#### **SCFG**

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- 1 CFG
- 2 CKY
- 3 Parsing as intersection
- 4 SCFG
- **5** Synchronous parsing
- **6** Further reading

$$G = \langle \Sigma, N, S, R \rangle$$

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•  $\Sigma$  terminal vocabulary

**CFG** 

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- $\Sigma$  terminal vocabulary
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- $S \in N$  start symbol

**CFG** 

$$G = \langle \Sigma, N, S, R \rangle$$

- $\Sigma$  terminal vocabulary
- N nonterminal vocabulary
- $S \in N$  start symbol
- $R \subseteq \{A \to \alpha : A \in V, \alpha \in (\Sigma \cup V)^+\}$  set of rules

# CFG - example

**CFG** 

#### Grammar

- $\mathbf{2} X \rightarrow \mathsf{luz}$
- **3**  $X \rightarrow \text{apague } X$

- $\mathbf{4} \ X \to X$  por favor
- **6**  $S \rightarrow X$

# CFG - example

**CFG** 

#### Grammar

- $2X \rightarrow luz$
- **3**  $X \rightarrow \text{apague } X$

#### Discrete set

infinite set of strings and trees

- $\mathbf{4} \ X \to X$  por favor
- **6**  $X \rightarrow XX$
- $\mathbf{6} \ S \to X$

#### Parsing a sentence

#### Input

sentence

### Parsing a sentence

#### Input

sentence

#### Forest (analyses)

subset of trees whose yield is the given sentence

### Parsing a sentence

#### Input

sentence

#### Forest (analyses)

subset of trees whose yield is the given sentence

#### **CKY**

bottom-up dynamic program

	apague	а	luz	por	favor
1					
2					
3					
4					
5					

- $2 \hspace{-.7cm} X \to \mathsf{luz}$
- f 3 X o apague X

- $f A \ X o X$  por favor
- $3 X \to XX$

	apague	a	luz	por	favor
1		$X_{1,2} \xrightarrow{1} a$			
2					
3					
4					
5					

- $1 X \to \mathsf{a}$
- $2 \hspace{-.7cm} X \to \mathsf{luz}$
- **3**  $X \rightarrow \text{apague } X$

- lack A X o X por favor
- $3 X \to XX$

	apague	a	luz	por	favor
1		$X_{1,2} \xrightarrow{1} a$	$X_{2,3} \xrightarrow{2} luz$		
2					
3					
4	-				
5					

- $1 \!\!\! 1 \hspace{1mm} X \to \mathsf{a}$
- $\mathbf{2} X \to \mathsf{luz}$
- **3**  $X \rightarrow \text{apague } X$

- lack A X o X por favor
- $3 X \to XX$

	apague	a	luz	por	favor
1		$X_{1,2} \stackrel{1}{ o} a$	$X_{2,3} \stackrel{2}{ o} luz$		
2		$X_{1,3} \xrightarrow{5}$	$X_{1,2}X_{2,3}$		
3					
4					
5					

- $1 \hspace{-.7cm} 1 \hspace{-.7cm} X \to \mathsf{a}$
- $\mathbf{2} \ X \to \mathsf{luz}$
- **3**  $X \rightarrow \text{apague } X$

- lack A X o X por favor
- $3 X \to XX$

	apague	a	luz	por	favor
1			$X_{2,3} \xrightarrow{2} luz$		
2		$X_{1,3} \xrightarrow{5}$	$X_{1,2}X_{2,3}$		
	$X_{0,2} \xrightarrow{3} a$	pague $X_{1,2}$			
3					
4					
5					

- $1 \hspace{-.7cm} 1 \hspace{-.7cm} X \to \mathsf{a}$
- $\mathbf{2} X \rightarrow \mathsf{luz}$
- **3**  $X \rightarrow \text{apague } X$

- lack A X o X por favor
- $3 X \to XX$

	apague	a	luz	por	favor
1		$X_{1,2} \xrightarrow{1} a$	$X_{2,3} \xrightarrow{2} luz$		
2			$X_{1,2}X_{2,3}$		
	$X_{0,2} \xrightarrow{3} a$	pague $X_{1,2}$	$X_2$	$_{,5} \xrightarrow{4} X_{2,3} \text{ por }$	favor
3					
4					
5					
_ 5					

- $1 \hspace{-.7cm} 1 \hspace{-.7cm} X \to \mathsf{a}$
- $\mathbf{2} X \to \mathsf{luz}$
- **3**  $X \rightarrow \text{apague } X$

- $\mathbf{4} \ X \to X$  por favor
- $3 X \to XX$

	apague	a	luz	por	favor
1		$X_{1,2} \xrightarrow{1} a$	$X_{2,3} \xrightarrow{2} luz$		
2	$X_{0,2} \stackrel{3}{ o} a$	$X_{1,3} \stackrel{5}{ ightarrow}$ pague $X_{1,2}$	$X_{1,2}X_{2,3}$ $X_{2,3}$	$_5 \xrightarrow{4} X_{2,3}$ por t	favor
3	X	$\frac{3}{0.3} \stackrel{3}{ o}$ apague .	$X_{1,3}$		
4					
5					

- $\mathbf{2} X \rightarrow \mathsf{luz}$
- **3**  $X \rightarrow \text{apague } X$

- $\mathbf{4} \ X \to X$  por favor
- $3 X \to XX$
- $\mathbf{6} \ S \to X$

	apague	a	luz	por	favor
1		$X_{1,2} \xrightarrow{1} a$	$X_{2,3} \xrightarrow{2} luz$		
2			$X_{1,2}X_{2,3}$		
	$X_{0,2} \xrightarrow{3} a$	pague $X_{1,2}$	X	$_{2,5} \xrightarrow{4} X_{2,3}$ por	favor
		$_{0,3} \xrightarrow{3} apague \ .$			
3		$X_{0,3} \xrightarrow{5} X_{0,2} X_{2}$	2,3		
4					
5					

- $1 X \to \mathsf{a}$
- $\mathbf{2} X \to \mathsf{luz}$
- **3**  $X \rightarrow \text{apague } X$

- **4**  $X \to X$  por favor
- $\bullet X \to XX$

	apague	а	luz	por	favor
1		$X_{1,2} \xrightarrow{1} a$	$X_{2,3} \xrightarrow{2} luz$		
2			$X_{1,2}X_{2,3}$		
	$X_{0,2} \xrightarrow{3} a$	pague $X_{1,2}$	$X_{2}$	$_5 \xrightarrow{4} X_{2,3} \text{ por } $	favor
	$X_0$	$_{0,3} \xrightarrow{3} apague \ 2$	$X_{1,3}$		
3		$X_{0,3} \xrightarrow{5} X_{0,2} X_2$	*		
			$X_{1,5} \xrightarrow{4} X$	$_{1,3}$ por favor	
4					
<u></u>					
5					

- $1 X \to \mathsf{a}$
- $\mathbf{2} X \rightarrow \mathsf{luz}$
- **3**  $X \rightarrow \text{apague } X$

- $\mathbf{4} \ X \to X$  por favor
- $3 X \to XX$

	apague	а	luz	por	favor
1		$X_{1,2} \stackrel{1}{ ightarrow}$ a	$X_{2,3} \xrightarrow{2} luz$		
2		$X_{1,3} \xrightarrow{5}$	$X_{1,2}X_{2,3}$		
	$X_{0,2} \xrightarrow{3} a$	pague $X_{1,2}$	$X_{2,}$	$\stackrel{4}{\longrightarrow} X_{2,3}$ por t	favor
	$X_0$	$_{0,3} \xrightarrow{3} apague \ 2$	$X_{1,3}$		
3	Ì	$X_{0,3} \xrightarrow{5} X_{0,2} X_2$	2,3		
				$_{ m 1,3}$ por favor	
			$X_{1,5} \xrightarrow{5}$	$X_{1,2}X_{2,5}$	
4					
5					

- $2 \hspace{-.7cm} X \to \mathsf{luz}$
- **3**  $X \rightarrow \text{apague } X$

- **4**  $X \rightarrow X$  por favor
- $3 X \to XX$

	apague	a	luz	por	favor			
1		$X_{1,2} \xrightarrow{1} a$	$X_{2,3} \xrightarrow{2} luz$					
2		$X_{1,3} \xrightarrow{5}$	$X_{1,2}X_{2,3}$					
	$X_{0,2} \xrightarrow{3} a$	pague $X_{1,2}$	$X_{2}$	$\stackrel{4}{\rightarrow} X_{2,3}$ por $\stackrel{4}{\rightarrow}$	favor			
	$X_0$	$_{0,3} \xrightarrow{3} apague \ 2$	$X_{1,3}$					
3	2	$X_{0,3} \xrightarrow{5} X_{0,2} X_2$	2,3					
				$_{1,3}$ por favor				
		$X_{1,5} \xrightarrow{5} X_{1,2}X_{2,5}$						
		2	$X_{0,5} \xrightarrow{5} X_{0,2} X_2$	,5				
4								
L.								
5								

$$1 \hspace{-.7cm} 1 \hspace{-.7cm} X \to \mathsf{a}$$

lack A X o X por favor

$$\mathbf{2} \ X \to \mathsf{luz}$$

$$3 X \to XX$$

**3** 
$$X \rightarrow \text{apague } X$$

	apague	а	luz	por	favor
1			$X_{2,3} \xrightarrow{2} luz$		
2			$X_{1,2}X_{2,3}$		
	$X_{0,2} \xrightarrow{3} a$	pague $X_{1,2}$	$X_{2}$	$_{.5} \xrightarrow{4} X_{2,3} \text{ por }$	favor
		$_{0,3} \xrightarrow{3} apague \ 2$			
3	-	$X_{0,3} \xrightarrow{5} X_{0,2} X_2$	2,3		
				$_{1,3}$ por favor	
				$X_{1,2}X_{2,5}$	
		2	$X_{0,5} \xrightarrow{5} X_{0,2} X_2$	,5	
4		$X_0$	$_{0,5} \xrightarrow{3} apague \ 2$	$X_{1,5}$	
4					
5					

- $2X \rightarrow luz$
- **3**  $X \rightarrow \text{apague } X$

- **4**  $X \rightarrow X$  por favor
- $3 X \to XX$

	apague	а	luz	por	favor		
1			$X_{2,3} \xrightarrow{2} luz$				
2	$X_{1,3} \stackrel{5}{ o} X_{1,2} X_{2,3}$						
		pague $X_{1,2}$		$_5 \xrightarrow{4} X_{2,3}$ por f	favor		
3	$X_{0,3} \xrightarrow{3}$ apague $X_{1,3}$						
	$X_{0,3} \xrightarrow{5} X_{0,2} X_{2,3}$						
	$X_{1,5} \xrightarrow{4} X_{1,3}$ por favor						
	$X_{1,5} \xrightarrow{5} X_{1,2} X_{2,5}$						
	$X_{0,5} \xrightarrow{5} X_{0,2} X_{2,5}$						
4	$X_{0,5} \stackrel{3}{ ightarrow}$ apague $X_{1,5}$						
	$X_{0,5} \xrightarrow{4} X_{0,3}$ por favor						
5							

- $1 \hspace{-.7cm} 1 \hspace{-.7cm} X \to \mathsf{a}$
- $\mathbf{2} X \rightarrow \mathsf{luz}$
- **3**  $X \rightarrow \text{apague } X$

- $\mathbf{4} \ X \to X$  por favor
- $3 X \to XX$

	apague	a	luz	por	favor		
1			$X_{2,3} \xrightarrow{2} luz$				
2		$X_{1,3} \xrightarrow{5}$	$X_{1,2}X_{2,3}$				
	$X_{0,2} \xrightarrow{3} a$	pague $X_{1,2}$	$X_{2,}$	$_5 \xrightarrow{4} X_{2,3}$ por f	avor		
3	$X_{0,3} \xrightarrow{3}$ apague $X_{1,3}$						
	$X_{0,3} \xrightarrow{5} X_{0,2} X_{2,3}$						
		$X_{1,5} \xrightarrow{4} X_{1,3}$ por favor					
	$X_{1,5} \xrightarrow{5} X_{1,2} X_{2,5}$						
	$X_{0,5} \xrightarrow{5} X_{0,2} X_{2,5}$						
4	$X_{0,5}\stackrel{3}{ ightarrow}$ apague $X_{1,5}$						
	$X_{0,5} \stackrel{4}{ o} X_{0,3}$ por favor						
5	$S_{0,5} \xrightarrow{6} X_{0,5}$						

$$1 X \to \mathsf{a}$$

$$\mathbf{2} X \rightarrow \mathsf{luz}$$

**3** 
$$X \rightarrow \text{apague } X$$

$$\mathbf{4} \ X \to X$$
 por favor

$$\mathbf{6} \ S \to X$$

- $1 \hspace{-.7cm} 1 \hspace{-.7cm} X_{1,2} \to \mathsf{a}$
- $2 X_{2,3} \to \mathsf{luz}$
- **3**  $X_{0,2} \rightarrow \text{apague } X_{1,2}$
- $4 X_{2,5} \to X_{2,3} \text{ por favor}$
- **6**  $X_{1,3} \rightarrow X_{1,2}X_{2,3}$
- **6**  $X_{1,5} \rightarrow X_{1,2}X_{2,5}$
- $X_{0,3} \to X_{0,2}X_{2,3}$
- **8**  $X_{0.5} \rightarrow X_{0.2}X_{2.5}$
- $\bigcirc X_{1,5} \rightarrow X_{1,3}$  por favor
- $\mathbf{Q} X_{0,5} \to X_{0,3}$  por favor
- **B**  $S_{0.5} \to X_{0.5}$

- $1 \hspace{-.7cm} 1 \hspace{-.7cm} X_{1,2} \to \mathsf{a}$
- $2 X_{2,3} \rightarrow luz$
- **3**  $X_{0,2} \rightarrow \text{apague } X_{1,2}$
- **6**  $X_{1,3} \to X_{1,2}X_{2,3}$
- **6**  $X_{1,5} \rightarrow X_{1,2}X_{2,5}$
- $X_{0,3} \to X_{0,2}X_{2,3}$
- **8**  $X_{0.5} \rightarrow X_{0.2}X_{2.5}$
- $X_{1.5} \rightarrow X_{1.3}$  por favor
- $\mathbf{Q} X_{0,5} \to X_{0,3}$  por favor
- **B**  $S_{0.5} \to X_{0.5}$

• the forest is itself a CFG

- **1**  $X_{1,2} \to a$
- 2  $X_{2,3} \rightarrow \mathsf{luz}$
- 3  $X_{0,2} \rightarrow \text{apague } X_{1,2}$
- **6**  $X_{1,3} \rightarrow X_{1,2}X_{2,3}$
- **6**  $X_{1,5} \rightarrow X_{1,2}X_{2,5}$
- $X_{0,3} \to X_{0,2}X_{2,3}$
- **8**  $X_{0.5} \rightarrow X_{0.2}X_{2.5}$
- $0 X_{0,3} \rightarrow \mathsf{apague}\ X_{1,3}$
- $X_{1.5} \rightarrow X_{1.3}$  por favor
- $\mathbf{Q} X_{0,5} \to X_{0,3}$  por favor
- **B**  $S_{0.5} \to X_{0.5}$

- the forest is itself a CFG
- nonterminals are annotated with input spans

- **1**  $X_{1,2} \to a$
- $2 X_{2,3} \to \mathsf{luz}$
- 3  $X_{0,2} \rightarrow \text{apague } X_{1,2}$
- $4 X_{2,5} \to X_{2,3} por favor$
- **6**  $X_{1,3} \rightarrow X_{1,2}X_{2,3}$
- **6**  $X_{1,5} \rightarrow X_{1,2}X_{2,5}$
- $X_{0,3} \to X_{0,2}X_{2,3}$
- **8**  $X_{0,5} \to X_{0,2}X_{2,5}$
- $X_{1.5} \rightarrow X_{1.3}$  por favor
- $\mathbf{Q} X_{0,5} \to X_{0,3}$  por favor
- **B**  $S_{0.5} \to X_{0.5}$

- the forest is itself a CFG
- nonterminals are annotated with input spans
- $O(n^2)$  specialised nonterminals

- **1**  $X_{1,2} \to a$
- $2 X_{2,3} \rightarrow luz$
- 3  $X_{0,2} \rightarrow \text{apague } X_{1,2}$
- **6**  $X_{1,3} \rightarrow X_{1,2}X_{2,3}$
- **6**  $X_{1,5} \rightarrow X_{1,2}X_{2,5}$
- $X_{0,3} \to X_{0,2}X_{2,3}$
- **8**  $X_{0,5} \to X_{0,2}X_{2,5}$
- $\mathbf{0} X_{1,5} \to X_{1,3}$  por favor
- $\mathbf{Q} X_{0,5} \to X_{0,3}$  por favor
- **B**  $S_{0.5} \to X_{0.5}$

- the forest is itself a CFG
- nonterminals are annotated with input spans
- $O(n^2)$  specialised nonterminals
- $O(n^3)$  specialised rules

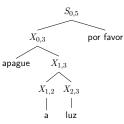
A graphical representation for the forest

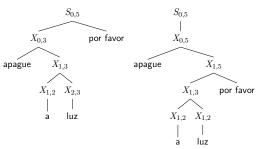
(hyper)nodes represent (labelled) input spans

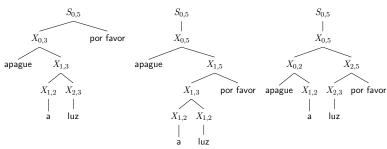
- (hyper)nodes represent (labelled) input spans
- (hyper)edges represent rules

- (hyper)nodes represent (labelled) input spans
- (hyper)edges represent rules
  - tail nodes: rule's RHS

- (hyper)nodes represent (labelled) input spans
- (hyper)edges represent rules
  - tail nodes: rule's RHS
  - head node: rule's LHS



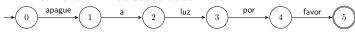




# Parsing as intersection

#### Input

linear-chain finite-state automaton



#### Output

subset of parse trees yielding valid input strings

$$G = \langle \Sigma, Q, I, F, E \rangle$$

$$G = \langle \Sigma, Q, I, F, E \rangle$$

ullet  $\Sigma$  terminal vocabulary

$$G = \langle \Sigma, Q, I, F, E \rangle$$

- $\Sigma$  terminal vocabulary
- ullet Q set of states

$$G = \langle \Sigma, Q, I, F, E \rangle$$

- $\Sigma$  terminal vocabulary
- Q set of states
- $I \subseteq Q$  set of initial states

$$G = \langle \Sigma, Q, I, F, E \rangle$$

- $\Sigma$  terminal vocabulary
- Q set of states
- $I \subseteq Q$  set of initial states
- $F \subseteq Q$  set of final states

$$G = \langle \Sigma, Q, I, F, E \rangle$$

- Σ terminal vocabulary
- Q set of states
- $I \subseteq Q$  set of initial states
- $F \subseteq Q$  set of final states
- $E \subseteq Q \times \Sigma \times Q$  is a set of labelled transitions

$$G = \langle \Sigma, Q, I, F, E \rangle$$

- Σ terminal vocabulary
- Q set of states
- $I \subseteq Q$  set of initial states
- $F \subseteq Q$  set of final states
- $E \subseteq Q \times \Sigma \times Q$  is a set of labelled transitions
- $\langle q, x, s \rangle \in E$  where  $q \in Q$ ,  $s \in Q$  and  $x \in \Sigma$  is a transition from q to s which recognises x

