41080 Theory of Computing Science
Week 6 Tutorial Class

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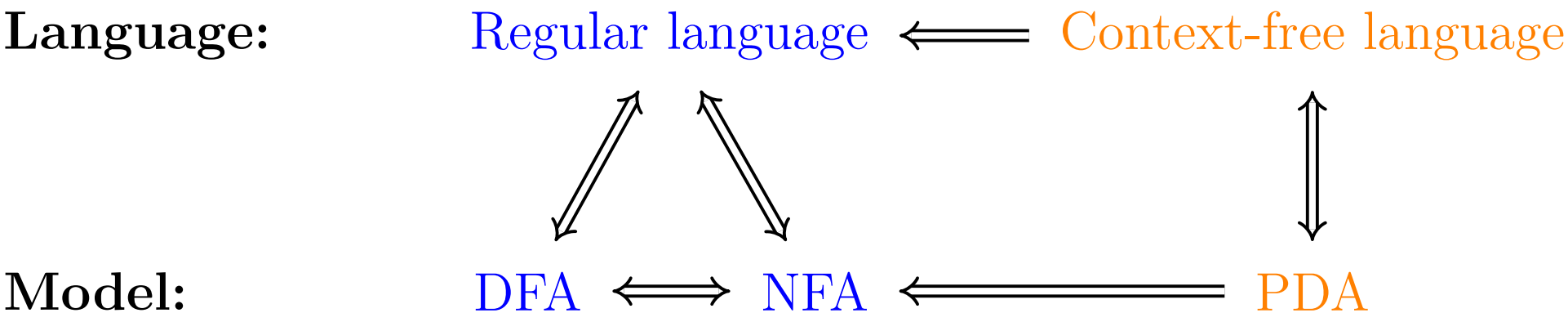
University of Technology Sydney

12th September, 2024

Background


Language:
Regular language
Context-free language
Model:
DFA
NFA
PDA

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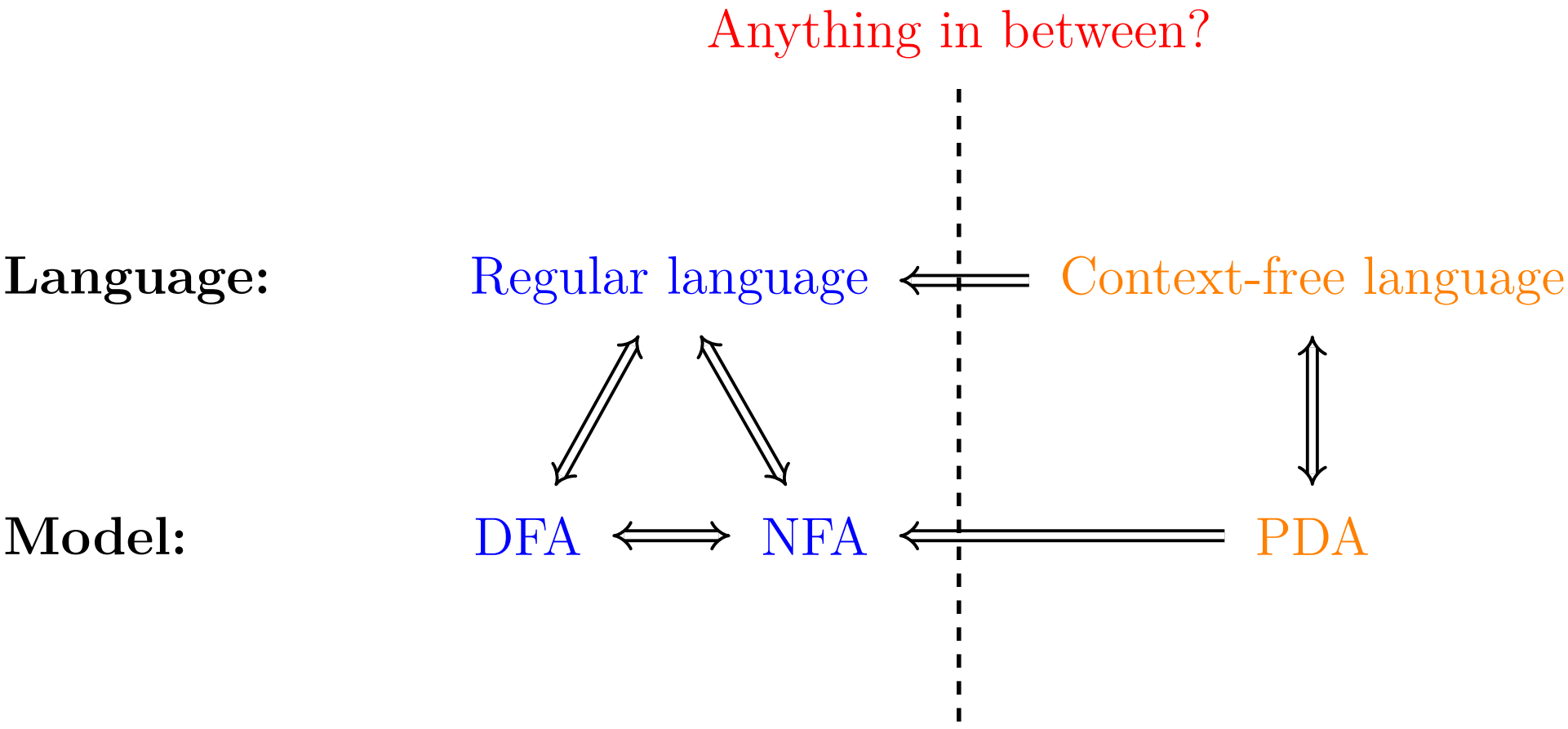
Anything in between?
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- From the practical perspective, we need determinism.
- So people come up with the idea of Deterministic PDA!
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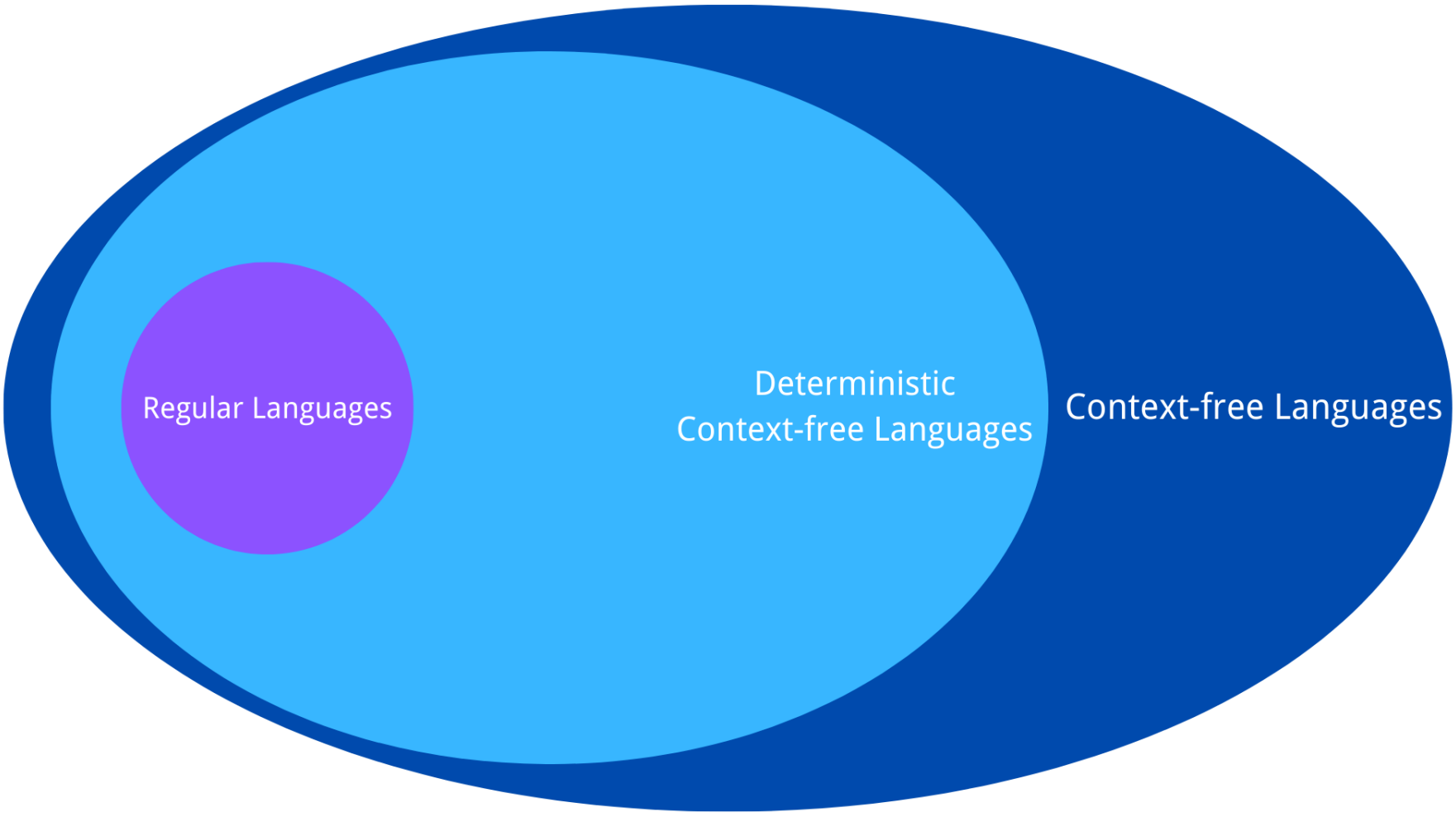

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From a more practical perspective, we need more restriction.

