		2 NP . Det N		3 N . caviar		1 VP V NP .				4 PP P NP .									
0 NP . NP PP		1 VP . V NP		2 NP . NP PP		3 N . spoon		2 NP NP . PP				5 NP NP . PP									
0 NP . Papa		1 VP . VP PP		2 NP . Papa				0 S NP VP .				2 NP NP PP .									
0 Det . the		1 PP . P NP		2 Det . the				1 VP VP . PP				1 VP VP PP .									
0 Det . a		1 V . ate		2 Det . a				4 PP . P NP				7 PP . P NP									
		1 P . with						0 ROOT S .				1 VP V NP .									
								4 P . with				2 NP NP . PP									
												0 S NP VP .									
												1 VP VP . PP									
												7 P . with									
												0 ROOT S .									

0      Papa      1      ate      2      the      3      caviar      4      with a spoon      7					
0 ROOT . S	0 NP Papa .	1 V ate .	2 Det the .	3 N caviar .	... 6 N spoon .
0 S . NP VP	0 S NP . VP	1 VP V . NP	2 NP Det . N	2 NP Det N .	5 NP Det N .
0 NP . Det N	0 NP NP . PP	2 NP . Det N	3 N . caviar	1 VP V NP .	4 PP P NP .
0 NP . NP PP	1 VP . V NP	2 NP . NP PP	3 N . spoon	2 NP NP . PP	5 NP NP . PP
0 NP . Papa	1 VP . VP PP	2 NP . Papa		0 S NP VP .	2 NP NP PP .
0 Det . the	1 PP . P NP	2 Det . the		1 VP VP . PP	1 VP VP PP .
0 Det . a	1 V . ate	2 Det . a		4 PP . P NP	7 PP . P NP
	1 P . with			0 ROOT S .	1 VP V NP .
				4 P . with	2 NP NP . PP
					0 S NP VP .
					1 VP VP . PP
					7 P . with
					0 ROOT S .

0 Papa 1 ate 2 the 3 caviar 4 with a spoon 7					
0 ROOT . S	0 NP Papa .	1 V ate .	2 Det the .	3 N caviar .	... 6 N spoon .
0 S . NP VP	0 S NP . VP	1 VP V . NP	2 NP Det . N	2 NP Det N .	5 NP Det N .
0 NP . Det N	0 NP NP . PP	2 NP . Det N	3 N . caviar	1 VP V NP .	4 PP P NP .
0 NP . NP PP	1 VP . V NP	2 NP . NP PP	3 N . spoon	2 NP NP . PP	5 NP NP . PP
0 NP . Papa	1 VP . VP PP	2 NP . Papa		0 S NP VP .	2 NP NP PP .
0 Det . the	1 PP . P NP	2 Det . the		1 VP VP . PP	1 VP VP PP .
0 Det . a	1 V . ate	2 Det . a		4 PP . P NP	7 PP . P NP
	1 P . with			0 ROOT S .	1 VP V NP .
				4 P . with	2 NP NP . PP
					0 S NP VP .
					1 VP VP . PP
					7 P . with
					0 ROOT S .

0	Papa	1	ate	2	the	3	caviar	4	with a spoon	7
0 ROOT . S	0 NP Papa .	1 V ate .	2 Det the .	3 N caviar .	...	6 N spoon .				
0 S . NP VP	0 S NP . VP	1 VP V . NP	2 NP Det . N	2 NP Det N .		5 NP Det N .				
0 NP . Det N	0 NP NP . PP	2 NP . Det N	3 N . caviar	1 VP V NP .		4 PP P NP .				
0 NP . NP PP	1 VP . V NP	2 NP . NP PP	3 N . spoon	2 NP NP . PP		5 NP NP . PP				
0 NP . Papa	1 VP . VP PP	2 NP . Papa		0 S NP VP .		2 NP NP PP .				
0 Det . the	1 PP . P NP	2 Det . the		1 VP VP . PP		1 VP VP PP .				
0 Det . a	1 V . ate	2 Det . a		4 PP . P NP		7 PP . P NP				
	1 P . with			0 ROOT S .		1 VP V NP .				
				4 P . with		2 NP NP . PP				
						0 S NP VP .				
						1 VP VP . PP				
						7 P . with				
						0 ROOT S .				