# Deductive proof system

A proof starts from its  $A{\rm XIOMS}$ 

 $\overline{\left[\mathrm{AXIOM}\right]}$  predicate

where  $\left[\mathrm{AXIOM}\right]$  is an item

# Deductive proof system

A proof starts from its Axioms

$$\overline{[AXIOM]}$$
 predicate

 $\mbox{where } \left[ \mbox{AXIOM} \right] \mbox{ is an item} \\ \mbox{and it follows by } \mbox{exhaustive } \mbox{deduction of new items} \\$ 

$$\frac{[\alpha_1][\alpha_2]\dots[\alpha_n]}{[\alpha_{n+1}]}$$
 predicate

- antecedents
- consequent
- conditions

# Deductive proof system

A proof starts from its AXIOMS

$$\overline{\left[ \mathrm{AXIOM} \right]}$$
 predicate

$$\frac{[\alpha_1][\alpha_2]\dots[\alpha_n]}{[\alpha_{n+1}]}$$
 predicate

- antecedents
- consequent
- conditions

the proof is valid if a goal item is provable

# Bottom-up parsing

AXIOMS

$$\overline{[X \to \bullet \alpha, q, q]} \quad q \in Q \land X \to \alpha \in R$$

GOAL

$$[S \to \alpha \bullet, q, r] \ q \in I \land r \in F$$

SCAN

$$\frac{[X \to \alpha \bullet x\beta, q, s]}{[X \to \alpha x \bullet \beta]} \quad \langle s, x, r \rangle \in E$$

Complete

$$\frac{[X \to \alpha \bullet Y\beta, q, s] [Y \to \gamma \bullet, s, r]}{[X \to \alpha Y_{s,r} \bullet \beta, q, r]}$$

- self-contained "algorithm"
- template for a hypergraph

- $2 [X \rightarrow \bullet luz, 2, 2]$

- $2 \hspace{-0.1cm} [X \to \bullet \mathsf{luz}, 2, 2]$
- $\ensuremath{ 3 \hspace{-0.8mm} [X \to \bullet apague \ X, 0, 0] }$

- $2 [X \rightarrow \bullet luz, 2, 2]$
- $\ \, \textbf{3} \,\, [X \rightarrow \bullet \text{apague} \,\, X, 0, 0]$
- $\ \, \textbf{4} \,\, [X \rightarrow \bullet X \,\, \mathrm{por} \,\, \mathrm{favor}, 0, 0]$

- **1**  $[X \to \bullet a, 1, 1]$
- $2 [X \rightarrow \bullet luz, 2, 2]$

- $\begin{tabular}{l} \begin{tabular}{l} \begin{tab$

- **1**  $[X \to \bullet a, 1, 1]$
- $2 [X \rightarrow \bullet luz, 2, 2]$
- **3**  $[X \rightarrow \bullet \text{apague } X, 0, 0]$
- **6**  $[X \to \bullet X \text{ por favor}, 1, 1]$
- $\textbf{ 6} \ [X \to \bullet X \ \mathrm{por \ favor}, 2, 2]$

- **1**  $[X \to \bullet a, 1, 1]$
- $2 [X \rightarrow \bullet luz, 2, 2]$
- $(X \to \bullet \text{apague } X, 0, 0]$
- **5**  $[X \rightarrow \bullet X \text{ por favor}, 1, 1]$
- **6**  $[X \to \bullet X \text{ por favor}, 2, 2]$
- **②**  $[X \to \bullet XX, 0, 0]$

- **1**  $[X \to \bullet a, 1, 1]$
- $\mathbf{Q}$   $[X \rightarrow \bullet luz, 2, 2]$
- $(X \to \bullet \text{apague } X, 0, 0]$
- **6**  $[X \to \bullet X \text{ por favor}, 1, 1]$
- **6**  $[X \to \bullet X \text{ por favor}, 2, 2]$
- **②**  $[X \to \bullet XX, 0, 0]$
- **8**  $[X \to \bullet XX, 1, 1]$

- **1**  $[X \to \bullet a, 1, 1]$
- $2 [X \rightarrow \bullet luz, 2, 2]$
- $(X \to \bullet \text{apague } X, 0, 0]$
- **6**  $[X \to \bullet X \text{ por favor}, 1, 1]$
- **6**  $[X \to \bullet X \text{ por favor}, 2, 2]$
- **②**  $[X \to \bullet XX, 0, 0]$
- **8**  $[X \to \bullet XX, 1, 1]$
- **9**  $[X \to \bullet XX, 2, 2]$

- **1**  $[X \to \bullet a, 1, 1]$
- $2 [X \rightarrow \bullet luz, 2, 2]$

- **6**  $[X \to \bullet X \text{ por favor}, 1, 1]$
- **6**  $[X \rightarrow \bullet X \text{ por favor}, 2, 2]$
- **8**  $[X \to \bullet XX, 1, 1]$

- **1**  $[X \to \bullet a, 1, 1]$
- $[X \to \bullet \mathsf{luz}, 2, 2]$

- **5** $[X \rightarrow \bullet X \text{ por favor}, 1, 1]$
- **6**  $[X \to \bullet X \text{ por favor}, 2, 2]$
- **②**  $[X \to \bullet XX, 0, 0]$
- **8**  $[X \to \bullet XX, 1, 1]$
- **9**  $[X \to \bullet XX, 2, 2]$

- 2  $[X \rightarrow \bullet luz, 2, 2]$ 3  $[X \rightarrow \bullet apague X, 0, 0]$
- **6**  $[X \rightarrow \bullet X \text{ por favor}, 2, 2]$
- **6**  $[X \to \bullet XX, 0, 0]$
- **7**  $[X \to \bullet XX, 1, 1]$
- **8**  $[X \to \bullet XX, 2, 2]$
- **9**  $[X \to \bullet XX, 3, 3]$

 $\mathbf{1}$   $[X \to a \bullet, 1, 2]$  scanned

 $[X \rightarrow \bullet luz, 2, 2] \leftarrow$ 

- $(X \rightarrow \bullet \mathsf{apague} X, 0, 0)$
- **6**  $[X \rightarrow \bullet X \text{ por favor}, 2, 2]$
- $\begin{bmatrix} X \to \bullet X \text{ por ravor}, 2, 2 \end{bmatrix}$
- **7** [*X* → •*XX*, 1, 1]
- **8**  $[X \to \bullet XX, 2, 2]$
- **9**  $[X \to \bullet XX, 3, 3]$
- $\begin{bmatrix} X \to \bullet XX, 5, 5 \end{bmatrix}$   $\begin{bmatrix} S \to \bullet X, 0, 0 \end{bmatrix}$

- $\mathbf{1}$   $[X \to a \bullet, 1, 2]$  scanned
- 2  $[X \rightarrow \mathsf{luz} \bullet, 2, 3]$  scanned 3  $[X \rightarrow \bullet \mathsf{apague} X, 0, 0] \leftarrow$
- **6**  $[X \rightarrow \bullet X \text{ por favor}, 2, 2]$
- **6**  $[X \to \bullet X \text{ por ravor}, 2, 2]$
- $\{X \to \bullet XX, 1, 1\}$
- **8**  $[X \to \bullet XX, 2, 2]$
- $\begin{bmatrix} X & Y & XX, 2, 2 \end{bmatrix}$
- **9**  $[X \to \bullet XX, 3, 3]$ **10**  $[S \to \bullet X, 0, 0]$

- $\mathbf{1}$   $[X \to a \bullet, 1, 2]$  scanned
- **2**  $[X \rightarrow \mathsf{luz} \bullet, 2, 3]$  scanned

- **6**  $[X \rightarrow \bullet X \text{ por favor}, 2, 2]$
- **6**  $[X \to \bullet XX, 0, 0]$
- $[X \to \bullet XX, 1, 1]$
- **8**  $[X \to \bullet XX, 2, 2]$
- **9**  $[X \to \bullet XX, 3, 3]$
- $(S \to \bullet X, 0, 0]$

- $1 \quad [X \to a \bullet, 1, 2] \text{ scanned}$
- **2**  $[X \rightarrow \mathsf{luz} \bullet, 2, 3]$  scanned
- $(X \rightarrow \text{apague} \bullet X, 0, 1] \text{ scanned}$
- **⑤**  $[X \rightarrow \bullet X \text{ por favor}, 2, 2]$
- **6**  $[X \to \bullet XX, 0, 0]$
- $[X \to \bullet XX, 1, 1]$
- **8**  $[X \to \bullet XX, 2, 2]$
- $\ \, [X \rightarrow \bullet XX,3,3]$
- $(S \to \bullet X, 0, 0)$
- [ $X \rightarrow X_{1,2}$  o por favor, 1, 2] completed

- **2**  $[X \rightarrow \mathsf{luz} \bullet, 2, 3]$  scanned
- $(X \rightarrow \text{apague} \bullet X, 0, 1] \text{ scanned}$
- **4**  $[X \rightarrow \bullet X \text{ por favor}, 1, 1]$  waiting
- **6**  $[X \rightarrow \bullet X \text{ por favor}, 2, 2] \leftarrow$
- **6**  $[X \to \bullet XX, 0, 0]$
- **7**  $[X \to \bullet XX, 1, 1]$
- **8**  $[X \to \bullet XX, 2, 2]$
- $(X \to \bullet XX, 2, 2)$
- **9**  $[X \to \bullet XX, 3, 3]$
- [ $X \rightarrow X_{1,2}$  o por favor, 1, 2] completed

- $1 \quad [X \to a \bullet, 1, 2] \text{ scanned}$
- **2**  $[X \rightarrow \mathsf{luz} \bullet, 2, 3]$  scanned
- **3**  $[X \rightarrow \mathsf{apague} \bullet X, 0, 1] \mathsf{scanned}$
- **4**  $[X \rightarrow \bullet X \text{ por favor}, 1, 1]$  waiting
- **6**  $[X \to \bullet X \text{ por favor}, 2, 2] \leftarrow$
- **6**  $[X \to \bullet XX, 0, 0]$
- $[X \to \bullet XX, 1, 1]$
- **8**  $[X \to \bullet XX, 2, 2]$
- $\mathbf{0} \ [X \to \bullet XX, 3, 3]$

- [ $X \rightarrow X_{2,3} \bullet$  por favor, 2, 3] completed

- $1 \quad [X \to a \bullet, 1, 2] \text{ scanned}$
- **2**  $[X \rightarrow \mathsf{luz} \bullet, 2, 3]$  scanned
- **3**  $[X \rightarrow \mathsf{apague} \bullet X, 0, 1] \mathsf{scanned}$
- **4**  $[X \to \bullet X \text{ por favor}, 1, 1]$  waiting
- **5**  $[X \to \bullet X \text{ por favor}, 2, 2]$  waiting
- $(X \rightarrow \bullet XX, 0, 0) \leftarrow$
- $[X \rightarrow \bullet XX, 1, 1]$
- **8**  $[X \to \bullet XX, 2, 2]$
- **9**  $[X \to \bullet XX, 3, 3]$  **10**  $[S \to \bullet X, 0, 0]$

- $1 \quad [X \to a \bullet, 1, 2] \text{ scanned}$
- **2**  $[X \rightarrow \mathsf{luz} \bullet, 2, 3]$  scanned
- **3**  $[X \rightarrow \mathsf{apague} \bullet X, 0, 1]$  scanned
- **4**  $[X \to \bullet X]$  por favor, [1, 1] waiting
- **5**  $[X \to \bullet X \text{ por favor}, 2, 2]$  waiting
- **6**  $[X \rightarrow \bullet XX, 0, 0]$  waiting
- $(X \to \bullet XX, 1, 1) \leftarrow$
- **8**  $[X \to \bullet XX, 2, 2]$
- [V . . VV 9 9]
- **9**  $[X \to \bullet XX, 3, 3]$

- [ $X \rightarrow X_{2,3} \bullet$  por favor, 2, 3] completed

- $1 \quad [X \rightarrow a \bullet, 1, 2] \text{ scanned}$
- **2**  $[X \rightarrow \mathsf{luz} \bullet, 2, 3]$  scanned
- **3**  $[X \rightarrow \mathsf{apague} \bullet X, 0, 1]$  scanned
- **4**  $[X \to \bullet X \text{ por favor}, 1, 1]$  waiting
- **5**  $[X \to \bullet X \text{ por favor}, 2, 2]$  waiting
- **6**  $[X \rightarrow \bullet XX, 0, 0]$  waiting
- $\begin{array}{c} \bullet & [X \to \bullet XX, 0, 0] \text{ waiting} \\ \bullet & [X \to \bullet XX, 1, 1] \leftarrow \end{array}$
- **8**  $[X \to \bullet XX, 2, 2]$
- **9**  $[X \to \bullet XX, 3, 3]$ **10**  $[S \to \bullet X, 0, 0]$
- $[X \to X_{2,3} \bullet \text{ por favor}, 2, 3]$  completed
- $[X o X_{2,3} \bullet]$  por favor, 2, 3] completed  $[X o X_{1,2} \bullet X, 1, 2]$  completed

- $1 [X \rightarrow a \bullet, 1, 2] scanned$
- $2 [X \to \mathsf{luz} \bullet, 2, 3] \mathsf{ scanned}$
- **3**  $[X \rightarrow \mathsf{apague} \bullet X, 0, 1]$  scanned
- **4**  $[X \to \bullet X \text{ por favor}, 1, 1]$  waiting
- **5**  $[X \to \bullet X \text{ por favor}, 2, 2]$  waiting
- **6**  $[X \rightarrow \bullet XX, 0, 0]$  waiting
- $\{X \rightarrow \bullet XX, 1, 1\}$  waiting
- $[\Lambda \to \bullet \Lambda \Lambda, 2, 2] \leftarrow$
- **9**  $[X \to \bullet XX, 3, 3]$ **10**  $[S \to \bullet X, 0, 0]$

- $\{X \rightarrow X_{1,2} \bullet X, 1, 2\}$  completed

- **1**  $[X \rightarrow a \bullet, 1, 2]$  scanned
- **2**  $[X \rightarrow \mathsf{luz} \bullet, 2, 3]$  scanned
- **3**  $[X \rightarrow \mathsf{apague} \bullet X, 0, 1]$  scanned
- **4**  $[X \to \bullet X \text{ por favor}, 1, 1]$  waiting
- **5**  $[X \rightarrow \bullet X \text{ por favor, } 2, 2]$  waiting
- **6**  $[X \rightarrow \bullet XX, 0, 0]$  waiting
- $\{X \to \bullet XX, 1, 1\}$  waiting

- **⑥**  $[S \to \bullet X, 0, 0]$
- $[X \to X_{2,3} \bullet \text{ por favor}, 2, 3] \text{ completed}$

- $\{X \rightarrow X_{2,3} \bullet X, 2, 3\}$  completed

- $\mathbf{1}$   $[X \to a \bullet, 1, 2]$  scanned
- $[X \rightarrow \mathsf{luz} \bullet, 2, 3]$  scanned
- $(X \to \mathsf{apague} \bullet X, 0, 1] \mathsf{ scanned}$
- **4**  $[X \to \bullet X \text{ por favor}, 1, 1]$  waiting
- **5**  $[X \rightarrow \bullet X \text{ por favor}, 2, 2]$  waiting
- **6**  $[X \rightarrow \bullet XX, 0, 0]$  waiting
- $X \to \bullet XX, 1, 1$  waiting
- $\{X \rightarrow \bullet XX, 2, 2\}$  waiting
- $[X \to \bullet XX, 2, 2] \text{ waiting}$   $[X \to \bullet XX, 3, 3] \leftarrow$
- **⑤** [S → •X, 0, 0]
- $\blacksquare$   $[X \to X_{1,2} \bullet \text{ por favor}, 1, 2]$  completed

- $[X \rightarrow X_{2,3} \bullet X, 2, 3]$  completed

- $1 \quad [X \rightarrow a \bullet, 1, 2] \text{ scanned}$
- $[X \rightarrow \mathsf{luz} \bullet, 2, 3]$  scanned
- **3**  $[X \rightarrow \mathsf{apague} \bullet X, 0, 1] \mathsf{scanned}$
- **4**  $[X \to \bullet X \text{ por favor}, 1, 1]$  waiting
- **5**  $[X \rightarrow \bullet X \text{ por favor, } 2, 2]$  waiting
- **6**  $[X \rightarrow \bullet XX, 0, 0]$  waiting
- $\{X \to \bullet XX, 1, 1\}$  waiting
- $\mathbf{Q}$   $[X \to \bullet XX, 3, 3]$  waiting

- $(X \rightarrow X_{1,2} \bullet X, 1, 2]$  completed
- $[X \rightarrow X_{2,3} \bullet X, 2, 3]$  completed

- $1 \quad [X \rightarrow a \bullet, 1, 2] \text{ scanned}$
- $[X \rightarrow \mathsf{luz} \bullet, 2, 3]$  scanned
- **3**  $[X \rightarrow \mathsf{apague} \bullet X, 0, 1]$  scanned
- **4**  $[X \to \bullet X \text{ por favor}, 1, 1]$  waiting
- **5**  $[X \rightarrow \bullet X \text{ por favor, } 2, 2]$  waiting
- **6**  $[X \rightarrow \bullet XX, 0, 0]$  waiting
- $\{X \to \bullet XX, 1, 1\}$  waiting

- $(X \rightarrow X_{1,2} \bullet X, 1, 2]$  completed
- $[X \rightarrow X_{2,3} \bullet X, 2, 3]$  completed

- 1  $[X \rightarrow a \bullet, 1, 2]$  scanned
- **2**  $[X \rightarrow \mathsf{luz} \bullet, 2, 3]$  scanned
- **3**  $[X \rightarrow \mathsf{apague} \bullet X, 0, 1] \mathsf{scanned}$
- **4**  $[X \to \bullet X \text{ por favor}, 1, 1]$  waiting
- **5**  $[X \rightarrow \bullet X \text{ por favor, } 2, 2]$  waiting
- **6**  $[X \rightarrow \bullet XX, 0, 0]$  waiting
- $\{X \to \bullet XX, 1, 1\}$  waiting
- $(X \to \bullet XX, 2, 2] \text{ waiting}$

- $\P$   $[X o X_{1,2} \bullet X, 1, 2]$  completed
- $\bigcirc$   $[X \rightarrow X_{2,3} \bullet X, 2, 3]$  completed

- 1  $[X \rightarrow a \bullet, 1, 2]$  scanned
- $2 [X \rightarrow \mathsf{luz} \bullet, 2, 3]$  scanned
- **3**  $[X \rightarrow \mathsf{apague} \bullet X, 0, 1]$  scanned
- **4**  $[X \to \bullet X \text{ por favor}, 1, 1]$  waiting
- **5**  $[X \rightarrow \bullet X \text{ por favor, } 2, 2]$  waiting
- **6**  $[X \rightarrow \bullet XX, 0, 0]$  waiting
- $\{X \to \bullet XX, 1, 1\}$  waiting