Problem

Given a grammar $G = (V, \Sigma, R, S)$ and a string $w \in L(G)$, how can we construct the process of generating w from S?

This is achieved through a parser. Two possible approaches:

- Top-down parsers: start from S and derive the string w.
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Why is it called top-down?

For some parsers, we can build a parsing tree to illustrate the generation process.

Example (Top-down parsers)

How string id + id is generated from the start variable E by applying a bunch of grammar rules:

This particular example is not only top-down, but also

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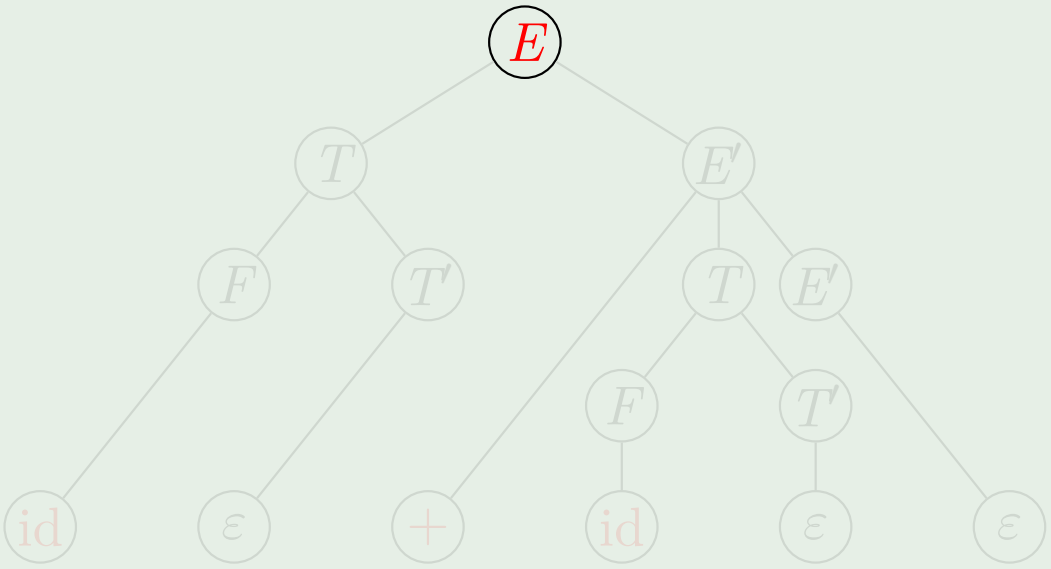

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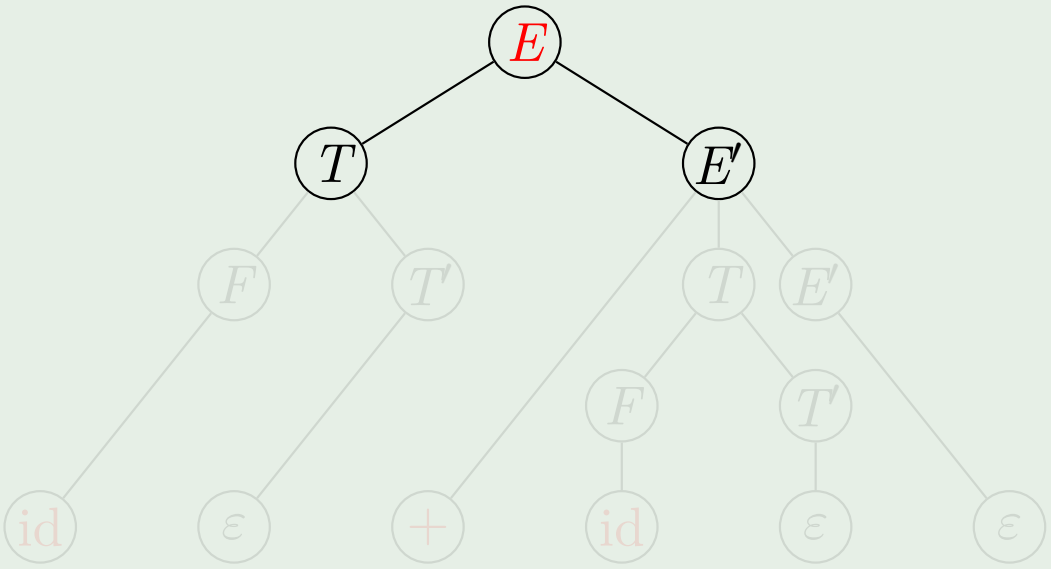

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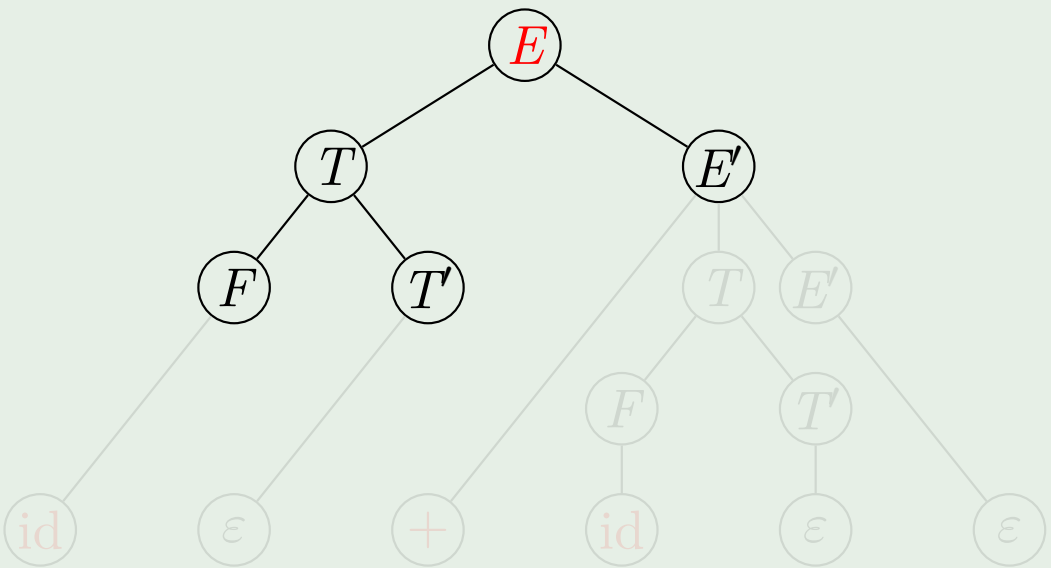

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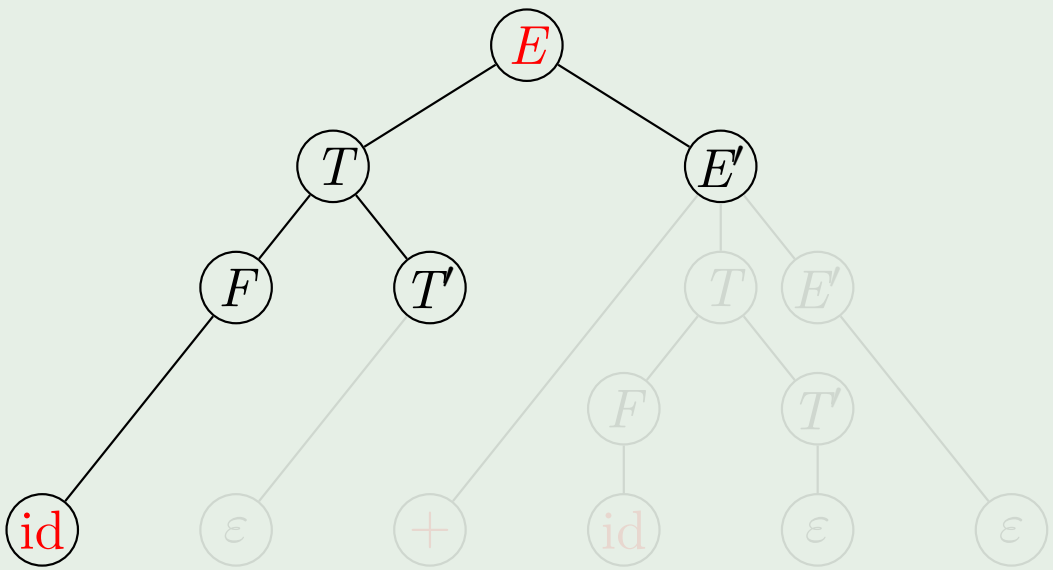