- $[X \rightarrow X_{2,3} \bullet X, 2, 3]$  completed

- **2**  $[X \rightarrow \mathsf{luz} \bullet, 2, 3]$  scanned
- **3**  $[X \rightarrow \mathsf{apague} \bullet X, 0, 1] \mathsf{scanned}$
- **5**  $[X \to \bullet X \text{ por favor}, 2, 2]$  waiting
- **6**  $[X \rightarrow \bullet XX, 0, 0]$  waiting

- $[X \to X_{2,3} \text{ por favor}, 2, 5]$  scanned
- $[X o X_{2,3} \text{ por ravor}, 2, 5]$  scanned  $[X o X_{1,2} \bullet X, 1, 2] \leftarrow$
- $[X \rightarrow X_{2,3} \bullet X, 2, 3]$  completed
- $[X \rightarrow X_{2,3} \bullet X, 2, 3]$  completed
- $(X \rightarrow X_{1,2}X_{2,3} \bullet, 1, 3)$  completed

- **2**  $[X \rightarrow \mathsf{luz} \bullet, 2, 3]$  scanned
- $X \to \text{apague} \bullet X, 0, 1$  scanned
- $\begin{tabular}{l} \P \end{tabular} \begin{tabular}{l} \P \end{tabular} \begin{tabula$
- **5**  $[X \to \bullet X \text{ por favor}, 2, 2]$  waiting
- **6**  $[X \rightarrow \bullet XX, 0, 0]$  waiting
- 7  $[X \rightarrow \bullet XX, 1, 1]$  waiting 8  $[X \rightarrow \bullet XX, 2, 2]$  waiting

- $\qquad \qquad \mathbb{P} \ [X \to X_{2,3} \text{ por favor} \bullet, 2, 5] \text{ scanned}$
- $(X \to X_{1,2} \bullet X, 1, 2) \leftarrow$   $(X \to X_{2,3} \bullet X, 2, 3)$  completed
- $[X \rightarrow X_{2,3} \bullet X, 2, 3]$  completed

- $2 [X \rightarrow \mathsf{luz} \bullet, 2, 3]$  scanned
- $\textbf{3} \ [X \to \mathsf{apague} \bullet X, 0, 1] \ \mathsf{scanned}$
- 4 [X → •X por favor, 1, 1] waiting
  5 [X → •X por favor, 2, 2] waiting
- **6**  $[X \rightarrow \bullet XX, 0, 0]$  waiting
- **8**  $[X \rightarrow \bullet XX, 2, 2]$  waiting

- $[X \to X_{2,3} \bullet X, 2, 3] \leftarrow$
- **ⓑ**  $[X \to X_{1,2} X_{2,3} \bullet, 1, 3]$  completed
- $(X \rightarrow X_{1,2}X_{2,5} \bullet, 1, 5]$  completed

- **2**  $[X \rightarrow \mathsf{luz} \bullet, 2, 3]$  scanned
- $\textbf{3} \ [X \to \mathsf{apague} \bullet X, 0, 1] \mathsf{\ scanned}$
- 4 [X → •X por favor, 1, 1] waiting
  5 [X → •X por favor, 2, 2] waiting
- **6**  $[X \rightarrow \bullet XX, 0, 0]$  waiting
- $[X \to \bullet XX, 0, 0]$  waiting  $[X \to \bullet XX, 1, 1]$  waiting
- $[X \rightarrow \bullet XX, 2, 2] \text{ waiting}$

- $\ \ \, \left[X \to X_{2,3} \text{ por favor} \bullet, 2, 5\right] \text{ scanned}$
- $[X \to X_{1,2} \bullet X, 1, 2] \text{ waiting}$

- **2**  $[X \rightarrow \mathsf{luz} \bullet, 2, 3]$  scanned
- **3**  $[X \rightarrow \text{apague} \bullet X, 0, 1]$  scanned
- $\textbf{4} \ [X \to \bullet X \text{ por favor}, 1, 1] \text{ waiting}$
- **5**  $[X \to \bullet X \text{ por favor}, 2, 2]$  waiting
- **6**  $[X \rightarrow \bullet XX, 0, 0]$  waiting
- $X \to \bullet XX, 1, 1$  waiting
- $\textbf{8} \ [X \rightarrow \bullet XX, 2, 2] \ \text{waiting}$
- $\ \, \textbf{9} \,\, [X \rightarrow \bullet XX, 3, \textbf{3}] \,\, \textbf{waiting} \\$

- $(X \to X_{1,2} \bullet X, 1, 2] \text{ waiting}$   $(X \to X_{2,3} \bullet X, 2, 3] \text{ waiting}$
- **(b)** [ $X \to X_{2,3} \bullet X, 2, 3$ ] waiting **(b)** [ $X \to X_{1,2}X_{2,3} \bullet, 1, 3$ ] ✓
- $\{X \to X_{1,2} X_{2,5} \bullet, 1, 5\} \leftarrow$

- **2**  $[X \rightarrow \mathsf{luz} \bullet, 2, 3]$  scanned
- **3**  $[X \rightarrow \mathsf{apague} \bullet X, 0, 1]$  scanned
- **5**  $[X \to \bullet X]$  por favor, 2, 2 waiting
- **6**  $[X \rightarrow \bullet XX, 0, 0]$  waiting  $[X \rightarrow \bullet XX, 1, 1]$  waiting
- $[X \rightarrow \bullet XX, 2, 2]$  waiting

- $(X \to X_{1,2} \bullet X, 1, 2) \text{ waiting}$   $(X \to X_{2,3} \bullet X, 2, 3) \text{ waiting}$
- **(b)** [ $X \to X_{2,3} \bullet X, 2, 3$ ] waiting **(c)** [ $X \to X_{1,2}X_{2,3} \bullet, 1, 3$ ] ✓
- $[X \to X_{1,2}X_{2,5} \bullet, 1, 5] \checkmark$

- $1 [X \to a \bullet, 1, 2] \checkmark$
- $[X \rightarrow \mathsf{luz} \bullet, 2, 3] \leftarrow$
- **3**  $[X \rightarrow \text{apague} \bullet X, 0, 1]$  scanned
- **4**  $[X \to \bullet X \text{ por favor, } 1, 1]$  waiting **5**  $[X \rightarrow \bullet X \text{ por favor}, 2, 2]$  waiting
- **6**  $[X \rightarrow \bullet XX, 0, 0]$  waiting
- $\{X \to \bullet XX, 1, 1\}$  waiting
- 8  $[X \rightarrow \bullet XX, 2, 2]$  waiting
- $\mathbf{Q}$  [ $X \to \bullet XX, 3, 3$ ] waiting
- $(S \rightarrow \bullet X, 0, 0)$  waiting
- $(X \rightarrow X_{1,2} \bullet \text{ por favor}, 1, 2] \times$
- $(X \to X_{2,3} \text{ por favor}, 2, 5]$  scanned
- $(X \rightarrow X_{1,2} \bullet X, 1, 2)$  waiting  $[X \rightarrow X_{2,3} \bullet X, 2, 3]$  waiting
- **(b)**  $[X \to X_{1,2}X_{2,3} \bullet, 1, 3] \checkmark$
- **16**  $[X \to X_{1,2}X_{2,5} \bullet, 1, 5] \checkmark$

- $2 \hspace{-0.2cm} [X \to \mathsf{luz} \bullet, 2, 3] \hspace{0.1cm} \checkmark \hspace{0.1cm}$
- 3  $[X \to \text{apague} \bullet X, 0, 1] \leftarrow$ 4  $[X \to \bullet X \text{ por favor}, 1, 1]$  waiting
- **5**  $[X \rightarrow \bullet X \text{ por favor}, 2, 2]$  waiting
- **6**  $[X \rightarrow \bullet XX, 0, 0]$  waiting
- $(X \to \bullet XX, 2, 2] \text{ waiting}$

- $[X o X_{2,3} \text{ por favor}, 2, 5]$  scanned  $[X o X_{1,2} o X, 1, 2]$  waiting
- $[X \rightarrow X_{2,3} \bullet X, 2, 3]$  waiting  $[X \rightarrow X_{1,2}X_{2,3} \bullet, 1, 3] \checkmark$
- **(** [X →  $X_{1,2}X_{2,5}$ •, 1, 5] ✓

- $1 \quad [X \to a \bullet, 1, 2] \checkmark$
- $\mathbf{Q} [X \to \mathsf{luz} \bullet, 2, 3] \checkmark$
- $(X \rightarrow \text{apague} \bullet X, 0, 1) \leftarrow$
- **4**  $[X \to \bullet X \text{ por favor}, 1, 1]$  waiting
- **5**  $[X \rightarrow \bullet X \text{ por favor}, 2, 2]$  waiting
- **6**  $[X \rightarrow \bullet XX, 0, 0]$  waiting
- $\{X \to \bullet XX, 1, 1\}$  waiting
- 8  $[X \rightarrow \bullet XX, 2, 2]$  waiting
- $\mathbf{Q}$  [ $X \to \bullet XX, 3, 3$ ] waiting
- $(S \rightarrow \bullet X, 0, 0)$  waiting
- $(X \rightarrow X_{1,2} \bullet \text{ por favor}, 1, 2] \times$
- $(X \to X_{2,3} \text{ por favor}, 2, 5]$  scanned
- $(X \rightarrow X_{1,2} \bullet X, 1, 2)$  waiting
- $[X \rightarrow X_2] \bullet X, 2, 3$  waiting
- **(b)**  $[X \to X_{1,2}X_{2,3} \bullet, 1, 3] \checkmark$
- **16**  $[X \to X_{1,2}X_{2,5} \bullet, 1, 5] \checkmark$

- **f**  $[X \to \text{apague } X_{1,2} \bullet, 0, 2]$  completed

- $1 \quad [X \to a \bullet, 1, 2] \checkmark$
- $2 [X \to \mathsf{luz} \bullet, 2, 3] \checkmark$
- $(X \rightarrow \mathsf{apague} \bullet X, 0, 1) \leftarrow$
- **5**  $[X \rightarrow \bullet X \text{ por favor}, 2, 2]$  waiting
- **6**  $[X \rightarrow \bullet XX, 0, 0]$  waiting
- $[X \rightarrow \bullet XX, 0, 0]$  waiting  $[X \rightarrow \bullet XX, 1, 1]$  waiting
- $(X \to \bullet XX, 2, 2] \text{ waiting}$
- $\bullet \quad [X \to \bullet X X, 2, 2] \text{ waiting}$

- $\bigcirc$   $[X \to X_{2,3} \text{ por favor}, 2, 5] scanned$
- $[X \rightarrow X_{1,2} \bullet X, 1, 2] \text{ waiting}$
- $[X \rightarrow X_{2,3} \bullet X, 2, 3]$  waiting
- **(b)**  $[X \to X_{1,2}X_{2,3}\bullet, 1, 3] \checkmark$
- **(b)**  $[X \to X_{1,2}X_{2,5} \bullet, 1, 5]$  ✓

- [ $X \to \text{apague } X_{1,3} \bullet, 0, 3$ ] completed

- $2 [X \to \mathsf{luz} \bullet, 2, 3] \checkmark$
- **3**  $[X \rightarrow \text{apague} \bullet X, 0, 1] \leftarrow$
- **4**  $[X \to \bullet X]$  por favor, [X, 1] waiting
- **5**  $[X \rightarrow \bullet X \text{ por favor}, 2, 2]$  waiting
- **6**  $[X \rightarrow \bullet XX, 0, 0]$  waiting
- $\begin{array}{c} \bullet & [X \rightarrow \bullet XX, 0, 0] \text{ waiting} \\ \bullet & [X \rightarrow \bullet XX, 1, 1] \text{ waiting} \end{array}$
- $(X \to \bullet XX, 2, 2] \text{ waiting}$

- $(X \to X_{2,3} \text{ por favor} \bullet, 2, 5] \text{ scanned}$
- $[X \to X_{1,2} \bullet X, 1, 2] \text{ waiting}$
- $[X \rightarrow X_{2,3} \bullet X, 2, 3]$  waiting
- [V . V V 1 2]
- **ⓑ**  $[X \to X_{1,2}X_{2,3} \bullet, 1, 3]$  ✓
- **ⓑ**  $[X \to X_{1,2}X_{2,5} \bullet, 1, 5]$  ✓

- $(X \to \mathsf{apague}\ X_{1,3} \bullet, 0, 3] \ \mathsf{completed}$
- $(X \to \mathsf{apague}\ X_{1,5} \bullet, 0, 5] \ \mathsf{completed}$

- $1 \quad [X \to \mathsf{a} \bullet, 1, 2] \checkmark$
- $2 \ [X \to \mathsf{luz} \bullet, 2, 3] \checkmark$
- $3 [X \rightarrow \text{apague} \bullet X, 0, 1] \text{ waiting}$
- **5**  $[X \to \bullet X \text{ por favor}, 2, 2]$  waiting
- **6**  $[X \rightarrow \bullet XX, 0, 0]$  waiting
- $\begin{array}{cccc} & [X & & & & & & & \\ & & & & & & & \\ & & & & & & \\ & & & & & & \\ & & & & & & \\ & & & & & & \\ & & & & & & \\ & & & & & & \\ & & & & & \\ & & & & & \\ & & & & & \\ & & & & & \\ & & & & & \\ & & & & & \\ & & & & \\ & & & & \\ & & & & \\ & & & & \\ & & & & \\ & & & & \\ & & & \\ & & & \\ & & & \\ & & & \\ & & & \\ & & & \\ & & & \\ & & & \\ & & \\ & & & \\ & \\ & & \\ & & \\ & & \\ & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & &$
- $\{X \rightarrow \bullet XX, 2, 2\}$  waiting
- $[X \to XX, 2, 2] \text{ waiting}$

- $\bigcirc$   $[X \to X_{2,3} \text{ por favor}, 2, 5] scanned$
- $[X \rightarrow X_{1,2} \bullet X, 1, 2]$  waiting
- $[X \rightarrow X_{2,3} \bullet X, 2, 3]$  waiting
- **(b**  $[X \to X_{1,2}X_{2,3} \bullet, 1, 3] \checkmark$
- **6**  $[X \to X_{1,2}X_{2,5} \bullet, 1, 5] \checkmark$

- **(a)**  $[X \to \text{apague } X_{1,2} \bullet, 0, 2]$  completed
- **®** [ $X \to \text{apague } X_{1,3} \bullet, 0, 3$ ] completed
- $(X \to \text{apague } X_{1,5} \bullet, 0, 5] \text{ completed}$

- $2 \ [X \to \mathsf{luz} \bullet, 2, 3] \checkmark$
- $(X \to \text{apague} \bullet X, 0, 1) \text{ waiting}$
- **5**  $[X \to \bullet X \text{ por favor}, 2, 2]$  waiting
- **6**  $[X \rightarrow \bullet XX, 0, 0]$  waiting
- $\{X \to \bullet XX, 1, 1\}$  waiting
- **8**  $[X \rightarrow \bullet XX, 2, 2]$  waiting

- $[X o X_{2,3} \text{ por favor} \bullet, 2, 5]$  scanned  $[X o X_{1,2} \bullet X, 1, 2]$  waiting

- **6**  $[X \to X_{1,2}X_{2,3} \bullet, 1, 3] \checkmark$
- **ⓑ**  $[X \to X_{1,2}X_{2,5} \bullet, 1, 5]$  ✓

- $\{X \to \text{apague } X_{1,3} \bullet, 0, 3\} \text{ completed}$

- $2 [X \to \mathsf{luz} \bullet, 2, 3] \checkmark$
- **3**  $[X \to \mathsf{apague} \bullet X, 0, 1]$  waiting
- **4**  $[X \to \bullet X \text{ por favor}, 1, 1]$  waiting
- $[X \to \bullet X \text{ por favor}, 2, 2] \leftarrow$
- **6**  $[X \rightarrow \bullet XX, 0, 0]$  waiting
- $(X \to \bullet XX, 1, 1]$  waiting
- **8**  $[X \rightarrow \bullet XX, 2, 2]$  waiting
- $\mathbf{Q}$  [ $X \to \bullet XX, 3, 3$ ] waiting

- $[X o X_{2,3} \text{ por favor} \bullet, 2, 5]$  scanned  $[X o X_{1,2} \bullet X, 1, 2]$  waiting

- **ⓑ**  $[X \to X_{1,2}X_{2,3} \bullet, 1, 3]$  ✓
- **⑤**  $[X \to X_{1,2}X_{2,5} \bullet, 1, 5]$  ✓

- **(8)**  $[X \to \text{apague } X_{1,3} \bullet, 0, 3]$  completed

- $2 [X \to \mathsf{luz} \bullet, 2, 3] \checkmark$
- **3**  $[X \rightarrow \mathsf{apague} \bullet X, 0, 1]$  waiting
- **4**  $[X \to \bullet X \text{ por favor}, 1, 1]$  waiting
- **5**  $[X \to \bullet X \text{ por favor}, 2, 2]$  waiting
- [ $X \rightarrow \bullet XX, 1, 1$ ] waiting
- $(X \to \bullet XX, 2, 2] \text{ waiting}$

- $[X \rightarrow X_{2,3} \text{ por favor}, 2, 5]$  scanned
- $[X \rightarrow X_{1,2} \bullet X, 1, 2]$  waiting
- $[X \rightarrow X_{2,3} \bullet X, 2, 3]$  waiting
- $[X \rightarrow A_{2,3} \bullet A, 2, 5] \text{ waiting}$
- **⑤**  $[X \to X_{1,2}X_{2,3} •, 1, 3]$  ✓
- **ⓑ**  $[X \to X_{1,2}X_{2,5} \bullet, 1, 5]$  ✓

- **(8)**  $[X \to \text{apague } X_{1,3} \bullet, 0, 3]$  completed
- $(X \to X_{1,3} \bullet \text{ por favor}, 1,3] \text{ completed}$

- $2 [X \to \mathsf{luz} \bullet, 2, 3] \checkmark$
- **3**  $[X \rightarrow \mathsf{apague} \bullet X, 0, 1]$  waiting
- **4**  $[X \to \bullet X \text{ por favor}, 1, 1]$  waiting
- **5**  $[X \to \bullet X \text{ por favor}, 2, 2]$  waiting
- $(X \to \bullet XX, 1, 1]$  waiting
- $(X \to \bullet XX, 2, 2]$  waiting

- $[X \to X_{2,3} \text{ por favor}, 2, 5]$  scanned
- $[X o X_{2,3} \text{ por ravol}, 2, 5]$  scanner  $[X o X_{1,2} \bullet X, 1, 2]$  waiting
- $[X \rightarrow X_{2,3} \bullet X, 2, 3]$  waiting
- **6**  $[X \to X_{1,2}X_{2,3} \bullet, 1, 3] \checkmark$
- **ⓑ**  $[X \to X_{1,2}X_{2,5} \bullet, 1, 5]$  ✓

- $(X \to \text{apague } X_{1,3} \bullet, 0, 3] \text{ completed}$
- $(X \to \mathsf{apague} \ X_{1,5} \bullet, 0, 5] \ \mathsf{completed}$   $(X \to X_{1,3} \bullet \mathsf{por} \ \mathsf{favor}, 1, 3] \ \mathsf{completed}$
- $(X \to X_{1,3} \bullet \text{ por ravor}, 1, 3] \text{ completed}$   $(X \to X_{0,2} \bullet X, 0, 2] \text{ completed}$

- $2 \ [X \to \mathsf{luz} \bullet, 2, 3] \checkmark$
- **3**  $[X \rightarrow \mathsf{apague} \bullet X, 0, 1]$  waiting
- $\textbf{4} \ [X \to \bullet X \text{ por favor}, 1, 1] \text{ waiting}$
- **5**  $[X \to \bullet X \text{ por favor}, 2, 2]$  waiting
- $(X \to \bullet XX, 1, 1]$  waiting
- $(X \to \bullet XX, 2, 2] \text{ waiting}$
- $(S \rightarrow \bullet X, 0, 0]$  waiting
- $[X \to X_{2,3} \text{ por favor}, 2, 5]$  scanned
- $[X o X_{2,3} \text{ por ravol}, 2, 5]$  scanner  $[X o X_{1,2} \bullet X, 1, 2]$  waiting
- $X \mapsto X_{2,3} \bullet X, 2, 3$  waiting
- $[X \rightarrow X_{2,3} \bullet X, 2, 3]$  waiting
- **ⓑ**  $[X \to X_{1,2} X_{2,3} \bullet, 1, 3] \checkmark$
- **ⓑ**  $[X \to X_{1,2}X_{2,5} \bullet, 1, 5]$  ✓

- $(X \to \text{apague } X_{1,3} \bullet, 0, 3] \text{ completed}$
- $(X \to \mathsf{apague} \ X_{1,5} \bullet, 0, 5] \ \mathsf{completed}$   $(X \to X_{1,3} \bullet \mathsf{por} \ \mathsf{favor}, 1, 3] \ \mathsf{completed}$
- $(X \to X_{0,2} \bullet X, 0, 2]$  completed
- $(X \to X_{0,3} \bullet X, 0, 3]$  completed

- $2 [X \to \mathsf{luz} \bullet, 2, 3] \checkmark$
- **3**  $[X \rightarrow \mathsf{apague} \bullet X, 0, 1]$  waiting
- **4**  $[X \to \bullet X \text{ por favor}, 1, 1]$  waiting
- **5**  $[X \to \bullet X \text{ por favor}, 2, 2]$  waiting
- **6**  $[X \rightarrow \bullet XX, 0, 0]$  waiting
- $(X \rightarrow \bullet XX, 1, 1) \leftarrow$
- $\begin{tabular}{l} \textbf{8} & [X \rightarrow \bullet XX, 2, \textcolor{red}{2}] \end{tabular} \begin{tabular}{l} \textbf{waiting} \\ \end{tabular}$

- $\bigcirc$   $[X \to X_{2,3} \text{ por favor}, 2, 5] scanned$
- $(X \to X_{2,3} \bullet X, 2, 3]$  waiting
- **6**  $[X \to X_{1,2}X_{2,3} \bullet, 1, 3] \checkmark$
- **⑤**  $[X \to X_{1,2}X_{2,5} \bullet, 1, 5]$  ✓

- $(X \to \text{apague } X_{1,3} \bullet, 0, 3] \text{ completed}$
- $(X \to \mathsf{apague} \ X_{1,5} \bullet, 0, 5] \ \mathsf{completed}$   $(X \to X_{1,3} \bullet \mathsf{por} \ \mathsf{favor}, 1, 3] \ \mathsf{completed}$
- $(X \to X_{1,3} \bullet \text{ por favor, 1, 5] completed}$
- $(X \to X_{0,3} \bullet X, 0, 3]$  completed

- $2 [X \to \mathsf{luz} \bullet, 2, 3] \checkmark$
- **3**  $[X \rightarrow \text{apague} \bullet X, 0, 1]$  waiting
- $\textbf{4} \ [X \to \bullet X \text{ por favor}, 1, \textbf{1}] \text{ waiting}$
- **5**  $[X \to \bullet X \text{ por favor}, 2, 2]$  waiting
- **6**  $[X \rightarrow \bullet XX, 0, 0]$  waiting
- $(X \to \bullet XX, 1, 1] \leftarrow$

- **(b)**  $[X \to X_{1,2}X_{2,3} \bullet, 1, 3] \checkmark$
- **⑤**  $[X \to X_{1,2}X_{2,5} \bullet, 1, 5]$  ✓

- $[X \to \text{apague } X_{1,3} \bullet, 0, 3] \text{ completed}$
- $(X \to \text{apague } X_{1,5} \bullet, 0, 5] \text{ completed}$   $(X \to X_{1,3} \bullet \text{ por favor, } 1, 3] \text{ completed}$
- $[X \to X_{0,2} \bullet X, 0, 2]$  completed
- $X \mapsto X_{0,3} \bullet X, 0, 3$  completed

- $2 [X \to \mathsf{luz} \bullet, 2, 3] \checkmark$
- **3**  $[X \to \mathsf{apague} \bullet X, 0, 1]$  waiting
- $\textbf{4} \ [X \to \bullet X \text{ por favor}, 1, 1] \text{ waiting}$
- **5**  $[X \to \bullet X \text{ por favor}, 2, 2]$  waiting
- **6**  $[X \rightarrow \bullet XX, 0, 0]$  waiting
- $\{X \rightarrow \bullet XX, 1, 1\}$  waiting
- $(X \to \bullet XX, 2, 2] \leftarrow$
- $[S \rightarrow \bullet X, 0, 0]$  waiting
- [11 / 11<sub>1,2</sub> por lavor, 1, 2] ×
- $[X o X_{2,3} \text{ por favor} \bullet, 2, 5]$  scanned  $[X o X_{1,2} \bullet X, 1, 2]$  waiting

- **ⓑ**  $[X \to X_{1,2} X_{2,3} \bullet, 1, 3] \checkmark$
- **ⓑ**  $[X \to X_{1,2}X_{2,5} \bullet, 1, 5]$  ✓

- $[X \to \text{apague } X_{1,3} \bullet, 0, 3] \text{ completed}$
- ①  $[X o X_{1,3} \bullet \text{ por favor}, 1, 3]$  completed ①  $[X o X_{0,2} \bullet X, 0, 2]$  completed
- $(X \to X_{1,3} \bullet X, 1, 3]$  completed

- $2 [X \rightarrow \mathsf{luz} \bullet, 2, 3] \checkmark$
- **3**  $[X \rightarrow \text{apague} \bullet X, 0, 1]$  waiting
- **6**  $[X \to \bullet X \text{ por favor}, 2, 2]$  waiting
- **6**  $[X \rightarrow \bullet XX, 0, 0]$  waiting
- $(X \to \bullet XX, 1, 1]$  waiting
- **8**  $[X \rightarrow \bullet XX, 2, 2]$  waiting
- $0 [X \to \bullet XX, 3, 3] \leftarrow$

- $[X \to X_{1,2} \bullet X, 1, 2] \text{ waiting}$
- **(b)**  $[X \to X_{1,2}X_{2,3} \bullet, 1, 3] \checkmark$
- **ⓑ**  $[X \to X_{1,2}X_{2,5} \bullet, 1, 5]$  ✓

- $(X \to \text{apague } X_{1,3} \bullet, 0, 3] \text{ completed}$
- $(X \to \mathsf{apague} \ X_{1,5} \bullet, 0, 5] \ \mathsf{completed}$   $(X \to X_{1,3} \bullet \mathsf{por} \ \mathsf{favor}, 1, 3] \ \mathsf{completed}$
- $[X \to X_{0,2} \bullet X, 0, 2]$  completed
- $2 (X \rightarrow X_{0.3} \bullet X, 0, 3]$  completed
- **2**  $[X \to X_{1,3} \bullet X, 1, 3]$  completed

- $2 [X \rightarrow \mathsf{luz} \bullet, 2, 3] \checkmark$
- **3**  $[X \rightarrow \mathsf{apague} \bullet X, 0, 1]$  waiting
- **6**  $[X \to \bullet X \text{ por favor}, 2, 2]$  waiting
- **6**  $[X \rightarrow \bullet XX, 0, 0]$  waiting
- $(X \to \bullet XX, 1, 1]$  waiting
- **8**  $[X \rightarrow \bullet XX, 2, 2]$  waiting
- $[S \rightarrow \bullet X, 0, 0] \leftarrow$
- [21 / 211,2 \* poi lavoi, 1, 2] X
- $[X o X_{2,3} \text{ por favor} \bullet, 2, 5]$  scanned  $[X o X_{1,2} \bullet X, 1, 2]$  waiting
- $(X \to X_{2,3} \bullet X, 2, 3) \text{ waiting}$
- **ⓑ**  $[X \to X_{1,2}X_{2,3} \bullet, 1, 3]$  ✓
- **ⓑ**  $[X \to X_{1,2}X_{2,5} \bullet, 1, 5]$  ✓

- $(X \to \text{apague } X_{1,3} \bullet, 0, 3] \text{ completed}$
- $(X \to \mathsf{apague}\ X_{1,5} \bullet, 0, 5] \ \mathsf{completed}$
- ①  $[X o X_{1,3} \bullet \text{ por favor}, 1, 3]$  completed ①  $[X o X_{0,2} \bullet X, 0, 2]$  completed

- $(X \to X_{1,3} \bullet X, 1, 3]$  completed

- $2 \hspace{-0.1cm} \begin{bmatrix} X \to \mathsf{luz} \bullet, 2, 3 \end{bmatrix} \checkmark$
- **3**  $[X \rightarrow \mathsf{apague} \bullet X, 0, 1]$  waiting
- **5**  $[X \to \bullet X \text{ por favor}, 2, 2]$  waiting
- **6**  $[X \rightarrow \bullet XX, 0, 0]$  waiting
- $(X \to \bullet XX, 1, 1]$  waiting
- $(X \to \bullet XX, 2, 2] \text{ waiting}$

- $[X o X_{2,3} \text{ por favor} \bullet, 2, 5]$  scanned  $[X o X_{1,2} \bullet X, 1, 2]$  waiting
- $X \mapsto X_{2,3} \bullet X, 2, 3$  waiting
- **ⓑ**  $[X \to X_{1,2}X_{2,3} \bullet, 1, 3]$  ✓
- **ⓑ**  $[X \to X_{1,2}X_{2,5} \bullet, 1, 5]$  ✓

- $[X \to \text{apague } X_{1,3} \bullet, 0, 3] \text{ completed}$
- ①  $[X \to X_{1,3} \bullet \text{ por favor}, 1, 3]$  completed ②  $[X \to X_{0,2} \bullet X, 0, 2]$  completed
- $(X \to X_{0,3} \bullet X, 0, 3]$  completed  $(X \to X_{0,3} \bullet X, 0, 3]$  completed
- $(X \to X_{1,3} \bullet X, 1, 3]$  completed

- $2 [X \to \mathsf{luz} \bullet, 2, 3] \checkmark$
- **3**  $[X \rightarrow \mathsf{apague} \bullet X, 0, 1]$  waiting
- **4**  $[X \to \bullet X \text{ por favor}, 1, 1]$  waiting
- **5**  $[X \to \bullet X \text{ por favor}, 2, 2]$  waiting
- **6**  $[X \rightarrow \bullet XX, 0, 0]$  waiting
- 7  $[X \rightarrow \bullet XX, 1, 1]$  waiting 8  $[X \rightarrow \bullet XX, 2, 2]$  waiting
- $[X \to \bullet XX, 2, 2]$  waiting

- **ⓑ**  $[X \to X_{1,2} X_{2,3} \bullet, 1, 3] \checkmark$
- **ⓑ**  $[X \to X_{1,2}X_{2,5} \bullet, 1, 5]$  ✓

- $[X \to \text{apague } X_{1,3} \bullet, 0, 3] \text{ completed}$
- $(X \to \text{apague } X_{1,5} \bullet, 0, 5] \text{ completed}$   $(X \to X_{1,3} \bullet \text{ por favor, } 1, 3] \text{ completed}$
- 2  $[X \rightarrow X_{0,3} \bullet X, 0, 3]$  completed
- $X = [X \rightarrow X_{1,3} \bullet X, 1, 3]$  completed
- $[S \rightarrow X_{0.5} \bullet, 0.5]$  completed

- $2 [X \to \mathsf{luz} \bullet, 2, 3] \checkmark$
- 3  $[X \rightarrow \text{apague} \bullet X, 0, 1]$  waiting
- $\begin{tabular}{l} \P \end{tabular} \begin{tabular}{l} \P \end{tabular} \begin{tabula$
- **5**  $[X \to \bullet X \text{ por favor}, 2, 2]$  waiting
- **6**  $[X \rightarrow \bullet XX, 0, 0]$  waiting
- $(X \to \bullet XX, 1, 1] \text{ waiting}$
- $(X \to \bullet XX, 2, 2] \text{ waiting}$

- $\begin{array}{c} (X \rightarrow X_{1,2} \bullet X, 1, 2) \\ (X \rightarrow X_{2,3} \bullet X, 2, 3) \end{array}$  waiting
- $[X \rightarrow X_{2,3} \bullet X, 2, 3] \text{ waiting}$
- **6**  $[X \to X_{1,2}X_{2,3} \bullet, 1, 3] \checkmark$
- **⑥**  $[X \to X_{1,2}X_{2,5} •, 1, 5]$  ✓

- **(B)**  $[X \to \text{apague } X_{1,3} \bullet, 0, 3] \text{ completed}$
- $(X \to \text{apague } X_{1,5} \bullet, 0, 5] \text{ completed}$   $(X \to X_{1,3} \bullet \text{ por favor, } 1, 3] \text{ completed}$
- $2 (X \rightarrow X_{0,3} \bullet X, 0, 3]$  completed
- $\S$   $[X \rightarrow X_{1,3} \bullet X, 1, 3]$  completed

- $2 [X \to \mathsf{luz} \bullet, 2, 3] \checkmark$
- $(X \to \mathsf{apague} \bullet X, 0, 1) \mathsf{ waiting}$
- $(X \to \bullet X \text{ por favor}, 2, 2) \text{ waiting}$
- **6**  $[X \rightarrow \bullet XX, 0, 0]$  waiting  $[X \rightarrow \bullet XX, 1, 1]$  waiting
- $[X \to \bullet XX, 2, 2] \text{ waiting}$

- $[X \rightarrow X_{1,2} \bullet X, 1, 2]$  waiting
- $[X o X_{1,2} \bullet X, 1, 2]$  waiting
- **ⓑ**  $[X \to X_{1,2}X_{2,3} •, 1, 3]$  ✓
- **⑥**  $[X \to X_{1,2}X_{2,5} •, 1, 5]$  ✓

- **(B)**  $[X \to \text{apague } X_{1,3} \bullet, 0, 3] \text{ completed}$
- $(X \to \text{apague } X_{1,5} \bullet, 0, 5] \text{ completed}$   $(X \to X_{1,3} \bullet \text{ por favor, } 1, 3] \text{ completed}$
- $[X \rightarrow X_{0,3} \bullet X, 0, 3]$  completed
- $X \mapsto X_{1,3} \bullet X, 1, 3$  completed
  - $[S \rightarrow X_{0.5} \bullet, 0, 5]$  completed

- $2 [X \to \mathsf{luz} \bullet, 2, 3] \checkmark$
- $(X \to \mathsf{apague} \bullet X, 0, 1) \mathsf{ waiting}$
- **5**  $[X \to \bullet X \text{ por favor}, 2, 2]$  waiting
- **6**  $[X \rightarrow \bullet XX, 0, 0]$  waiting
- 7  $[X \rightarrow \bullet XX, 1, 1]$  waiting 8  $[X \rightarrow \bullet XX, 2, 2]$  waiting
- $\{X \rightarrow \bullet XX, 2, 2\}$  waiting
- $[S \rightarrow \bullet X, 0, 0]$  waiting

- **(b)**  $[X \to X_{1,2}X_{2,3} \bullet, 1, 3] \checkmark$
- **⑤**  $[X \to X_{1,2}X_{2,5} \bullet, 1, 5]$  ✓

- $\{X \to \text{apague } X_{1,3} \bullet, 0, 3\} \text{ completed}$
- ①  $[X \to \text{apague } X_{1,5} \bullet, 0, 5]$  completed ②  $[X \to X_{1,3} \bullet \text{ por favor, } 1, 3]$  completed
- $[X \rightarrow X_0 \ _2 \bullet X, 0, 2]$  completed
- $X = [X \rightarrow X_{1,3} \bullet X, 1, 3]$  completed

- $2 [X \to \mathsf{luz} \bullet, 2, 3] \checkmark$
- **3**  $[X \rightarrow \mathsf{apague} \bullet X, 0, 1]$  waiting
- **5**  $[X \to \bullet X \text{ por favor}, 2, 2]$  waiting
- **6**  $[X \rightarrow \bullet XX, 0, 0]$  waiting
- $\begin{array}{c} \bullet & [X \to \bullet XX, 1, 1] \text{ waiting} \\ \bullet & [X \to \bullet XX, 2, 2] \end{array}$
- $(X \to \bullet XX, 2, 2] \text{ waiting}$

- $[X \rightarrow X_{1,2} \bullet X, 1, 2]$  waiting

- **ⓑ**  $[X \to X_{1,2}X_{2,3} \bullet, 1, 3]$  ✓
- **ⓑ**  $[X \to X_{1,2}X_{2,5} \bullet, 1, 5]$  ✓

- $[X \to X_{1,3} \bullet \text{ por favor}, 1, 3] \text{ completed}$
- $(X \to X_{0,2} \bullet X, 0, 2]$  completed
- $[X \rightarrow X_{0,3} \bullet X, 0, 3]$  completed
- $X \mapsto X_{1,3} \bullet X, 1, 3$  completed

- $2 [X \to \mathsf{luz} \bullet, 2, 3] \checkmark$
- $(X \to \mathsf{apague} \bullet X, 0, 1) \mathsf{ waiting}$
- **4**  $[X \to \bullet X]$  por favor, [1, 1] waiting
- **5**  $[X \to \bullet X]$  por favor, 2, 2 waiting
- **6**  $[X \rightarrow \bullet XX, 0, 0]$  waiting
- 7  $[X \rightarrow \bullet XX, 1, 1]$  waiting 8  $[X \rightarrow \bullet XX, 2, 2]$  waiting
- $[X \to \bullet XX, 2, 2] \text{ waiting}$

- $[X \to X_{2,3} \text{ por favor} \bullet, 2, 5] \checkmark$
- $(X \rightarrow X_{1,2} \bullet X, 1, 2]$  waiting
- $[X \rightarrow X_{2,3} \bullet X, 2, 3]$  waiting
- **⑤**  $[X \to X_{1,2}X_{2,3} \bullet, 1, 3]$  ✓
- **⑥**  $[X \to X_{1,2}X_{2,5} •, 1, 5]$  ✓

- $[X \to \mathsf{apague} \ X_{1,3} \bullet, 0, 3] \checkmark$
- $(X \to X_{0,2} \bullet X, 0, 2]$  completed
- $X \mapsto X_{0,3} \bullet X, 0, 3$  completed
- $X \rightarrow X_{1,3} \bullet X, 1, 3$  completed
  - $[S \rightarrow X_{0.5} \bullet, 0, 5]$  completed

- $2 [X \to \mathsf{luz} \bullet, 2, 3] \checkmark$
- 3  $[X \to \text{apague} \bullet X, 0, 1]$  waiting 4  $[X \to \bullet X \text{ por favor}, 1, 1]$  waiting
- $\textbf{ 5} \ [X \to \bullet X \text{ por favor}, 2, 2] \text{ waiting}$
- **6**  $[X \rightarrow \bullet XX, 0, 0]$  waiting
- $(X \to \bullet XX, 1, 1]$  waiting
- **8**  $[X \rightarrow \bullet XX, 2, 2]$  waiting
- $\mathbf{Q}$  [ $X \to \bullet XX, 3, 3$ ] waiting