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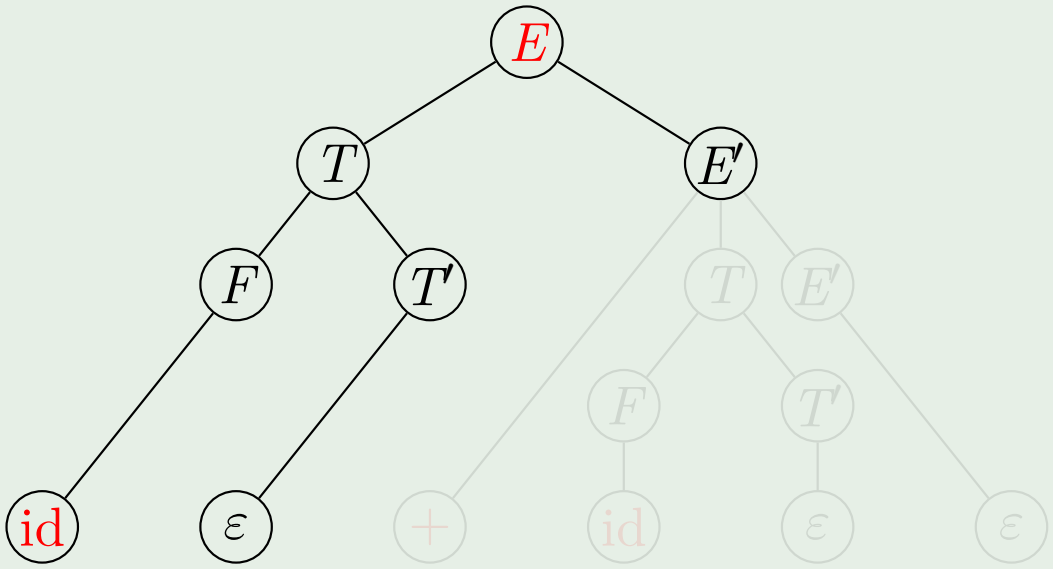

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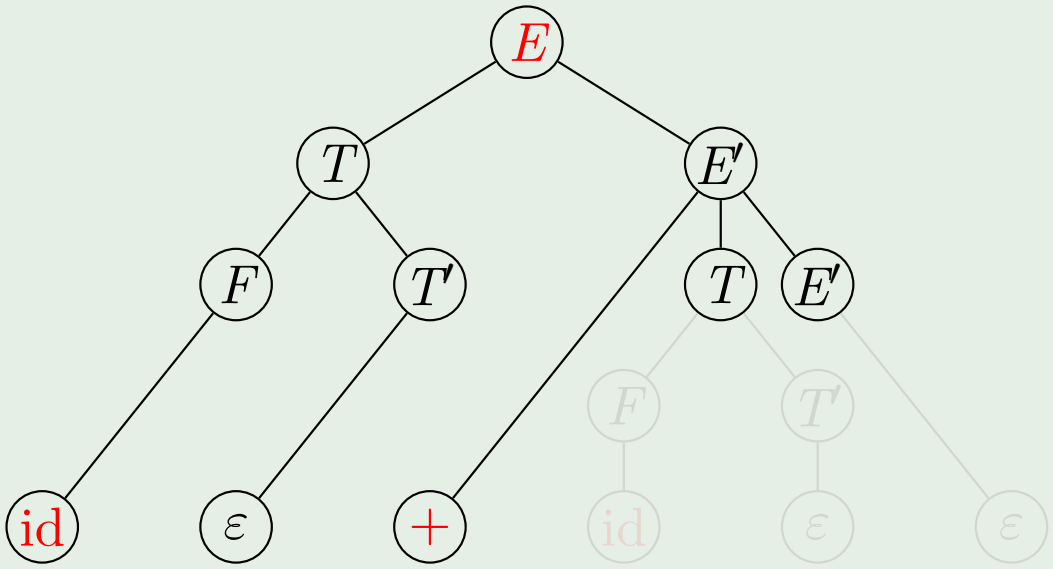

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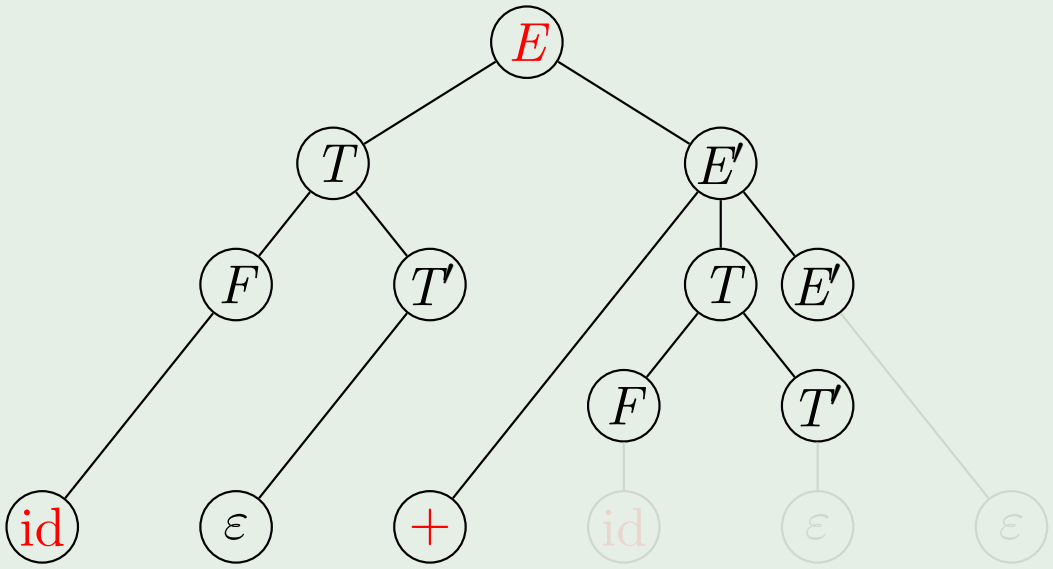

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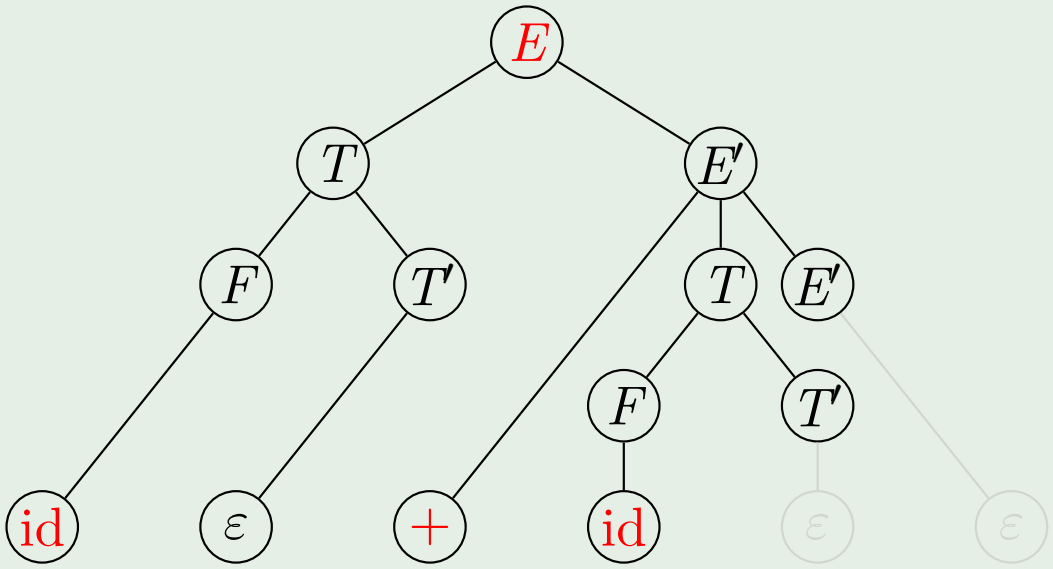

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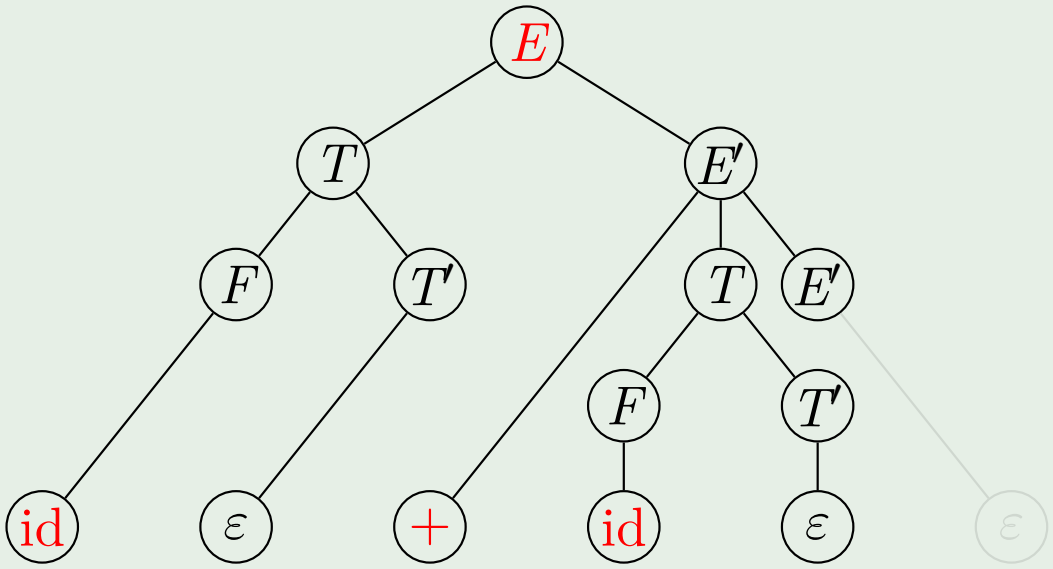