- $[X \rightarrow X_{1,2} \bullet X, 1, 2]$  waiting
- $[X \rightarrow X_{2,3} \bullet X, 2, 3]$  waiting
- **(b)**  $[X \to X_{1,2}X_{2,3} \bullet, 1, 3] \checkmark$
- **(6)**  $[X \to X_{1,2}X_{2,5} \bullet, 1, 5]$  ✓

- $\ \ \, \textbf{\textcircled{1}} \ \, [X \rightarrow X_{0,2} \bullet X,0,2] \ \, \text{completed}$
- $(X \rightarrow X_{0,3} \bullet X, 0, 3]$  completed
- $(X \to X_{1,3} \bullet X, 1, 3]$  completed
- $2 S = [S \rightarrow X_{0.5} \bullet, 0, 5]$  completed

- $2 [X \to \mathsf{luz} \bullet, 2, 3] \checkmark$
- **3**  $[X \to \mathsf{apague} \bullet X, 0, 1]$  waiting
- **5**  $[X \to \bullet X \text{ por favor}, 2, 2]$  waiting
- **6**  $[X \rightarrow \bullet XX, 0, 0]$  waiting
- $(X \to \bullet XX, 1, 1] \text{ waiting}$
- $(X \to \bullet XX, 2, 2] \text{ waiting}$

- $[X \rightarrow X_{1,2} \bullet X, 1, 2]$  waiting
- $[A \rightarrow A_{2,3} \bullet A, 2, 5] \text{ Waiting}$
- **ⓑ**  $[X \to X_{1,2}X_{2,3} •, 1, 3]$  ✓
- **ⓑ**  $[X \to X_{1,2}X_{2,5} \bullet, 1, 5]$  ✓

- $\mathfrak{Q}$   $[X \to X_{1,3} \text{ por favor} \bullet, 1, 5]$  scanned
- **4** [ $X \to X_{0,2} \bullet X, 0, 2$ ] ←
- $2 \hspace{-.7cm} \begin{array}{c} [X \rightarrow X_{0,3} \bullet X, 0, 3] \text{ completed} \end{array}$
- $(X \to X_{1,3} \bullet X, 1, 3]$  completed

- $2 [X \to \mathsf{luz} \bullet, 2, 3] \checkmark$
- **3**  $[X \rightarrow \mathsf{apague} \bullet X, 0, 1]$  waiting
- **5**  $[X \to \bullet X \text{ por favor}, 2, 2]$  waiting
- **6**  $[X \rightarrow \bullet XX, 0, 0]$  waiting
- $\{X \to \bullet XX, 1, 1\}$  waiting
- $\{X \rightarrow \bullet XX, 2, 2\}$  waiting

- $[X \to X_{1,2} \bullet \text{por favor}, 1, 2] \land$   $[X \to X_{2,3} \text{ por favor}, 2, 5] \checkmark$
- $[X \rightarrow X_{1,2} \bullet X, 1, 2]$  waiting
- $[X o X_{1,2} \bullet X, 1, 2]$  waiting
- $(X \to X_{2,3} \bullet X, 2, 3]$  waiting
- **ⓑ**  $[X \to X_{1,2}X_{2,3} \bullet, 1, 3]$  ✓
- **ⓑ**  $[X \to X_{1,2}X_{2,5} \bullet, 1, 5]$  ✓

- $\mathfrak{Q}$   $[X \to X_{1,3} \text{ por favor} \bullet, 1, 5]$  scanned
- **2**  $[X \to X_{0,2} \bullet X, 0, 2] \leftarrow$
- $2 \hspace{-.7cm} \begin{array}{c} [X \rightarrow X_{0,3} \bullet X, 0, 3] \text{ completed} \end{array}$
- $(X \to X_{1,3} \bullet X, 1, 3]$  completed
- - **4**  $[X \to X_{0,2}X_{2,3} \bullet, 0, 3]$  completed

- $2 [X \rightarrow \mathsf{luz} \bullet, 2, 3] \checkmark$
- **3**  $[X \rightarrow \mathsf{apague} \bullet X, 0, 1]$  waiting
- **4**  $[X \to \bullet X]$  por favor, [X, 1] waiting
- **6**  $[X \to \bullet X \text{ por favor}, 2, 2]$  waiting
- **6**  $[X \rightarrow \bullet XX, 0, 0]$  waiting
- $\{X \to \bullet XX, 1, 1\}$  waiting
- **8**  $[X \rightarrow \bullet XX, 2, 2]$  waiting

- $(X \rightarrow X_{1,2} \bullet X, 1, 2]$  waiting
- **(b**  $[X \to X_{1,2}X_{2,3} \bullet, 1, 3] \checkmark$
- **ⓑ**  $[X \to X_{1,2}X_{2,5} \bullet, 1, 5]$  ✓

- $\mathfrak{Q}$   $[X \to X_{1,3} \text{ por favor} \bullet, 1, 5]$  scanned
- **4**  $[X \to X_{0,2} \bullet X, 0, 2] \leftarrow$
- $2 \hspace{-.7cm} \begin{array}{c} [X \rightarrow X_{0,3} \bullet X, 0, 3] \text{ completed} \end{array}$
- $X = [X \rightarrow X_{1,3} \bullet X, 1, 3]$  completed
- $(S \to X_{0,5} \bullet, 0, 5]$  completed
- **25**  $[X \to X_{0,2}X_{2,3} \bullet, 0, 3]$  completed
- **3** [*X* →  $X_{0,2}X_{2,5}$ •, 0, 5] completed

- $1 \quad [X \to a \bullet, 1, 2] \checkmark$
- $2 [X \rightarrow \mathsf{luz} \bullet, 2, 3] \checkmark$
- $(X \to \mathsf{apague} \bullet X, 0, 1] \mathsf{ waiting}$
- **4**  $[X \to \bullet X \text{ por favor}, 1, 1]$  waiting
- **5**  $[X \to \bullet X \text{ por favor}, 2, 2]$  waiting
- **6**  $[X \rightarrow \bullet XX, 0, 0]$  waiting
- $\{X \to \bullet XX, 1, 1\}$  waiting
- $\{X \rightarrow \bullet XX, 2, 2\}$  waiting

- $[X \to X_{2,3} \text{ por favor} \bullet, 2, 5] \checkmark$

- **(b)**  $[X \to X_{1,2}X_{2,3} \bullet, 1, 3] \checkmark$
- **ⓑ**  $[X \to X_{1,2}X_{2,5} \bullet, 1, 5]$  ✓

- $\mathfrak{Q}$   $[X \to X_{1,3} \text{ por favor} \bullet, 1, 5]$  scanned

- $\mathfrak{F}[X \to X_{1,3} \bullet X, 1, 3]$  completed
- $(S \rightarrow X_{0,5} \bullet, 0, 5]$  completed
- $(X \to X_{0,2}X_{2,3} \bullet, 0, 3]$  completed
- $\ \ \, [X \rightarrow X_{0,2}X_{2,5} \bullet,0,5] \ \, {\rm completed} \ \,$

- $2 [X \to \mathsf{luz} \bullet, 2, 3] \checkmark$
- **3**  $[X \rightarrow \mathsf{apague} \bullet X, 0, 1]$  waiting
- **5**  $[X \to \bullet X \text{ por favor}, 2, 2]$  waiting
- **6**  $[X \rightarrow \bullet XX, 0, 0]$  waiting
- $(X \rightarrow \bullet XX, 1, 1) \text{ waiting}$
- $\{X \rightarrow \bullet XX, 2, 2\}$  waiting
- $\bullet$  [ $X \to \bullet XX, 3, 3$ ] waiting

- $[X \to X_{2,3} \text{ por favor} \bullet, 2, 5] \checkmark$

- **ⓑ**  $[X \to X_{1,2} X_{2,3} \bullet, 1, 3] \checkmark$
- **ⓑ**  $[X \to X_{1,2}X_{2,5} \bullet, 1, 5]$  ✓

- $\mathfrak{Q}$   $[X \to X_{1,3} \text{ por favor}, 1, 5]$  scanned
- $(X \rightarrow X_{0,3} \bullet X, 0, 3]$  waiting
- - $(S \to X_{0,5} \bullet, 0, 5]$  completed
  - **3**  $[X \to X_{0,2}X_{2,3} \bullet, 0, 3]$  completed
- **26**  $[X \to X_{0,2}X_{2,5} \bullet, 0, 5]$  completed

- $2 [X \to \mathsf{luz} \bullet, 2, 3] \checkmark$
- $(X \to \mathsf{apague} \bullet X, 0, 1) \mathsf{ waiting}$
- **4**  $[X \to \bullet X \text{ por favor}, 1, 1]$  waiting
- **5**  $[X \to \bullet X \text{ por favor}, 2, 2]$  waiting
- **6**  $[X \rightarrow \bullet XX, 0, 0]$  waiting
- $\{X \rightarrow \bullet XX, 1, 1\}$  waiting
- **8**  $[X \rightarrow \bullet XX, 2, 2]$  waiting

- $(X \rightarrow X_{2,3} \text{ por favor} \bullet, 2, 5)$
- $\P$   $[X o X_{1,2} extbf{\bullet} X, 1, 2]$  waiting
- $\{X \rightarrow X_{2,3} \bullet X, 2, 3\}$  waiting
- **(b**  $[X \to X_{1,2}X_{2,3} \bullet, 1, 3] \checkmark$
- **6**  $[X \to X_{1,2}X_{2,5} \bullet, 1, 5] \checkmark$

- $\mathfrak{Q}$   $[X \to X_{1,3} \text{ por favor} \bullet, 1, 5]$  scanned
- 2  $[X o X_{0,3} \bullet X, 0, 3]$  waiting
- $(X \to X_{1,3} \bullet X, 1, 3] \text{ waiting}$
- $[S \rightarrow X_{0.5} \bullet, 0, 5] \leftarrow$ 
  - **3**  $[X \to X_{0,2}X_{2,3} \bullet, 0, 3]$  completed
- $(X \to X_{0,2}X_{2,5} \bullet, 0, 5]$  completed

- $1 \quad [X \to \mathsf{a} \bullet, 1, 2] \checkmark$
- $2 [X \rightarrow \mathsf{luz} \bullet, 2, 3] \checkmark$
- **3**  $[X \rightarrow \mathsf{apague} \bullet X, 0, 1]$  waiting
- **4**  $[X \to \bullet X]$  por favor, [X, 1] waiting
- **5**  $[X \to \bullet X \text{ por favor}, 2, 2]$  waiting
- **6**  $[X \rightarrow \bullet XX, 0, 0]$  waiting
- $(X \to \bullet XX, 1, 1]$  waiting
- **8**  $[X \rightarrow \bullet XX, 2, 2]$  waiting

- $\bigcirc$   $[X \to X_{2,3} \text{ por favor} \bullet, 2, 5] \checkmark$
- $\P$   $[X o X_{1,2} \bullet X, 1, 2]$  waiting
- $[X \rightarrow X_{2,3} \bullet X, 2, 3]$  waiting
- **(b)**  $[X \to X_{1,2}X_{2,3} \bullet, 1, 3] \checkmark$
- **ⓑ**  $[X \to X_{1,2}X_{2,5} \bullet, 1, 5]$  ✓

- $(X \to X_{1,3} \text{ por favor} \bullet, 1, 5] \text{ scanned}$
- $(X \to X_{0,2} \bullet X, 0, 2]$  waiting
- $(X \to X_{0,3} \bullet X, 0, 3]$  waiting
- - **②**  $[X \to X_{0,2}X_{2,3} \bullet, 0, 3]$  ←
- $(X \to X_{0,2}X_{2,5} \bullet, 0, 5]$  completed

- $2 [X \to \mathsf{luz} \bullet, 2, 3] \checkmark$
- **3**  $[X \rightarrow \mathsf{apague} \bullet X, 0, 1]$  waiting
- **4**  $[X \to \bullet X]$  por favor, [X, 1] waiting
- **5**  $[X \to \bullet X \text{ por favor}, 2, 2]$  waiting
- **6**  $[X \rightarrow \bullet XX, 0, 0]$  waiting
- [ $X \rightarrow \bullet XX, 1, 1$ ] waiting
- **8**  $[X \rightarrow \bullet XX, 2, 2]$  waiting

- **(b)**  $[X \to X_{1,2}X_{2,3} \bullet, 1, 3] \checkmark$
- **⑤**  $[X \to X_{1,2}X_{2,5} \bullet, 1, 5]$  ✓

- (8)  $[X \to \text{apague } X_{1,3} \bullet, 0, 3] \checkmark$ (9)  $[X \to \text{apague } X_{1,5} \bullet, 0, 5] \checkmark$
- a pague  $X_{1,5} \bullet, 0, 5$   $\bullet$   $X_{1,3} \bullet, 0, 5$   $\bullet$  $X_{1,3} \bullet, 0, 0, 5$   $\bullet$
- $\begin{bmatrix} N & V & N \end{bmatrix}$
- $(X \to X_{0,3} \bullet X, 0, 3]$  waiting
- - ②  $[S \to X_{0,5} \bullet, 0, 5] \checkmark$ ③  $[X \to X_{0,2} X_{2,3} \bullet, 0, 3] \checkmark$

- $1 \quad [X \to \mathsf{a} \bullet, 1, 2] \checkmark$
- $2 [X \to \mathsf{luz} \bullet, 2, 3] \checkmark$
- **3**  $[X \rightarrow \mathsf{apague} \bullet X, 0, 1]$  waiting
- **4**  $[X \to \bullet X]$  por favor, [X, 1] waiting
- **5**  $[X \to \bullet X \text{ por favor}, 2, 2]$  waiting
- **6**  $[X \rightarrow \bullet XX, 0, 0]$  waiting
- **8**  $[X \rightarrow \bullet XX, 2, 2]$  waiting
- **9**  $[X \rightarrow \bullet XX, 3, 3]$  waiting **10**  $[S \rightarrow \bullet X, 0, 0]$  waiting

- $(X \rightarrow X_{2,3} \text{ por favor} \bullet, 2, 5)$
- $\P$   $[X o X_{1,2} \bullet X, 1, 2]$  waiting
- $\P$   $[X \to X_{2,3} \bullet X, 2, 3]$  waiting
- **(b)**  $[X \to X_{1,2}X_{2,3} \bullet, 1, 3] \checkmark$
- **⑤**  $[X \to X_{1,2}X_{2,5} \bullet, 1, 5]$  ✓

- $\mathfrak{Q}$   $[X \to X_{1,3} \text{ por favor} \bullet, 1, 5]$  scanned
- $(X \to X_{0,2} \bullet X, 0, 2] \text{ waiting}$
- $(X \rightarrow X_{0,3} \bullet X, 0, 3]$  waiting
- $(X \to X_{1,3} \bullet X, 1, 3] \text{ waiting}$ 
  - ②  $[S \to X_{0,5} \bullet, 0, 5] \checkmark$ ③  $[X \to X_{0,2} X_{2,3} \bullet, 0, 3] \checkmark$
- **26**  $[X \to X_{0.2}X_{2.5} \bullet, 0, 5] \checkmark$
- [A / M<sub>0,2</sub>M<sub>2,5</sub>•, 0, 0] V

- $1 \quad [X \to \mathsf{a} \bullet, 1, 2] \checkmark$
- $2 [X \rightarrow \mathsf{luz} \bullet, 2, 3] \checkmark$
- **3**  $[X \rightarrow \text{apague} \bullet X, 0, 1]$  waiting
- **5**  $[X \to \bullet X \text{ por favor}, 2, 2]$  waiting
- **6**  $[X \rightarrow \bullet XX, 0, 0]$  waiting
- $(X \to \bullet XX, 1, 1]$  waiting
- **8**  $[X \rightarrow \bullet XX, 2, 2]$  waiting

- **(b)**  $[X \to X_{1,2}X_{2,3} \bullet, 1, 3] \checkmark$
- **⑤**  $[X \to X_{1,2}X_{2,5} \bullet, 1, 5]$  ✓

- $\begin{bmatrix} X & Y & X_{1,3} & \text{por favor} & Y_{1,0} \end{bmatrix} \text{ so}$
- $(X \to X_{0,2} \bullet X, 0, 2]$  waiting  $(X \to X_{0,3} \bullet X, 0, 3]$  waiting
- **2**  $[X \to X_{1,3} \bullet X, 0, 0]$  waiting **2**  $[X \to X_{1,3} \bullet X, 1, 3]$  waiting
- **2**  $[X \to X_{1,3} \bullet X, 1, 3]$  waiting **2**  $[S \to X_{0.5} \bullet, 0, 5]$
- **26**  $[X \to X_{0.2}X_{2.5} \bullet, 0, 5] \checkmark$

- $2 [X \to \mathsf{luz} \bullet, 2, 3] \checkmark$
- **3**  $[X \rightarrow \mathsf{apague} \bullet X, 0, 1]$  waiting
- **4**  $[X \to \bullet X \text{ por favor}, 1, 1]$  waiting
- **5**  $[X \to \bullet X \text{ por favor}, 2, 2]$  waiting
- **6**  $[X \rightarrow \bullet XX, 0, 0]$  waiting
- **8**  $[X \rightarrow \bullet XX, 2, 2]$  waiting

- **ⓑ**  $[X \to X_{1,2}X_{2,3} \bullet, 1, 3]$  ✓
- **⑤**  $[X \to X_{1,2}X_{2,5} \bullet, 1, 5]$  ✓

- $[X \to \mathsf{apague} \ X_{1,3} \bullet, 0, 3] \checkmark$
- $(X \to X_{1,3} \text{ por favor} \bullet, 1, 5] \text{ scanned}$
- $(X \to X_{0,3} \bullet X, 0, 3]$  waiting
- - ②  $[S \to X_{0,5} \bullet, 0, 5] \checkmark$ ②  $[X \to X_{0,2} X_{2,3} \bullet, 0, 3] \checkmark$
- $X \rightarrow X_{0,2}X_{2,5} \bullet, 0, 0] \lor$   $X \rightarrow X \text{ por favor, } 0, 0] \leftarrow$ 
  - $[X \to \bullet X \text{ por ravor}, 0, 0] \leftarrow$

- $2 [X \to \mathsf{luz} \bullet, 2, 3] \checkmark$
- $(X \to \mathsf{apague} \bullet X, 0, 1] \mathsf{ waiting}$
- **5**  $[X \to \bullet X \text{ por favor}, 2, 2]$  waiting
- **6**  $[X \rightarrow \bullet XX, 0, 0]$  waiting
- $\begin{array}{c} \bullet & [X \to \bullet XX, 1, 1] \text{ waiting} \\ \bullet & [X \to \bullet XX, 2, 2] \end{array}$

- $[S \rightarrow \bullet X, 0, 0]$  waiting

- $(X \rightarrow X_{1,2} \bullet X, 1, 2]$  waiting
- $\mathbb{P}[X \to X_{2,3} \bullet X, 2, 3]$  waiting
- **(b)**  $[X \to X_{1,2}X_{2,3} \bullet, 1, 3] \checkmark$
- **ⓑ**  $[X \to X_{1,2}X_{2,5} \bullet, 1, 5]$  ✓

- $\begin{bmatrix} X & Y_{1,3} & Y_{1,3} & Y_{1,0} \end{bmatrix}$
- $(X \to X_{0,2} \bullet X, 0, 2]$  waiting  $(X \to X_{0,3} \bullet X, 0, 3]$  waiting
- **2**  $[X \to X_{1,3} \bullet X, 1, 3]$  waiting
- $[A \rightarrow A_{1,3} \bullet A, 1, 3] \text{ waiting}$ 
  - **2**  $[S \to X_{0,5} •, 0, 5]$  ✓
- **3**  $[X \to X_{0,2}X_{2,3} \bullet, 0, 3] \checkmark$ **4**  $[X \to X_{0,2}X_{2,5} \bullet, 0, 5] \checkmark$
- $X \rightarrow X_{0,2}X_{2,5} \bullet, 0, 0$   $X \rightarrow X \text{ por favor, } 0, 0 \leftarrow$
- [X -> VX poi lavoi, 0, 0]
- $(X \to X_{0,2} \bullet \text{ por favor}, 0, 2] \text{ completed}$

- $1\hspace{-.7cm} 1\hspace{-.7cm} [X \to \mathsf{a} \bullet, 1, 2] \checkmark$
- $2 [X \rightarrow \mathsf{luz} \bullet, 2, 3] \checkmark$
- **3**  $[X \rightarrow \mathsf{apague} \bullet X, 0, 1]$  waiting
- **4**  $[X \to \bullet X \text{ por favor}, 1, 1]$  waiting
- **6**  $[X \to \bullet X \text{ por favor}, 2, 2]$  waiting
- **6**  $[X \rightarrow \bullet XX, 0, 0]$  waiting
- [ $X \rightarrow \bullet XX, 1, 1$ ] waiting
- $\{X \rightarrow \bullet XX, 2, 2\}$  waiting

- **6**  $[X \to X_{1,2}X_{2,3} \bullet, 1, 3] \checkmark$
- **⑥**  $[X \to X_{1,2}X_{2,5} •, 1, 5]$  ✓

- $\begin{array}{c} \bullet \\ X \rightarrow X_{0,2} \bullet X, 0, 2 \end{array}$  waiting  $\begin{array}{c} \bullet \\ X \rightarrow X_{0,3} \bullet X, 0, 3 \end{array}$  waiting
- $(X \to X_{1,3} \bullet X, 1, 3)$  waiting
- - **25**  $[X \to X_{0,2}X_{2,3} \bullet, 0, 3] \checkmark$
- **26**  $[X \to X_{0.2}X_{2.5} \bullet, 0, 5] \checkmark$
- $[X \to \bullet X \text{ por favor, } 0, 0] \leftarrow$
- $X = [X \rightarrow X_{0,2} \bullet \text{ por favor } 0, 2]$  completed
- $\ \ \, \textbf{\textcircled{2}} \ \, [X \rightarrow X_{0,3} \bullet \ \, \text{por favor}, 0,3] \ \, \text{completed}$

- $1 \hspace{-0.1cm} \begin{array}{c} [X \rightarrow \mathsf{a} \bullet, 1, 2] \checkmark \end{array}$
- $2 [X \to \mathsf{luz} \bullet, 2, 3] \checkmark$
- **3**  $[X \rightarrow \mathsf{apague} \bullet X, 0, 1]$  waiting
- **4**  $[X \to \bullet X \text{ por favor}, 1, 1]$  waiting
- **5**  $[X \to \bullet X \text{ por favor}, 2, 2]$  waiting
- **6**  $[X \rightarrow \bullet XX, 0, 0]$  waiting
- $(X \rightarrow \bullet XX, 1, 1)$  waiting
- **8**  $[X \rightarrow \bullet XX, 2, 2]$  waiting

- $[X \rightarrow X_{2,3} \bullet X, 2, 3]$  waiting
- **1**  $[X \to X_{1,2}X_{2,3}\bullet, 1, 3]$
- **1** [*X* →  $X_{1,2}X_{2,5}$ •, 1, 5]  $\checkmark$

- $(X \to \mathsf{apague}\ X_{1,3} \bullet, 0, 3] \checkmark$
- $(X \to X_{1,3} \text{ por favor} \bullet, 1, 5] \text{ scanned}$
- $(X \to X_{0,2} \bullet X, 0, 2]$  waiting

- **26**  $[X \to X_{0.2}X_{2.5} \bullet, 0, 5] \checkmark$
- $[X \rightarrow \bullet X \text{ por favor, } 0, 0] \leftarrow$
- $[X \to \bullet X \text{ por ravor}, 0, 0] \leftarrow$
- **3**  $[X \to X_{0,2} \bullet \text{ por favor}, 0, 2]$  completed
- $(X \to X_{0,3} \bullet \text{ por favor}, 0, 3] \text{ completed}$

- $1\hspace{-.7cm} 1\hspace{-.7cm} [X \to \mathbf{a} \bullet, 1, 2] \checkmark$
- $2 [X \to \mathsf{luz} \bullet, 2, 3] \checkmark$
- **3**  $[X \rightarrow \mathsf{apague} \bullet X, 0, 1]$  waiting
- **5**  $[X \to \bullet X \text{ por favor}, 2, 2]$  waiting
- **6**  $[X \rightarrow \bullet XX, 0, 0]$  waiting
- $\{X \to \bullet XX, 1, 1\}$  waiting
- **8**  $[X \rightarrow \bullet XX, 2, 2]$  waiting
- $\mathbf{Q}$  [ $X \to \bullet XX, 3, 3$ ] waiting

- $[X \rightarrow X_{2,3} \bullet X, 2, 3]$  waiting
- **ⓑ**  $[X \to X_{1,2}X_{2,3} •, 1, 3]$  ✓
- **ⓑ**  $[X \to X_{1,2}X_{2,5} \bullet, 1, 5]$  ✓

- $(X \to \mathsf{apague}\ X_{1,3} \bullet, 0, 3) \checkmark$
- $(X \to X_{1,3} \text{ por favor} \bullet, 1, 5] \text{ scanned}$
- $(X \to X_{0,2} \bullet X, 0, 2]$  waiting
- $[X \to X_{0,3} \bullet X, 0, 3]$  waiting
- - ②  $[S \to X_{0,5} \bullet, 0, 5] \checkmark$ ③  $[X \to X_{0,2} X_{2,3} \bullet, 0, 3] \checkmark$
- $[X \rightarrow A_{0,2}A_{2,5} \bullet, 0, 5] \checkmark$
- - $\mathfrak{D}$   $[X \to X_{0,3} \bullet \text{ por favor}, 0, 3]$  completed
  - $[A \rightarrow A_{0,3} \bullet \text{ por ravor}, 0, 3] \text{ complete}$

- $1 [X \to a \bullet, 1, 2] \checkmark$
- $[X \rightarrow \mathsf{luz} \bullet, 2, 3] \checkmark$
- 3  $[X \rightarrow \text{apague} \bullet X, 0, 1]$  waiting
- **4**  $[X \rightarrow \bullet X \text{ por favor, } 1, 1]$  waiting
- **5**  $[X \rightarrow \bullet X \text{ por favor}, 2, 2]$  waiting
- **6**  $[X \rightarrow \bullet XX, 0, 0]$  waiting
- $\{X \to \bullet XX, 1, 1\}$  waiting
- $\{X \to \bullet XX, 2, 2\}$  waiting
- $\mathbf{Q}$  [ $X \to \bullet XX, 3, 3$ ] waiting
- $(S \rightarrow \bullet X, 0, 0)$  waiting
- $(X \rightarrow X_{1,2} \bullet \text{ por favor}, 1, 2] \times$
- $[X \to X_{2,3} \text{ por favor}, 2, 5] \checkmark$
- $(X \rightarrow X_{1,2} \bullet X, 1, 2)$  waiting
- $[X \rightarrow X_{2,3} \bullet X, 2, 3]$  waiting
- **(b)**  $[X \to X_{1,2}X_{2,3} \bullet, 1, 3] \checkmark$
- **16**  $[X \to X_{1,2}X_{2,5} \bullet, 1, 5] \checkmark$

- **(h)**  $[X \rightarrow \text{apague } X_{1,2} \bullet, 0, 2] \checkmark$
- **18**  $[X \rightarrow \text{apague } X_{1,3} \bullet, 0, 3] \checkmark$
- $(X \rightarrow \text{apague } X_{1,5} \bullet, 0, 5) \checkmark$
- $\mathfrak{D}$  [ $X \to X_{1,3}$  por favor $\bullet$ , 1, 5] scanned
- $X \rightarrow X_0 \ 2 \bullet X, 0, 2$  waiting
- $X \rightarrow X_0 \rightarrow X_0 \rightarrow X_1 \rightarrow X_2 \rightarrow X_3 \rightarrow X_3 \rightarrow X_4 \rightarrow X_4 \rightarrow X_5 \rightarrow X_6 \rightarrow$
- $X \rightarrow X_{1,3} \bullet X, 1, 3$  waiting
- **2**  $[S \to X_{0.5} \bullet, 0, 5] \checkmark$
- **4** [*X* →  $X_{0,2}X_{2,3}$ •, 0, 3] ✓
- **26**  $[X \to X_{0.2}X_{2.5} \bullet, 0, 5] \checkmark$ 
  - $X \to X$  por favor, [X, 0] waiting
- $X \rightarrow X_{0,2} \bullet \text{ por favor}, 0, 2 \times$ 
  - $\mathfrak{P}$   $[X \to X_{0,3} \bullet \text{ por favor}, 0, 3] \leftarrow$
- $X \to X_{0.5} \bullet \text{ por favor}, 0, 5 \text{ completed}$

- $1 [X \to a \bullet, 1, 2] \checkmark$
- $[X \rightarrow \mathsf{luz} \bullet, 2, 3] \checkmark$
- 3  $[X \rightarrow \text{apague} \bullet X, 0, 1]$  waiting
- **4**  $[X \rightarrow \bullet X \text{ por favor, } 1, 1]$  waiting
- **5**  $[X \rightarrow \bullet X \text{ por favor}, 2, 2]$  waiting
- **6**  $[X \rightarrow \bullet XX, 0, 0]$  waiting
- $[X \to \bullet XX, 1, 1]$  waiting
- $\{X \rightarrow \bullet XX, 2, 2\}$  waiting
- $\mathbf{Q}$  [ $X \to \bullet XX, 3, 3$ ] waiting
- $(S \rightarrow \bullet X, 0, 0)$  waiting
- $(X \rightarrow X_{1,2} \bullet \text{ por favor}, 1, 2] \times$
- $[X \to X_{2,3} \text{ por favor}, 2, 5] \checkmark$
- $(X \rightarrow X_{1,2} \bullet X, 1, 2)$  waiting
- $[X \rightarrow X_{2,3} \bullet X, 2, 3]$  waiting
- **(b)**  $[X \to X_{1,2}X_{2,3} \bullet, 1, 3] \checkmark$
- **6**  $[X \to X_{1,2}X_{2,5} \bullet, 1, 5] \checkmark$

- **(h)**  $[X \rightarrow \text{apague } X_{1,2} \bullet, 0, 2] \checkmark$
- **18**  $[X \rightarrow \text{apague } X_{1,3} \bullet, 0, 3] \checkmark$
- $(X \rightarrow \text{apague } X_{1,5} \bullet, 0, 5) \checkmark$
- $\mathfrak{D}$  [ $X \to X_{1,3}$  por favor $\bullet$ , 1, 5] scanned
- $X \rightarrow X_0 \ 2 \bullet X, 0, 2$  waiting
- $X \rightarrow X_0 \rightarrow X_0 \rightarrow X_1 \rightarrow X_2 \rightarrow X_3 \rightarrow X_3 \rightarrow X_4 \rightarrow X_4 \rightarrow X_5 \rightarrow X_6 \rightarrow$
- $X \rightarrow X_{1,3} \bullet X, 1, 3$  waiting
  - **2**  $[S \to X_{0.5} \bullet, 0, 5] \checkmark$
- **4** [*X* →  $X_{0,2}X_{2,3}$ •, 0, 3] ✓
- **26**  $[X \to X_{0.2}X_{2.5} \bullet, 0, 5] \checkmark$
- $X \to X$  por favor, 0, 0 waiting
- $X \rightarrow X_{0,2} \bullet \text{ por favor}, 0, 2 \times$
- $\mathfrak{P}$   $[X \to X_{0,3} \text{ por favor}, 0, 5]$  scanned
- $\{X \rightarrow X_{0.5} \bullet \text{ por favor}, 0, 5\} \leftarrow$

- $1 \quad [X \to a \bullet, 1, 2] \checkmark$
- $2 [X \rightarrow \mathsf{luz} \bullet, 2, 3] \checkmark$
- **3**  $[X \rightarrow \mathsf{apague} \bullet X, 0, 1]$  waiting
- **4**  $[X \to \bullet X \text{ por favor}, 1, 1]$  waiting
- **5**  $[X \to \bullet X \text{ por favor}, 2, 2]$  waiting
- **6**  $[X \rightarrow \bullet XX, 0, 0]$  waiting
- $(X \rightarrow \bullet XX, 1, 1]$  waiting
- **8**  $[X \rightarrow \bullet XX, 2, 2]$  waiting

- $(X \rightarrow X_{1,2} \bullet X, 1, 2]$  waiting
- $[X \rightarrow X_{2,3} \bullet X, 2, 3]$  waiting
- **(b)**  $[X \to X_{1,2}X_{2,3} \bullet, 1, 3] \checkmark$
- **6**  $[X \to X_{1,2}X_{2,5} \bullet, 1, 5] \checkmark$

- $\mathfrak{Q}$   $[X \to X_{1,3} \text{ por favor} \bullet, 1, 5] scanned$
- $(X \to X_{0,2} \bullet X, 0, 2] \text{ waiting}$
- $X \rightarrow X_{0,3} \bullet X, 0, 3$  waiting
- **2** [S →  $X_{0,5}$ •, 0, 5] ✓
  - **4** [ $X \to X_{0,2}X_{2,3} •, 0, 3$ ] ✓
- **26**  $[X \to X_0 \ _2X_2 \ _5 \bullet, 0, 5] \checkmark$
- $[X \to \bullet X \text{ por favor, } 0, 0] \text{ waiting}$
- $[X \rightarrow VX \text{ por ravor}, 0, 0]$  waiting
- $(X \to X_{0,2} \bullet \text{ por favor}, 0, 2] \times$
- $\mathfrak{Q}$   $[X \to X_{0,3} \text{ por favor} \bullet, 0, 5]$  scanned

- $2 [X \to \mathsf{luz} \bullet, 2, 3] \checkmark$
- **3**  $[X \rightarrow \mathsf{apague} \bullet X, 0, 1]$  waiting
- **5**  $[X \to \bullet X \text{ por favor}, 2, 2]$  waiting
- **6**  $[X \rightarrow \bullet XX, 0, 0]$  waiting
- $(X \rightarrow \bullet XX, 1, 1)$  waiting
- **8**  $[X \rightarrow \bullet XX, 2, 2]$  waiting
- $[X \rightarrow XX, Z, Z]$  waiting

- $[X \rightarrow X_{2,3} \bullet X, 2, 3]$  waiting
- **(b)**  $[X \to X_{1,2}X_{2,3} \bullet, 1, 3] \checkmark$
- **6**  $[X \to X_{1,2}X_{2,5} \bullet, 1, 5] \checkmark$

- 2  $[X o X_{0,3} \bullet X, 0, 3]$  waiting
- **2** [S →  $X_{0,5}$ •, 0, 5] ✓
  - **4** [ $X \to X_{0,2}X_{2,3} •, 0, 3$ ] ✓
- **26**  $[X \to X_0 \ _2X_2 \ _5 \bullet, 0, 5] \checkmark$
- $X \to X$  por favor, [0,0] waiting
- The second of th
- $(X \to X_{0,2} \bullet \text{ por favor}, 0, 2] \times$
- $\mathfrak{Q}$   $[X \to X_{0,3} \text{ por favor} \bullet, 0, 5]$  scanned
- $(X \to X_{0,5} \bullet \text{ por favor}, 0, 5] \times$

- $2 [X \to \mathsf{luz} \bullet, 2, 3] \checkmark$
- **3**  $[X \rightarrow \mathsf{apague} \bullet X, 0, 1]$  waiting
- **5**  $[X \to \bullet X \text{ por favor}, 2, 2]$  waiting
- **6**  $[X \rightarrow \bullet XX, 0, 0]$  waiting
- **3**  $[X \rightarrow \bullet XX, 2, 2]$  waiting
- $[X \to XX, Z, Z] \text{ waiting}$

- $\P$   $[X o X_{1,2} \bullet X, 1, 2]$  waiting
- $[X \rightarrow X_{2,3} \bullet X, 2, 3]$  waiting
- **(b)**  $[X \to X_{1,2}X_{2,3} \bullet, 1, 3] \checkmark$
- **6**  $[X \to X_{1,2}X_{2,5} \bullet, 1, 5] \checkmark$

- $(X \to X_{1,3} \text{ por favor} \bullet, 1, 5) \checkmark$

- $(X \to X_{1,3} \bullet X, 1, 3] \text{ waiting}$
- **2**  $[S \to X_{0,5} •, 0, 5]$  ✓
- **4** [ $X \to X_{0,2}X_{2,3} \bullet, 0, 3$ ] ✓
- **26** [ $X \to X_{0,2}X_{2,5} \bullet, 0, 5$ ] ✓
  - **2**  $[X \to \bullet X \text{ por favor}, 0, 0]$  waiting
- $(X \to X_{0,2} \bullet \text{ por favor}, 0, 2] \times$
- $\mathfrak{Q}$   $[X \to X_{0,3} \text{ por favor} \bullet, 0, 5]$  scanned
- $(X \to X_{0,5} \bullet \text{ por favor}, 0, 5] \times$

- $2 [X \rightarrow \mathsf{luz} \bullet, 2, 3] \checkmark$
- **3**  $[X \rightarrow \mathsf{apague} \bullet X, 0, 1]$  waiting
- **6**  $[X \to \bullet X \text{ por favor}, 2, 2]$  waiting
- **6**  $[X \rightarrow \bullet XX, 0, 0]$  waiting
- $(X \rightarrow \bullet XX, 1, 1]$  waiting
- $[X \rightarrow \bullet XX, 2, 2]$  waiting

- $(X \rightarrow X_{1,2} \bullet X, 1, 2)$  waiting
- $[X \rightarrow X_{2,3} \bullet X, 2, 3]$  waiting
- **6**  $[X \to X_{1,2}X_{2,5} \bullet, 1, 5] \checkmark$

- $\{X \to \text{apague } X_{1,3} \bullet, 0, 3\} \checkmark$
- $(X \to X_{1,3} \text{ por favor} \bullet, 1, 5) \checkmark$