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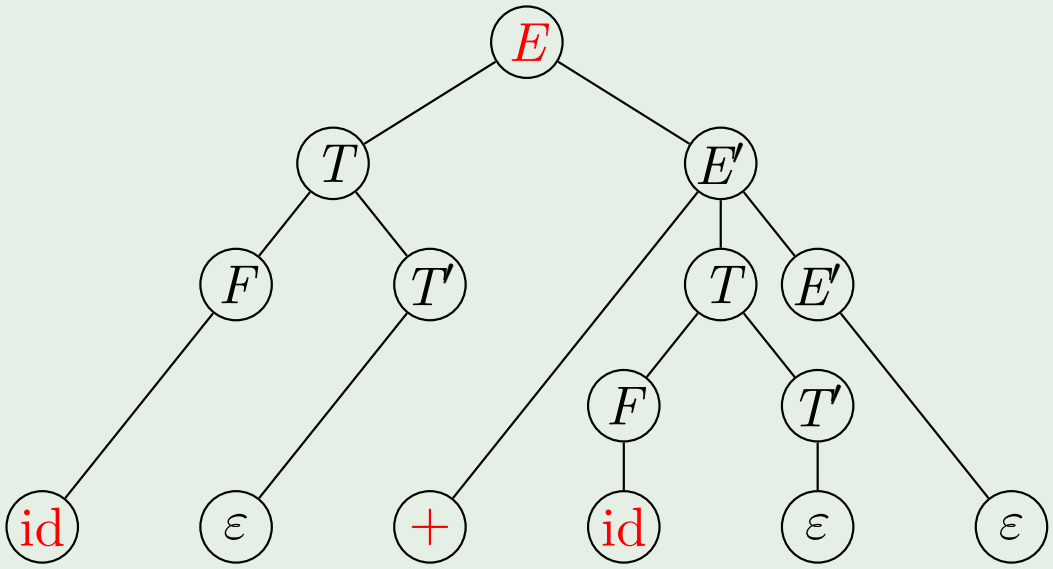

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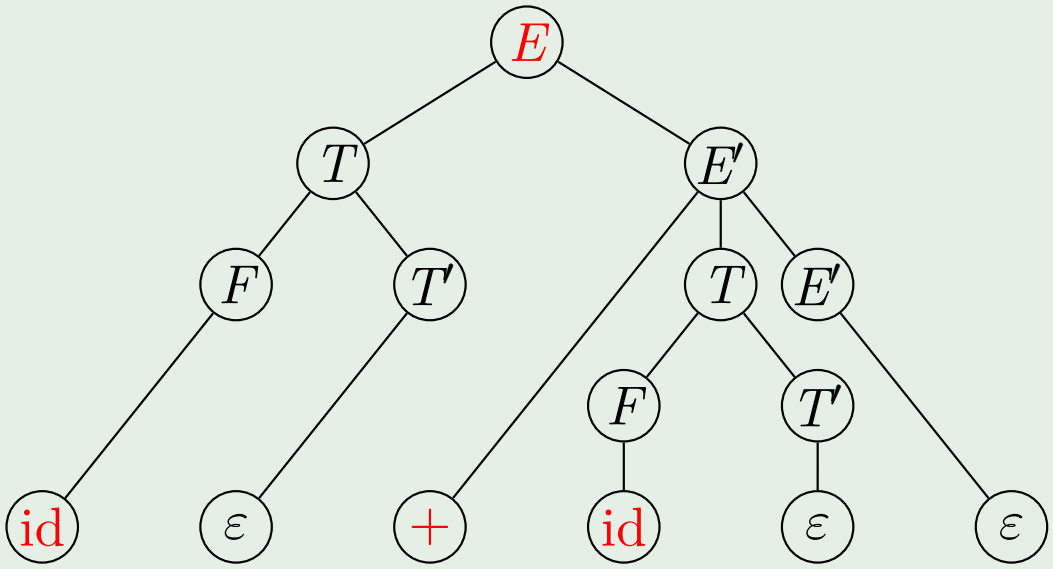

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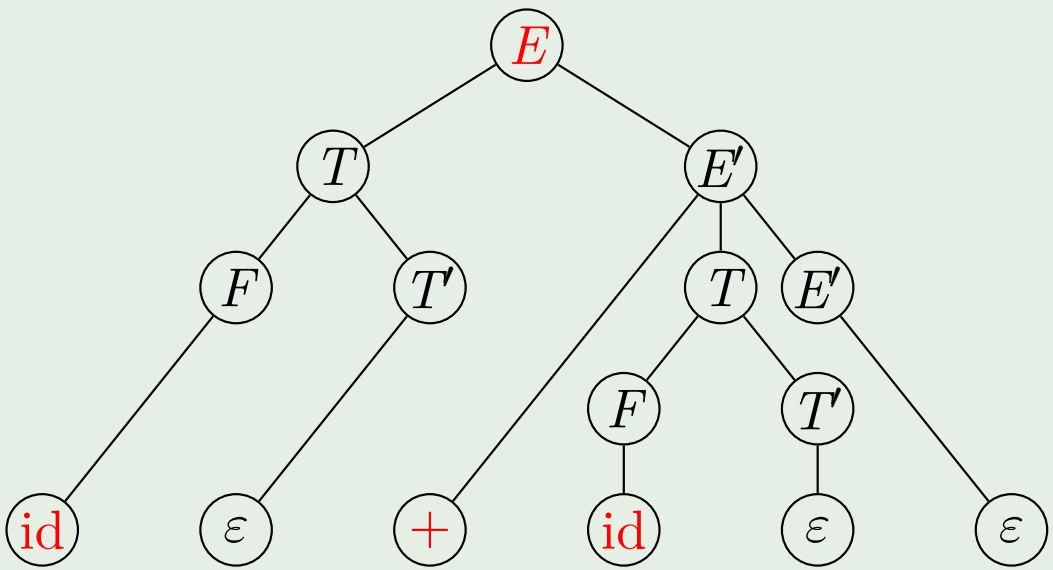

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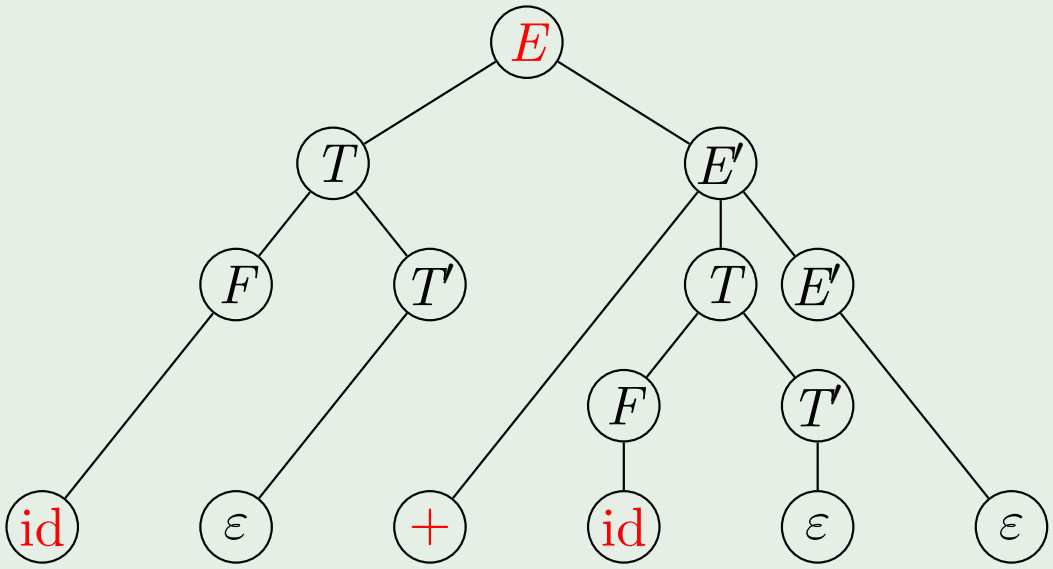

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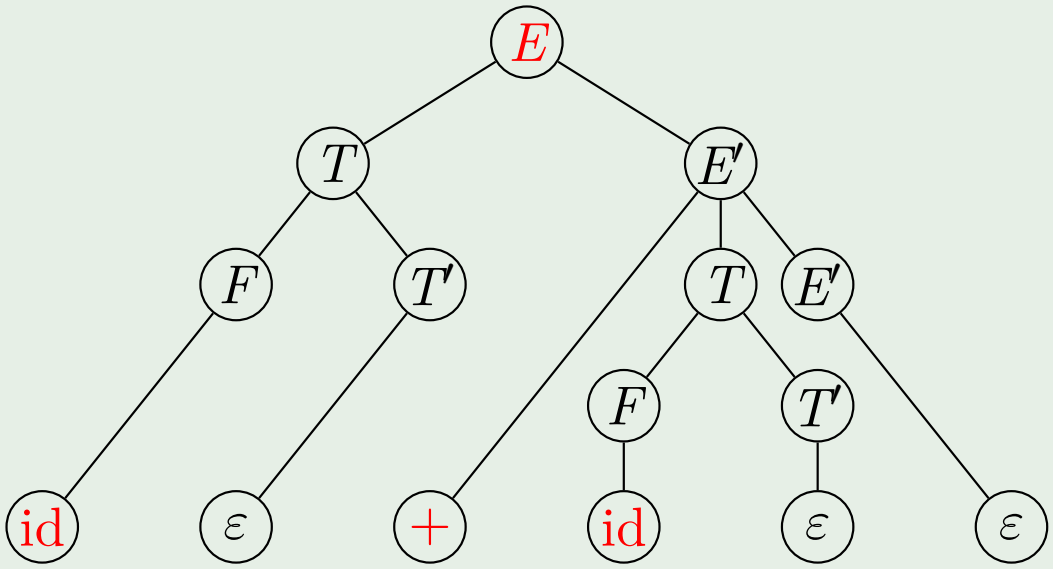