- $(X \to X_{1,3} \bullet X, 1, 3]$  waiting
- **2**  $[S \to X_{0,5} •, 0, 5]$  ✓
- **②**  $[X \to X_{0,2}X_{2,3} •, 0, 3]$  ✓
- **26**  $[X \to X_0 \ _2X_2 \ _5 \bullet, 0, 5] \checkmark$
- $[X \to \bullet X]$  por favor, [0,0] waiting
- $[X \rightarrow X_{0,2} \bullet \text{ por favor}, 0, 0] \times$
- $2 [X \rightarrow X_{0,3} \text{ por favor}, 0, 5] \leftarrow$
- $\{X \to X_{0,3} \text{ por favor} \bullet, 0, 5\} \leftarrow$
- $(X \to X_{0,5} \bullet \text{ por favor}, 0, 5] \times$

- $2 [X \to \mathsf{luz} \bullet, 2, 3] \checkmark$
- **3**  $[X \to \mathsf{apague} \bullet X, 0, 1]$  waiting
- **5**  $[X \to \bullet X \text{ por favor}, 2, 2]$  waiting
- **6**  $[X \rightarrow \bullet XX, 0, 0]$  waiting
- $[X \rightarrow \bullet XX, 2, 2]$  waiting

- $[X \rightarrow X_{2,3} \bullet X, 2, 3]$  waiting
- **(b)**  $[X \to X_{1,2}X_{2,3} \bullet, 1, 3] \checkmark$
- **6**  $[X \to X_{1,2}X_{2,5} \bullet, 1, 5] \checkmark$

- $(X \to X_{1,3} \text{ por favor} \bullet, 1, 5) \checkmark$
- 2  $[X \rightarrow X_{0,3} \bullet X, 0, 3]$  waiting
- $(X \to X_{1,3} \bullet X, 1, 3]$  waiting
  - **2**  $[S \to X_{0,5} •, 0, 5]$  ✓
  - **4** [ $X \to X_{0,2}X_{2,3} •, 0, 3$ ] ✓
- **26**  $[X \to X_{0,2}X_{2,5} \bullet, 0, 5] \checkmark$ 
  - **3**  $[X \to \bullet X \text{ por favor}, 0, 0]$  waiting
- **28**  $[X \rightarrow X_{0,2} \bullet \text{ por favor}, 0, 2] \times$
- $\{X \rightarrow X_{0,5} \bullet \text{ por favor}, 0, 5\} \times$

# Forest

- **1**  $[X_{1,2} \to a]$
- **2**  $[X_{2,3} \to luz]$
- 3  $[X_{0,2} \rightarrow \text{apague } X_{1,2}]$
- **6**  $[X_{1,3} \to X_{1,2}X_{2,3}]$
- **6**  $[X_{1.5} \rightarrow X_{1.2}X_{2.5}]$
- $[X_{0.3} \to X_{0.2}X_{2.3}]$
- **8**  $[X_{0.5} \rightarrow X_{0.2}X_{2.5}]$
- $\bullet$   $[X_{0,3} \rightarrow \text{apague } X_{1,3}]$
- $\bullet$   $[X_{1.5} \rightarrow X_{1.3} \text{ por favor}]$
- $\bullet$   $[X_{0.5} \rightarrow \text{apague } X_{1.5}]$
- $\bullet$   $[X_{0.5} \rightarrow X_{0.3} \text{ por favor}]$
- $[S_{0.5} \to X_{0.5}]$

$$G = \langle \Sigma, \Delta, N, S, R \rangle$$

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•  $\Sigma$  input terminal vocabulary

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- $S \in N$  start symbol

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- $S \in N$  start symbol
- R is a set of synchronous rules

$$G = \langle \Sigma, \Delta, N, S, R \rangle$$

- $\Sigma$  input terminal vocabulary
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- $S \in N$  start symbol
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- $\Sigma$  input terminal vocabulary
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  - $X \in N$

$$G = \langle \Sigma, \Delta, N, S, R \rangle$$

- $\Sigma$  input terminal vocabulary
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- $S \in N$  start symbol
- R is a set of synchronous rules each of the form  $X \to \langle \alpha, \beta, \sim \rangle$ 
  - $X \in N$
  - $\alpha \in (\Sigma \cup N)^+$

$$G = \langle \Sigma, \Delta, N, S, R \rangle$$

- $\Sigma$  input terminal vocabulary
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- $S \in N$  start symbol
- R is a set of synchronous rules each of the form  $X \to \langle \alpha, \beta, \sim \rangle$ 
  - $X \in N$
  - $\alpha \in (\Sigma \cup N)^+$
  - $\beta \in (\Delta \cup N)^+$

$$G = \langle \Sigma, \Delta, N, S, R \rangle$$

- $\Sigma$  input terminal vocabulary
- $\Delta$  output terminal vocabulary
- N shared nonterminal vocabulary
- $S \in N$  start symbol
- R is a set of synchronous rules each of the form  $X \to \langle \alpha, \beta, \sim \rangle$ 
  - $X \in N$
  - $\alpha \in (\Sigma \cup N)^+$
  - $\beta \in (\Delta \cup N)^+$
  - $\sim$  is a one-to-one mapping between nonterminals in  $\alpha$  and  $\beta$

#### Synchronous grammar

- $1 X \rightarrow \langle a, the \rangle$
- **2**  $X \rightarrow \langle \mathsf{luz}, \mathsf{light} \rangle$
- **3**  $X \to \langle \text{apague } X_1, \text{switch } X_1 \text{ off} \rangle$
- **4**  $X \to \langle X_1 \text{ por favor, please, } X_1 \rangle$
- **6**  $X \rightarrow \langle X_1 X_2, X_1 X_2 \rangle$
- **6**  $S \rightarrow \langle X_1, X_1 \rangle$

Recognise pair of strings

Recognise pair of strings

Example

(apague a luz por favor, please, switch off the light)

Recognise pair of strings

Example

(apague a luz por favor, please, switch off the light)

A valid tree yields a pair of strings

Intersect the input

#### Intersect the input

• a valid tree yields the input string

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- a valid tree yields the input string
- 2 the intersection itself is a CFG

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#### Intersect the input

- a valid tree yields the input string
- 2 the intersection itself is a CFG
- an output projection defines a set of output strings

Intersect the output

#### Intersect the input

- a valid tree yields the input string
- 2 the intersection itself is a CFG
- 3 an output projection defines a set of output strings

#### Intersect the output

1 a valid tree yields the output string

AXIOMS

$$\overline{[X \to \langle \bullet \beta, \zeta \rangle \,, q, q]} \quad q \in \, Q \wedge X \to \langle \beta, \zeta \rangle \in R$$

GOAL

$$[X \to \langle \alpha \bullet, \zeta \rangle, q, r] \ q \in I \land r \in F \land X \in S$$

SCAN

$$\frac{[X \to \langle \alpha \bullet x\beta, \zeta \rangle\,,\, q,s]}{[X \to \langle \alpha x \bullet \beta, \zeta \rangle]} \quad \langle s,x,r \rangle \in E$$

Complete

$$\frac{[X \to \langle \alpha \bullet Y\beta, \zeta \rangle, q, s] [Y \to \langle \gamma \bullet, \xi \rangle, s, r]}{[X \to \langle \alpha Y_{s,r} \bullet \beta, \zeta \rangle, q, r]}$$

- algorithm remains the same
- keep track of target RHS

#### First intersection

$$1 X_{1,2} \rightarrow \langle a, \mathsf{the} \rangle$$

**2** 
$$X_{2,3} \rightarrow \langle \mathsf{luz}, \mathsf{light} \rangle$$

3 
$$X_{0,2} \rightarrow \langle \text{apague } X_{1,2}, \text{switch } X_{1,2} \text{ off} \rangle$$

**4** 
$$X_{2,5} \rightarrow \langle X_{2,3} \text{ por favor, please, } X_{2,3} \rangle$$

**6** 
$$X_{1,3} \to \langle X_{1,2} X_{2,3}, X_{1,2} X_{2,3} \rangle$$

**6** 
$$X_{1,5} \rightarrow \langle X_{1,2}X_{2,5}, X_{1,2}X_{2,5} \rangle$$

$$X_{0,3} \to \langle X_{0,2} X_{2,3}, X_{0,2} X_{2,3} \rangle$$

**8** 
$$X_{0,5} \rightarrow \langle X_{0,2}X_{2,5}, X_{0,2}X_{2,5} \rangle$$

**9** 
$$X_{0,3} \rightarrow \langle \text{apague } X_{1,3}, \text{switch } X_{1,3} \text{ off} \rangle$$

$$X_{1,5} \rightarrow \langle X_{1,3} \text{ por favor, please, } X_{1,3} \rangle$$

$$\bullet$$
  $X_{0.5} \rightarrow \langle \text{apague } X_{1.5}, \text{switch } X_{1.5} \text{ off} \rangle$ 

$$\bullet$$
  $X_{0,5} \rightarrow \langle X_{0,3} \text{ por favor, please, } X_{0,3} \rangle$ 

**B** 
$$S_{0,5} \to \langle X_{0,5}, X_{0,5} \rangle$$

#### $1 X_{1,2} \to \mathsf{the}$

2 
$$X_{2,3} \rightarrow \mathsf{light}$$

**3** 
$$X_{0,2} \rightarrow \text{switch } X_{1,2} \text{ off}$$

**4** 
$$X_{2,5} \to \mathsf{please}, \ X_{2,3}$$

**6** 
$$X_{1,3} \to X_{1,2}X_{2,3}$$

**6** 
$$X_{1,5} \rightarrow X_{1,2}X_{2,5}$$

$$X_{0,3} \to X_{0,2}X_{2,3}$$

**8** 
$$X_{0.5} \rightarrow X_{0.2}X_{2.5}$$

$$\mathbf{0}$$
  $X_{1.5} \rightarrow \mathsf{please}, X_{1.3}$ 

$$\bullet$$
  $X_{0,5} \rightarrow \text{switch } X_{1,5} \text{ off}$ 

$$\mathbf{P}$$
  $X_{0,5} \rightarrow \mathsf{please}, X_{0,3}$ 

$$S_{0.5} \to X_{0.5}$$

$$1 X^{1,2} \to \mathsf{the}$$

$$2 X^{2,3} \to \mathsf{light}$$

**3** 
$$X^{0,2} \rightarrow \text{switch } X^{1,2} \text{ off}$$

**4** 
$$X^{2,5} \to \text{please}, X^{2,3}$$

**6** 
$$X^{1,3} \to X^{1,2}X^{2,3}$$

**6** 
$$X^{1,5} \to X^{1,2}X^{2,5}$$

$$X^{0,3} \to X^{0,2} X^{2,3}$$

**8** 
$$X^{0,5} \to X^{0,2}X^{2,5}$$

$$\mathbf{n}$$
  $X^{0,5} \to \text{switch } X^{1,5} \text{ off}$ 

$$X^{0,5} \rightarrow \text{please}$$
.  $X^{0,3}$ 

$$S^{0,5} \to X^{0,5}$$

	please,	switch	the	light	off
1					
2					
3					
4					
5					

$$1 X^{1,2} \to \mathsf{the}$$

2 
$$X^{2,3} \rightarrow \mathsf{light}$$

$$3 X^{0,2} \to \mathsf{switch}\ X^{1,2}\ \mathsf{off}$$

**4** 
$$X^{2,5} \to \text{please}, X^{2,3}$$

**6** 
$$X^{1,3} \to X^{1,2}X^{2,3}$$

**6** 
$$X^{1,5} \to X^{1,2}X^{2,5}$$

$$X^{0,3} \to X^{0,2} X^{2,3}$$

**8** 
$$X^{0,5} \to X^{0,2} X^{2,5}$$

$$9 X^{0,3} \to \mathsf{switch} \ X^{1,3} \ \mathsf{off}$$

$${\bf 6} S^{0,5} \to X^{0,5}$$

	please,	switch	the	light	off
1			$X^{1,2} \xrightarrow{1} the$		
2					
3					
4					
5					

$$1 X^{1,2} \to \mathsf{the}$$

$$2 \hspace{-.8cm} X^{2,3} \to \mathsf{light}$$

$$3 X^{0,2} \to \mathsf{switch}\ X^{1,2}\ \mathsf{off}$$

**4** 
$$X^{2,5} \to \text{please}, X^{2,3}$$

**6** 
$$X^{1,3} \to X^{1,2}X^{2,3}$$

**6** 
$$X^{1,5} \to X^{1,2}X^{2,5}$$

$$X^{0,3} \to X^{0,2} X^{2,3}$$

**8** 
$$X^{0,5} \to X^{0,2} X^{2,5}$$

**(3** 
$$S^{0,5} \to X^{0,5}$$

	please,	switch	the	light	off
1			$X^{1,2} \xrightarrow{1} the$	$X^{2,3} \xrightarrow{2} ligh$	t
2					
3					
4					
5					

$$1 X^{1,2} \to \mathsf{the}$$

$$2 X^{2,3} \to \mathsf{light}$$

$$3 X^{0,2} \to \mathsf{switch}\ X^{1,2}\ \mathsf{off}$$

**4** 
$$X^{2,5} \to \text{please}, X^{2,3}$$

**6** 
$$X^{1,3} \to X^{1,2}X^{2,3}$$

**6** 
$$X^{1,5} \to X^{1,2}X^{2,5}$$

$$X^{0,3} \to X^{0,2} X^{2,3}$$

**8** 
$$X^{0,5} \to X^{0,2} X^{2,5}$$

$$S^{0,5} \to X^{0,5}$$

	please,	switch	the	light	off
1			$X^{1,2} \xrightarrow{1} the$	$X^{2,3} \xrightarrow{2} \text{light}$	
2			$X^{1,3} \stackrel{5}{=}$	$X^{1,2}X^{2,3}$	
3					
4					
5					

$$1 X^{1,2} \to \mathsf{the}$$

2 
$$X^{2,3} \rightarrow \mathsf{light}$$

$$3 X^{0,2} \rightarrow \mathsf{switch} \ X^{1,2} \ \mathsf{off}$$

**4** 
$$X^{2,5} \to \text{please}, X^{2,3}$$

**6** 
$$X^{1,3} \to X^{1,2}X^{2,3}$$

**6** 
$$X^{1,5} \to X^{1,2}X^{2,5}$$

$$X^{0,3} \to X^{0,2} X^{2,3}$$

**8** 
$$X^{0,5} \to X^{0,2}X^{2,5}$$

$$9 X^{0,3} \to \mathsf{switch} \ X^{1,3} \ \mathsf{off}$$

$${\bf B} S^{0,5} \to X^{0,5}$$

	please,	switch	the	light	off	
1			$X^{1,2} \xrightarrow{1} the$	$X^{2,3} \xrightarrow{2} light$		
2	$X^{1,3} \xrightarrow{5} X^{1,2} X^{2,3}$					
3			$X^{0,3} \xrightarrow{9} \text{sw}$	vitch $X^{1,3}$ off		
4						
5						

$$1 X^{1,2} \to \mathsf{the}$$

2 
$$X^{2,3} \rightarrow \text{light}$$

$$3 \hspace{-0.8em} X^{0,2} \to \mathsf{switch} \hspace{0.8em} X^{1,2} \hspace{0.8em} \mathsf{off}$$

**4** 
$$X^{2,5} \to \mathsf{please}, \ X^{2,3}$$

**6** 
$$X^{1,3} \to X^{1,2}X^{2,3}$$

**6** 
$$X^{1,5} \to X^{1,2}X^{2,5}$$

$$X^{0,3} \to X^{0,2} X^{2,3}$$

**8** 
$$X^{0,5} \to X^{0,2}X^{2,5}$$

$$9 X^{0,3} \to \mathsf{switch} \ X^{1,3} \ \mathsf{off}$$

$${\bf G} S^{0,5} \to X^{0,5}$$

	please,	switch	the	light	off		
1			$X^{1,2} \xrightarrow{1} the$	$X^{2,3} \xrightarrow{2} $ light			
2	$X^{1,3} \xrightarrow{5} X^{1,2} X^{2,3}$						
3	$X^{0,3} \xrightarrow{9} $ switch $X^{1,3}$ off						
4	$X^{0,5} \xrightarrow{12} please, X^{0,3}$						
5							

$$1 X^{1,2} \to \mathsf{the}$$

$$2 \hspace{-.8cm} X^{2,3} \to \mathsf{light}$$

$$3 X^{0,2} \to \mathsf{switch} \ X^{1,2} \ \mathsf{off}$$

**4** 
$$X^{2,5} \to \text{please}, X^{2,3}$$

**6** 
$$X^{1,3} \to X^{1,2}X^{2,3}$$

**6** 
$$X^{1,5} \to X^{1,2}X^{2,5}$$

$$X^{0,3} \to X^{0,2} X^{2,3}$$

**8** 
$$X^{0,5} \to X^{0,2} X^{2,5}$$

$$2 \hspace{-0.1cm} \hbox{$\chi$}^{0,5} \to {\rm please,} \ X^{0,3}$$

$${\bf B} \ S^{0,5} \to X^{0,5}$$

	please,	switch	the	light	off		
1			$X^{1,2} \xrightarrow{1} the$	$X^{2,3} \xrightarrow{2} \text{lig}$	ht		
2	$X^{1,3} \xrightarrow{5} X^{1,2} X^{2,3}$						
3	$X^{0,3} \xrightarrow{9} $ switch $X^{1,3}$ off						
4	$X^{0,5} \xrightarrow{12} please, X^{0,3}$						
5	$S^{0,5} \xrightarrow{13} X^{0,5}$						

$$1 X^{1,2} \to \mathsf{the}$$

2 
$$X^{2,3} \rightarrow \mathsf{light}$$

$$3 X^{0,2} \to \mathsf{switch} \ X^{1,2} \ \mathsf{off}$$

**4** 
$$X^{2,5} \to \text{please}, X^{2,3}$$

**6** 
$$X^{1,3} \to X^{1,2}X^{2,3}$$

**6** 
$$X^{1,5} \to X^{1,2}X^{2,5}$$

$$X^{0,3} \to X^{0,2} X^{2,3}$$

**8** 
$$X^{0,5} \to X^{0,2} X^{2,5}$$

$$\ \ \, \textbf{9} \ \, X^{0,3} \rightarrow \text{switch} \,\, X^{1,3} \,\, \text{off} \,\,$$

$$X^{0,5} \rightarrow \text{please}, X^{0,3}$$

**B** 
$$S^{0,5} \to X^{0,5}$$

	please,	switch	the	light	off		
1			$X_{2,3}^{1,2} \xrightarrow{1} the$	$X^{2,3} \xrightarrow{2} ligh^{1}$	t		
2	$X^{1,3} \xrightarrow{5} X^{1,2} X^{2,3}$						
3	$X^{0,3} \xrightarrow{9} $ switch $X^{1,3}$ off						
4	$X^{0,5} \xrightarrow{12} please, X^{0,3}$						
5	$S^{0,5} \xrightarrow{13} X^{0,5}$						

$$1 X^{1,2} \to \mathsf{the}$$

$$2 X^{2,3} \to \mathsf{light}$$

$$3 X^{0,2} \to \mathsf{switch}\ X^{1,2}\ \mathsf{off}$$

**4** 
$$X^{2,5} \to \text{please}, X^{2,3}$$

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$$X^{1,3} \to X^{1,2}X^{2,3}$$

**6** 
$$X^{1,5} \to X^{1,2}X^{2,5}$$

$$X^{0,3} \to X^{0,2} X^{2,3}$$

**8** 
$$X^{0,5} \to X^{0,2} X^{2,5}$$

$$\ \ \, \textbf{9} \ \, X^{0,3} \rightarrow \text{switch} \,\, X^{1,3} \,\, \text{off} \,\,$$