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- We focus on $LL(1)$ parsers, a special type of top-down parsers.
  - L: left-right
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- Not every grammar allows for $LL(1)$ parsing.
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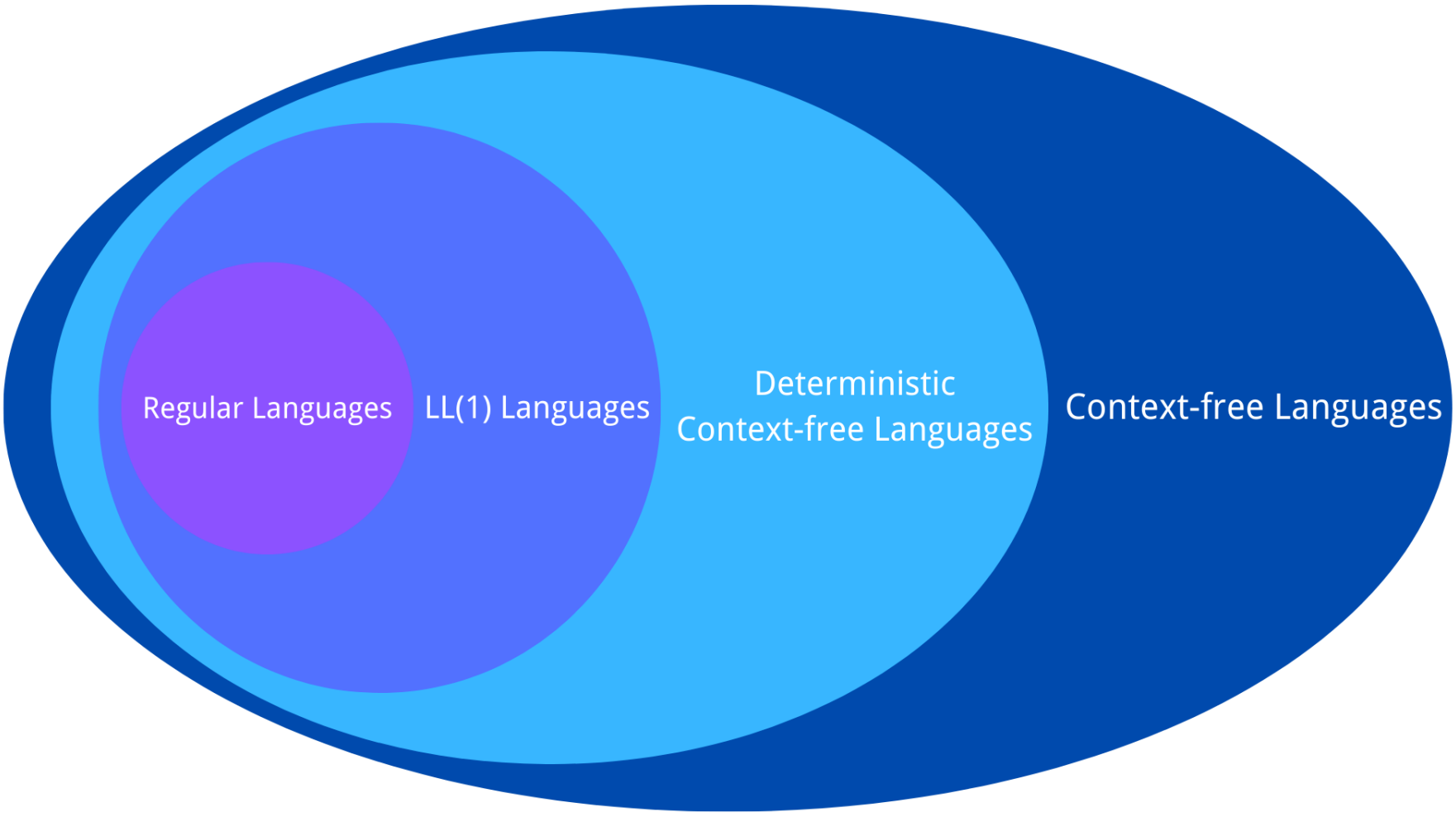

What is a predicative parsing table?

Generate string id + id from the start variable E:

Example

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Predicative parsing table for the left-hand side grammar.

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Predicative parsing table for the left-hand side grammar.

What is a predicative parsing table?

Generate string id + id from the left-most variable F:

$$E \overset{1}{\Rightarrow} TE' \overset{4}{\Rightarrow} FT'E' \overset{8}{\Rightarrow} \mathrm{id}\,T'E' \overset{6}{\Rightarrow} \mathrm{id}\,E' \overset{2}{\Rightarrow} \mathrm{id} + TE' \Rightarrow \cdots \Rightarrow \mathrm{id} + \mathrm{id}$$

Example

1. $E \to TE'$
2. $E' \to +TE'$
3. $E' \to \varepsilon$
4. $T \to FT'$
5. $T' \to *FT'$
6. $T' \to \varepsilon$
7. $F \to (E)$
8. $F \to \mathrm{id}$

	id	+	*	(	)	$
E	1			1		
E'		2			3	3
T	4			4		
T'		6	5		6	6
F	8			7		

Predicative parsing table for the left-hand side grammar.

What is a predicative parsing table?

Generate string id + id from the left-most variable T':

$$E \overset{1}{\Rightarrow} TE' \overset{4}{\Rightarrow} FT'E' \overset{8}{\Rightarrow} \mathrm{id}\,T'E' \overset{6}{\Rightarrow} \mathrm{id}\,E' \overset{2}{\Rightarrow} \mathrm{id} + TE' \Rightarrow \cdots \Rightarrow \mathrm{id} + \mathrm{id}$$

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	id	+	*	(	)	$
E	1			1		
E'		2			3	3
T	4			4		
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Predicative parsing table for the left-hand side grammar.

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	id	+	*	(	)	$
E	1			1		
E'		2			3	3
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	id	+	*	(	)	$
E	1			1		
E'		2			3	3
T	4			4		
T'		6	5		6	6
F	8			7		

Predicative parsing table for the left-hand side grammar.

What is a predicative parsing table?

Generate string $\mathrm{id} + \mathrm{id}$ from the left-most variable T:

$$E \overset{1}{\Rightarrow} TE' \overset{4}{\Rightarrow} FT'E' \overset{8}{\Rightarrow} \mathrm{id}\,T'E' \overset{6}{\Rightarrow} \mathrm{id}E' \overset{2}{\Rightarrow} \mathrm{id} + TE' \Rightarrow \cdots \Rightarrow \mathrm{id} + \mathrm{id}$$

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3. $E' \to \varepsilon$
4. $T \to FT'$
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7. $F \to (E)$
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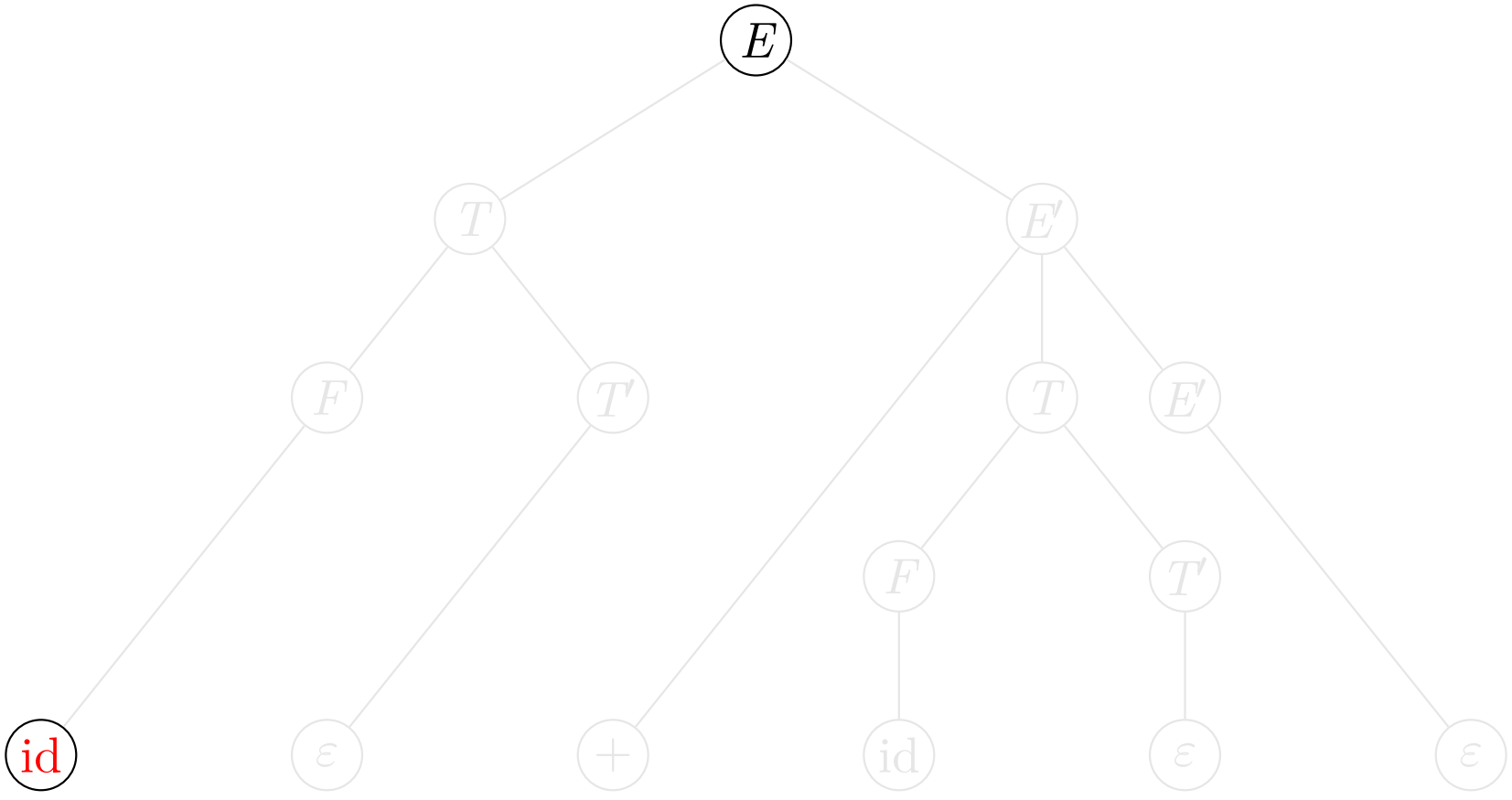
	id	+	*	(	)	$
E	1			1		
E'		2			3	3
T	4			4		
T'		6	5		6	6
F	8			7		

Predicative parsing table for the left-hand side grammar.