**B** 
$$S^{0,5} \to X^{0,5}$$

	please,	switch	the	light	off		
1			$X_{2,3}^{1,2} \xrightarrow{1} the$	$X_{3,4}^{2,3} \xrightarrow{2} \text{lig}$	ht		
2	$X^{1,3} \xrightarrow{5} X^{1,2} X^{2,3}$						
3	$X^{0,3} \xrightarrow{9} $ switch $X^{1,3}$ off						
4	$X^{0,5} \xrightarrow{12} please, X^{0,3}$						
5	$S^{0,5} \xrightarrow{13} X^{0,5}$						

$$1 X^{1,2} \to \mathsf{the}$$

$$2 X^{2,3} \to \mathsf{light}$$

$$3 \hspace{-0.8em} X^{0,2} \to \mathsf{switch} \hspace{0.8em} X^{1,2} \hspace{0.8em} \mathsf{off}$$

**4** 
$$X^{2,5} \to \text{please}, X^{2,3}$$

**6** 
$$X^{1,3} \to X^{1,2}X^{2,3}$$

**6** 
$$X^{1,5} \to X^{1,2}X^{2,5}$$

$$X^{0,3} \to X^{0,2} X^{2,3}$$

**8** 
$$X^{0,5} \to X^{0,2} X^{2,5}$$

$$\ \ \, \textbf{9} \ \, X^{0,3} \rightarrow \text{switch} \,\, X^{1,3} \,\, \text{off} \,\,$$

$$X^{0,5} \rightarrow \text{please}. X^{0,3}$$

$$X^{\circ,\circ} \to \mathsf{please}, X^{\circ,\circ}$$

**B** 
$$S^{0,5} \to X^{0,5}$$

	please,	switch	the	light	off		
1			$X_{2,3}^{1,2} \xrightarrow{1} the$	$X_{3,4}^{2,3} \xrightarrow{2} $ light			
2	$X_{2,4}^{1,3} \xrightarrow{5} X^{1,2} X^{2,3}$						
3	$X^{0,3} \xrightarrow{9} $ switch $X^{1,3}$ off						
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5	$S^{0,5} \xrightarrow{13} X^{0,5}$						

$$1 X^{1,2} \to \mathsf{the}$$

$$2 X^{2,3} \to \mathsf{light}$$

$$3 X^{0,2} \to \mathsf{switch}\ X^{1,2}\ \mathsf{off}$$

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$$X^{2,5} \to \text{please}, X^{2,3}$$

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$$X^{1,3} \to X^{1,2}X^{2,3}$$

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$$X^{1,5} \to X^{1,2}X^{2,5}$$

$$X^{0,3} \to X^{0,2} X^{2,3}$$

**8** 
$$X^{0,5} \to X^{0,2} X^{2,5}$$

$$X^{0,5} \rightarrow \text{please}$$
.  $X^{0,3}$ 

**B** 
$$S^{0,5} \to X^{0,5}$$

	please,	switch	the	light	off		
1			$X_{2,3}^{1,2} \xrightarrow{1} the$	$X_{3,4}^{2,3} \xrightarrow{2} $ light			
2	$X_{2,4}^{1,3} \xrightarrow{5} X_{2,3}^{1,2} X^{2,3}$						
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4	$X^{0,5} \xrightarrow{12} please, X^{0,3}$						
5	$S^{0,5} \xrightarrow{13} X^{0,5}$						

$$1 X^{1,2} \to \mathsf{the}$$

$$2 X^{2,3} \to \mathsf{light}$$

$$3 \hspace{-0.2cm} X^{0,2} \to \mathsf{switch} \hspace{0.1cm} X^{1,2} \hspace{0.1cm} \mathsf{off}$$

**4** 
$$X^{2,5} \to \text{please}, X^{2,3}$$

**6** 
$$X^{1,3} \to X^{1,2}X^{2,3}$$

**6** 
$$X^{1,5} \to X^{1,2}X^{2,5}$$

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**8** 
$$X^{0,5} \to X^{0,2} X^{2,5}$$

$$9 \ X^{0,3} \to \mathsf{switch} \ X^{1,3} \ \mathsf{off}$$

$$\mathbf{\Phi} \ X^{0,5} \to \mathsf{please}, \ X^{0,3}$$

$$\mathbb{S}^{0,5} \to X^{0,5}$$

	please,	switch	the	light	off		
1			$X_{2,3}^{1,2} \xrightarrow{1} the$	$X_{3,4}^{2,3} \xrightarrow{2} $ light			
2	$X_{2,4}^{1,3} \xrightarrow{5} X_{2,3}^{1,2} X_{3,4}^{2,3}$						
3	$X^{0,3} \xrightarrow{9} $ switch $X^{1,3}$ off						
4	$X^{0,5} \xrightarrow{12} please, X^{0,3}$						
5	$S^{0,5} \xrightarrow{13} X^{0,5}$						

$$1 X^{1,2} \to \mathsf{the}$$

$$2 X^{2,3} \to \mathsf{light}$$

$$3 \hspace{-0.2cm} X^{0,2} \to \mathsf{switch} \hspace{0.1cm} X^{1,2} \hspace{0.1cm} \mathsf{off}$$

**4** 
$$X^{2,5} \to \text{please}, X^{2,3}$$

**6** 
$$X^{1,3} \to X^{1,2}X^{2,3}$$

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$$9 \ X^{0,3} \to \mathsf{switch} \ X^{1,3} \ \mathsf{off}$$

$$\mathbf{\Phi} \ X^{0,5} \to \mathsf{please}, \ X^{0,3}$$

$$\mathbb{S}^{0,5} \to X^{0,5}$$

	please,	switch	the	light	off	
1			$X_{2,3}^{1,2} \xrightarrow{1} the$	$X_{3,4}^{2,3} \xrightarrow{2} ligh$	nt	
2	$X_{2,4}^{1,3} \xrightarrow{5} X_{2,3}^{1,2} X_{3,4}^{2,3}$					
3	$X_{1,5}^{0,3} \xrightarrow{9} $ switch $X^{1,3}$ off					
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5	$S^{0,5} \xrightarrow{13} X^{0,5}$					

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$$2 X^{2,3} \to \mathsf{light}$$

$$3 \hspace{-0.2cm} X^{0,2} \to \mathsf{switch} \hspace{0.1cm} X^{1,2} \hspace{0.1cm} \mathsf{off}$$

**4** 
$$X^{2,5} \to \text{please}, X^{2,3}$$

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$$X^{1,3} \to X^{1,2}X^{2,3}$$

**6** 
$$X^{1,5} \to X^{1,2}X^{2,5}$$

$$X^{0,3} \to X^{0,2} X^{2,3}$$

**8** 
$$X^{0,5} \to X^{0,2} X^{2,5}$$

$$X^{0,5} \rightarrow \text{please}$$
.  $X^{0,3}$ 

$$X^{\circ,\circ} \to \mathsf{please}, X^{\circ,\circ}$$

**B** 
$$S^{0,5} \to X^{0,5}$$

	please,	switch	the	light	off	
1			$X_{2,3}^{1,2} \xrightarrow{1} the$	$X_{3,4}^{2,3} \xrightarrow{2} $ light		
2	$X_{2,4}^{1,3} \xrightarrow{5} X_{2,3}^{1,2} X_{3,4}^{2,3}$					
3	$X_{1,5}^{0,3} \xrightarrow{9} $ switch $X_{2,4}^{1,3}$ off					
4	$X^{0,5} \xrightarrow{12} please, X^{0,3}$					
5	$S^{0,5} \xrightarrow{13} X^{0,5}$					

$$1 X^{1,2} \to \mathsf{the}$$

$$2 X^{2,3} \to \mathsf{light}$$

$$3 \hspace{-0.2cm} X^{0,2} \to \mathsf{switch} \hspace{0.1cm} X^{1,2} \hspace{0.1cm} \mathsf{off}$$

**4** 
$$X^{2,5} \to \text{please}, X^{2,3}$$

**6** 
$$X^{1,3} \to X^{1,2}X^{2,3}$$

**6** 
$$X^{1,5} \to X^{1,2}X^{2,5}$$

$$X^{0,3} \to X^{0,2} X^{2,3}$$

**8** 
$$X^{0,5} \to X^{0,2} X^{2,5}$$

$$9 X^{0,3} \to \mathsf{switch} \ X^{1,3} \ \mathsf{off}$$

$${\bf B} S^{0,5} \to X^{0,5}$$

	please,	switch	the	light	off		
1			$X_{2,3}^{1,2} \xrightarrow{1} $ the	$X_{3,4}^{2,3} \xrightarrow{2} $ light			
2	$X_{2,4}^{1,3} \xrightarrow{5} X_{2,3}^{1,2} X_{3,4}^{2,3}$						
3	$X_{1,5}^{0,3} \xrightarrow{9} $ switch $X_{2,4}^{1,3}$ off						
4	$X_{0,5}^{0,5} \stackrel{12}{\longrightarrow} please, X^{0,3}$						
5	$S^{0,5} \xrightarrow{13} X^{0,5}$						

$$1 X^{1,2} \to \mathsf{the}$$

$$2 X^{2,3} \to \mathsf{light}$$

$$3 \hspace{-0.8em} X^{0,2} \to \text{switch} \hspace{0.8em} X^{1,2} \hspace{0.8em} \text{off}$$

**4** 
$$X^{2,5} \to \mathsf{please}, X^{2,3}$$

**6** 
$$X^{1,3} \to X^{1,2}X^{2,3}$$

**6** 
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**8** 
$$X^{0,5} \to X^{0,2} X^{2,5}$$

$$9 X^{0,3} \to \mathsf{switch} \ X^{1,3} \ \mathsf{off}$$

$$X^{0,5} \to \text{please}, X^{0,3}$$

$$X^{\circ,\circ} \to \mathsf{please}, X^{\circ,\circ}$$

**B** 
$$S^{0,5} \to X^{0,5}$$

	please,	switch	the	light	off	
1			$X_{2,3}^{1,2} \xrightarrow{1} the$	$X_{3,4}^{2,3} \xrightarrow{2} ligh^{1}$	t	
2			$X_{2,4}^{1,3} \stackrel{5}{=}$	$\rightarrow X_{2,3}^{1,2} X_{3,4}^{2,3}$		
3	$X_{1,5}^{0,3} \xrightarrow{9} $ switch $X_{2,4}^{1,3}$ off					
4	$X_{0,5}^{0,5} \stackrel{12}{\longrightarrow} please, X_{1,5}^{0,3}$					
5	$S^{0,5} \xrightarrow{13} X^{0,5}$					

$$1 X^{1,2} \to \mathsf{the}$$

2 
$$X^{2,3} \rightarrow \text{light}$$

$$3 X^{0,2} \to \mathsf{switch} \ X^{1,2} \ \mathsf{off}$$

**4** 
$$X^{2,5} \to \text{please}, X^{2,3}$$

**6** 
$$X^{1,3} \to X^{1,2}X^{2,3}$$

**6** 
$$X^{1,5} \to X^{1,2}X^{2,5}$$

$$X^{0,3} \to X^{0,2} X^{2,3}$$

**8** 
$$X^{0,5} \to X^{0,2} X^{2,5}$$

$$9 X^{0,3} \to \mathsf{switch} \ X^{1,3} \ \mathsf{off}$$

$$2 \hspace{-0.1cm} \begin{array}{c} X^{0,5} \rightarrow \mathsf{please}, \ X^{0,3} \end{array}$$

**B** 
$$S^{0,5} \to X^{0,5}$$

	please,	switch	the	light	off	
1			$X_{2,3}^{1,2} \xrightarrow{1} the$	$X_{3,4}^{2,3} \xrightarrow{2} $ light		
2	$X_{2,4}^{1,3} \xrightarrow{5} X_{2,3}^{1,2} X_{3,4}^{2,3}$					
3	$X_{1,5}^{0,3} \xrightarrow{9} $ switch $X_{2,4}^{1,3}$ off					
4	$X_{0,5}^{0,5} \stackrel{12}{\longrightarrow} please, X_{1,5}^{0,3}$					
5	$S_{0,5}^{0,5} \xrightarrow{13} X^{0,5}$					

$$1 X^{1,2} \to \mathsf{the}$$

$$2 X^{2,3} \to \mathsf{light}$$

$$3 X^{0,2} \to \mathsf{switch} \ X^{1,2} \ \mathsf{off}$$

**4** 
$$X^{2,5} \to \text{please}, X^{2,3}$$

**6** 
$$X^{1,3} \to X^{1,2}X^{2,3}$$

**6** 
$$X^{1,5} \to X^{1,2}X^{2,5}$$

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**8** 
$$X^{0,5} \to X^{0,2} X^{2,5}$$

$$9 X^{0,3} \to \mathsf{switch} \ X^{1,3} \ \mathsf{off}$$

$$\mathbb{B} \ S^{0,5} \to X^{0,5}$$

	please,	switch	the	light	off	
1			$X_{2,3}^{1,2} \xrightarrow{1} the$	$X_{3,4}^{2,3} \xrightarrow{2} ligh$	nt	
2	$X_{2,4}^{1,3} \xrightarrow{5} X_{2,3}^{1,2} X_{3,4}^{2,3}$					
3	$X_{1,5}^{0,3} \xrightarrow{9} $ switch $X_{2,4}^{1,3}$ off					
4	$X_{0,5}^{0,5} \xrightarrow{12} please, X_{1,5}^{0,3}$					
5	$S_{0,5}^{0,5} \xrightarrow{13} X_{0,5}^{0,5}$					

$$1 X^{1,2} \to \mathsf{the}$$

$$2 X^{2,3} \to \mathsf{light}$$

$$3 X^{0,2} \to \mathsf{switch} \ X^{1,2} \ \mathsf{off}$$

**4** 
$$X^{2,5} \to \text{please}, X^{2,3}$$

**6** 
$$X^{1,3} \to X^{1,2}X^{2,3}$$

**6** 
$$X^{1,5} \to X^{1,2}X^{2,5}$$

$$X^{0,3} \to X^{0,2} X^{2,3}$$

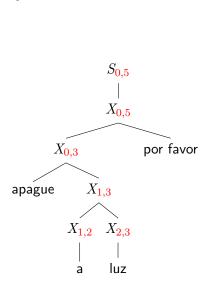
**8** 
$$X^{0,5} \to X^{0,2} X^{2,5}$$

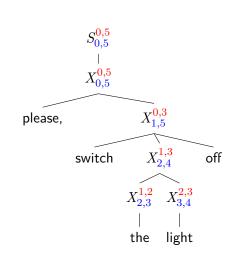
$$9 X^{0,3} \to \mathsf{switch} \ X^{1,3} \ \mathsf{off}$$

$$\mathbf{Q} X^{0,5} \rightarrow \mathsf{please}, X^{0,3}$$

**B** 
$$S^{0,5} \to X^{0,5}$$

## **Analysis**





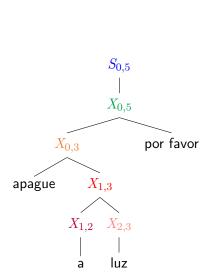
## Example 1

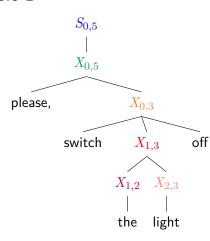
#### Synchronous grammar

- $\mathbf{1} X \to \langle \mathbf{a}, \mathsf{the} \rangle$
- **2**  $X \rightarrow \langle \mathsf{luz}, \mathsf{light} \rangle$
- **3**  $X \to \langle \text{apague } X_1, \text{switch } X_1 \text{ off} \rangle$
- **4**  $X \to \langle X_1 \text{ por favor, please, } X_1 \rangle$
- **6**  $X \rightarrow \langle X_1 X_2, X_1 X_2 \rangle$
- **6**  $S \rightarrow \langle X_1, X_1 \rangle$

Input: apague a luz por favor

## Synchronous derivation - example 1





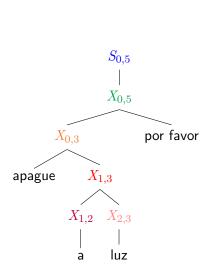
## Example 2

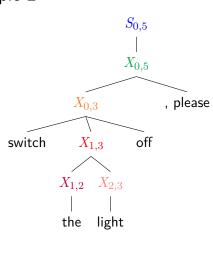
#### Synchronous grammar

- $\bullet X \rightarrow \langle a, the \rangle$
- **2**  $X \rightarrow \langle luz, light \rangle$
- 3  $X \to \langle \text{apague } X_1, \text{switch } X_1 \text{ off} \rangle$
- **4**  $X \to \langle X_1 \text{ por favor, please, } X_1 \rangle$
- **6**  $X \rightarrow \langle X_1 X_2, X_1 X_2 \rangle$
- **6**  $S \rightarrow \langle X_1, X_1 \rangle$

Input: apague a luz por favor

## Synchronous derivation - example 2





parsing as intersection

- parsing as intersection
- 2 deductive proof systems
  - compact representation
  - template for hypergraph

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  - output projection
  - intersect output

- parsing as intersection
- 2 deductive proof systems
  - compact representation
  - template for hypergraph
- 3 synchronous parsing is a straightforward extension
  - intersect input
  - output projection
  - intersect output
- 4 isomorphic trees
  - explicit reordering rules

## Earley parsing

Top-down, left-to-right algorithm

[Earley, 1970]

- same asymptotic complexity as CKY
- top-down predictions
- bottom-up completions
- more efficient in several cases

Intersection with arbitrary automata

[Dyer and Resnik, 2010]

### Earley intersection

AXIOMS

$$\overline{[S' \to \bullet S, q, q]} \quad q \in I$$

GOAL

$$\begin{bmatrix} S' \to S \bullet, q, r \end{bmatrix} \ q \in I \land r \in F$$

Scan

$$\frac{[X \to \alpha \bullet x\beta, q, s]}{[X \to \alpha x \bullet \beta]} \quad \langle s, x, r \rangle \in E$$

Predict

$$\frac{[X \to \alpha \bullet Y\beta, q, r]}{[Y \to \bullet \gamma, r, r]} \quad Y \to \gamma \in R$$

Complete

$$\frac{[X \to \alpha \bullet Y\beta, q, s] [Y \to \gamma \bullet, s, r]}{[X \to \alpha Y_{s,r} \bullet \beta, q, r]} \quad X \neq S'$$

Accept

$$\frac{[S' \to \bullet S, q, q] [S \to \gamma \bullet, q, r]}{[S' \to S_{q,r} \bullet, q, r]} \quad r \in F$$



#### References I

Chris Dyer and Philip Resnik. Context-free reordering, finite-state translation. In *Human Language Technologies: The 2010 Annual Conference of the North American Chapter of the Association for Computational Linguistics*, HLT '10, pages 858–866, Stroudsburg, PA, USA, 2010. Association for Computational Linguistics. ISBN 1-932432-65-5. URL http://dl.acm.org/citation.cfm?id=1857999.1858127.

Jay Earley. An efficient context-free parsing algorithm. *Commun. ACM*, 13(2):94–102, February 1970. ISSN 0001-0782. doi: 10.1145/362007.362035. URL http://doi.acm.org/10.1145/362007.362035.