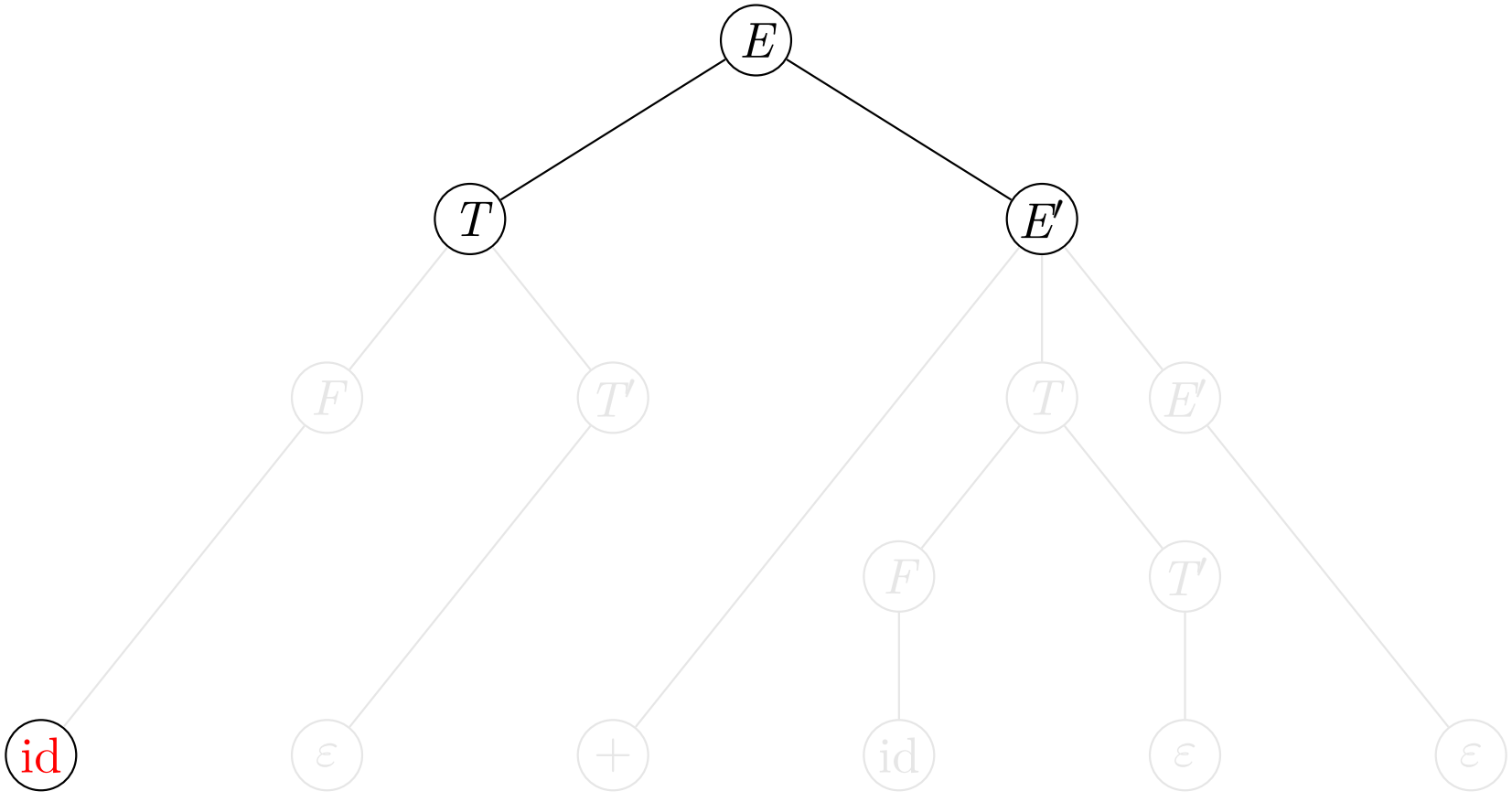
From the perspective of a parsing tree

Generate string id + id from the start variable E:



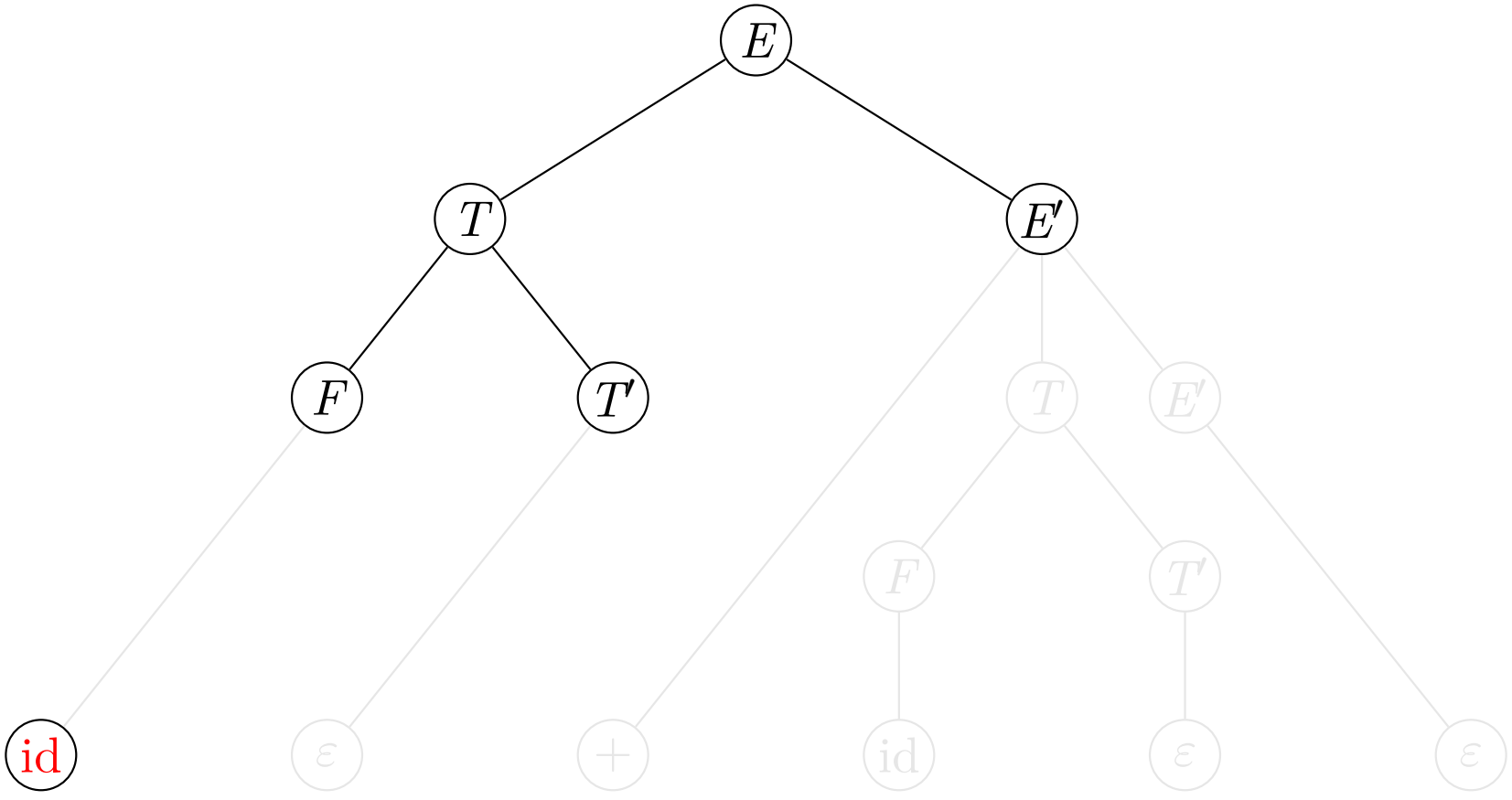
From the perspective of a parsing tree

Generate string id + id from the start variable E:



From the perspective of a parsing tree

Generate string id + id from the start variable E:



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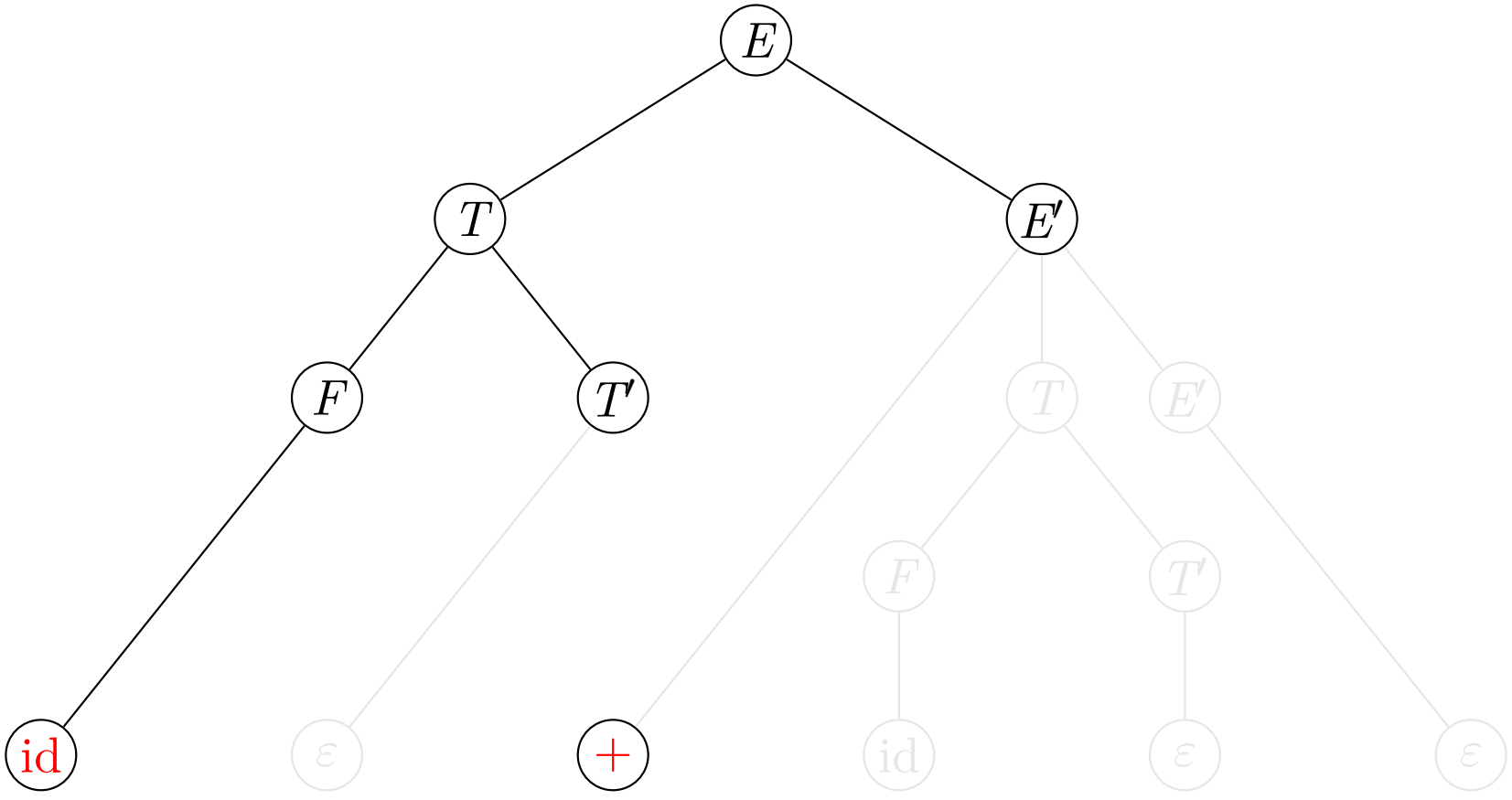
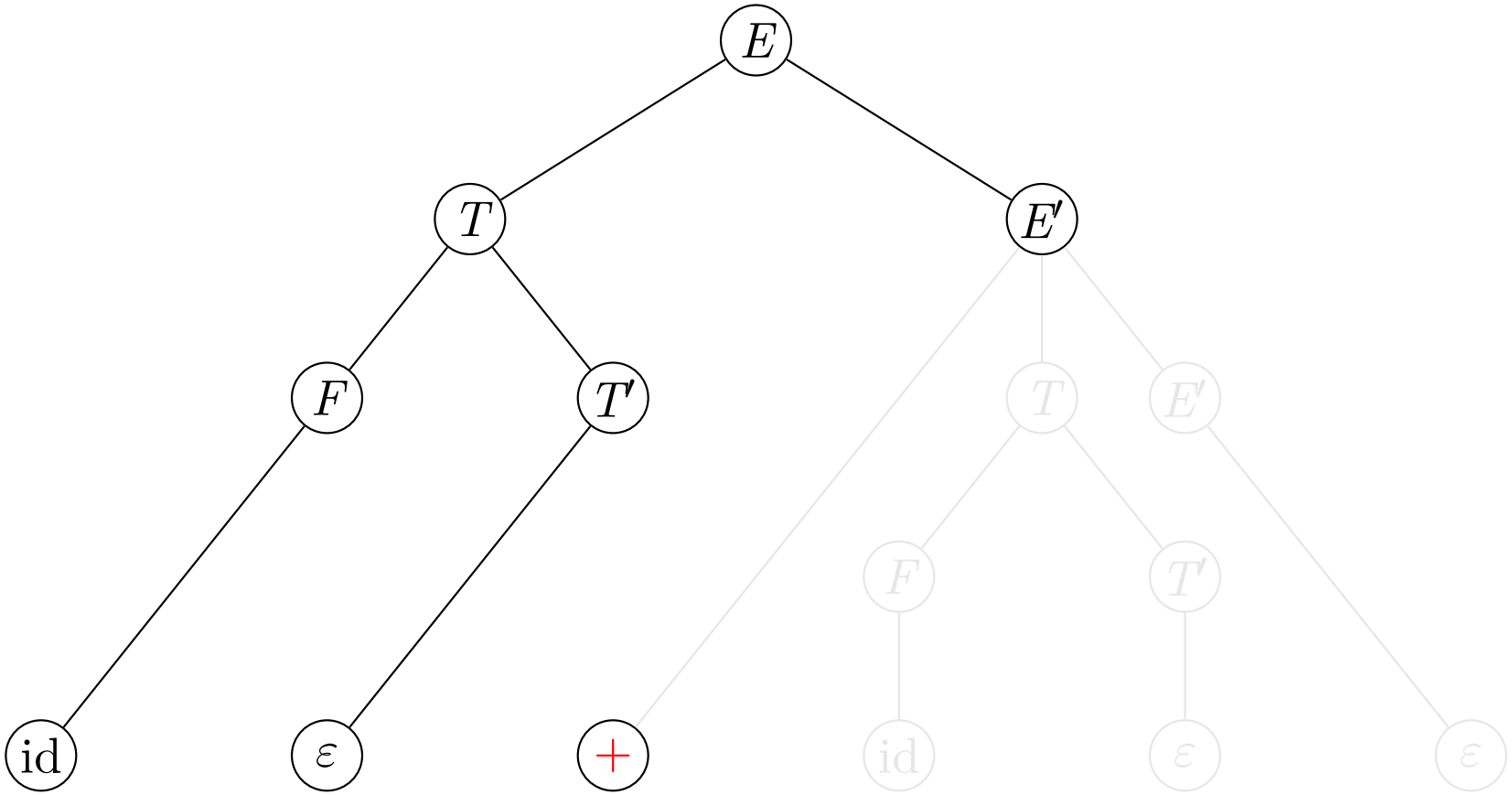


From the perspective of a parsing tree

Generate string id + id from the start variable E:



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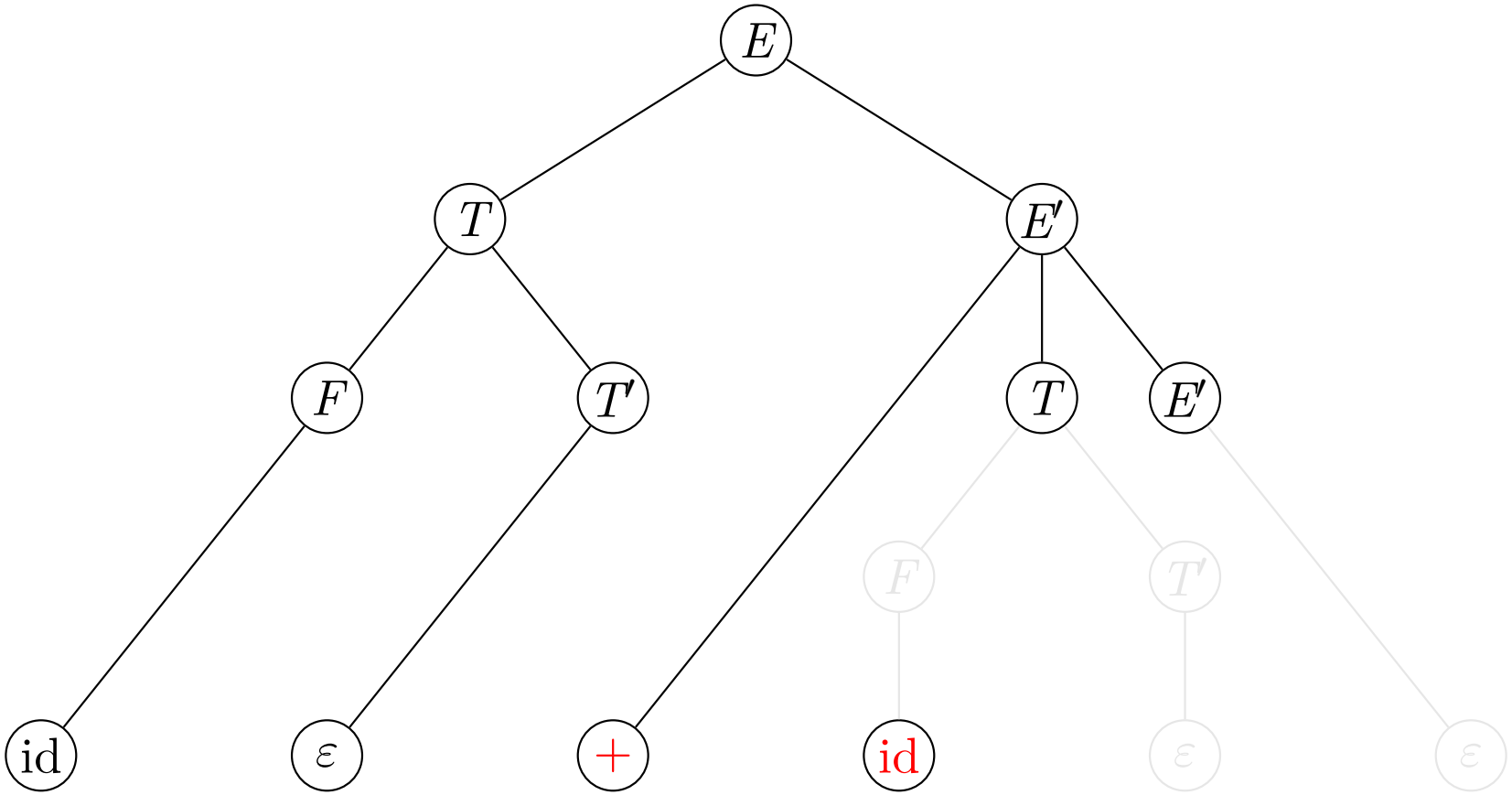
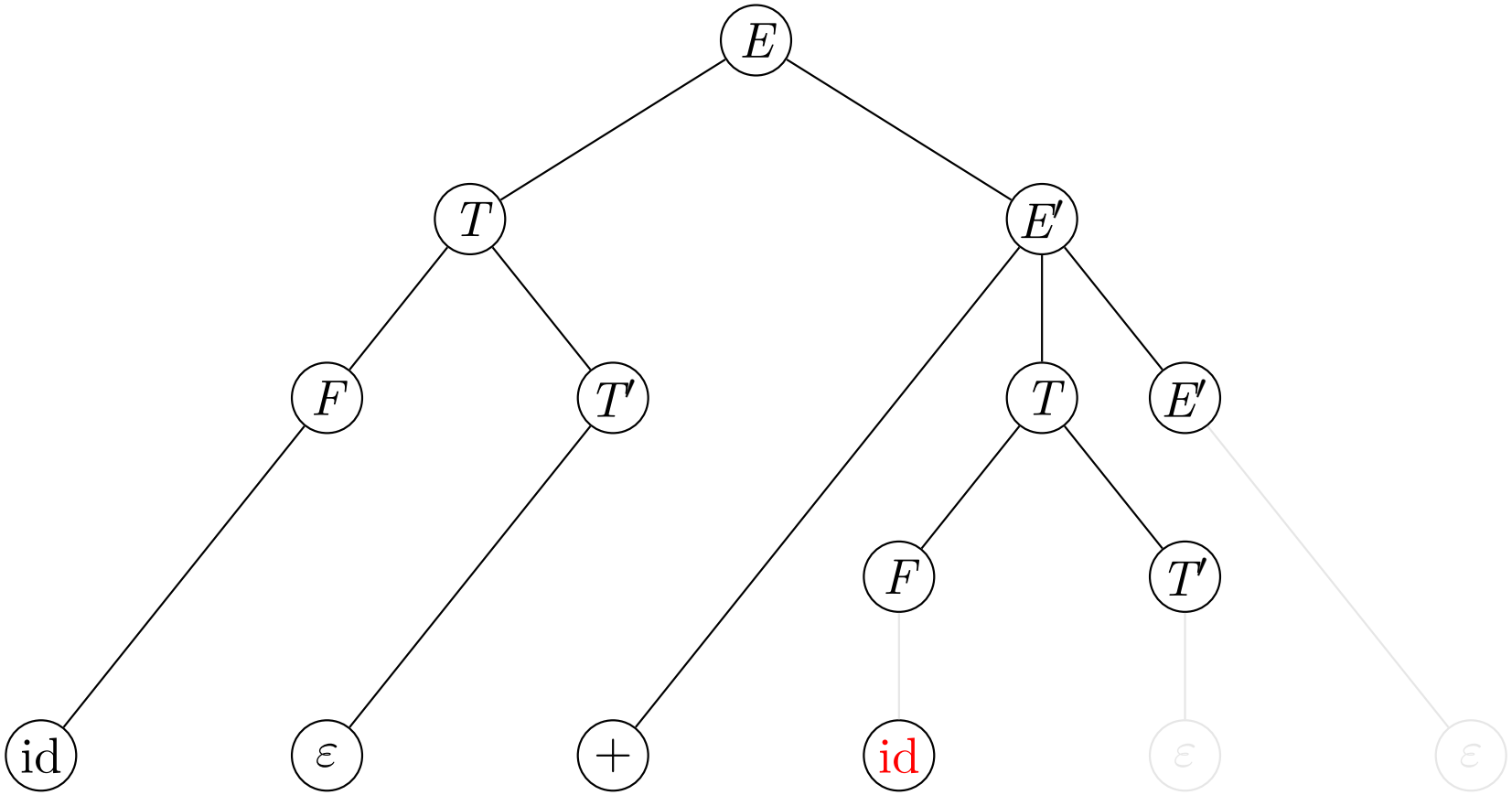


From the perspective of a parsing tree

Generate string id + id from the start variable E:



From the perspective of a parsing tree

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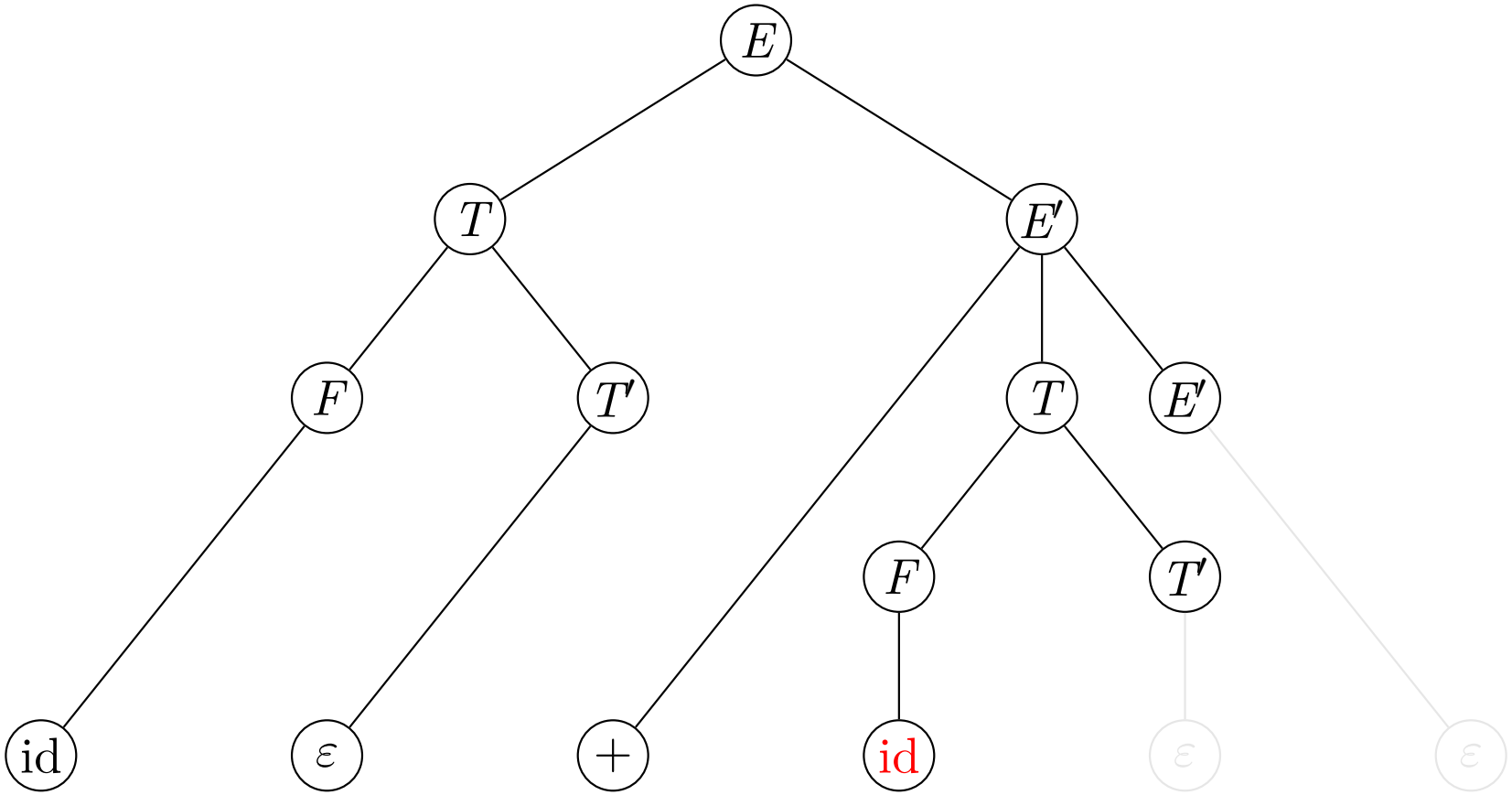

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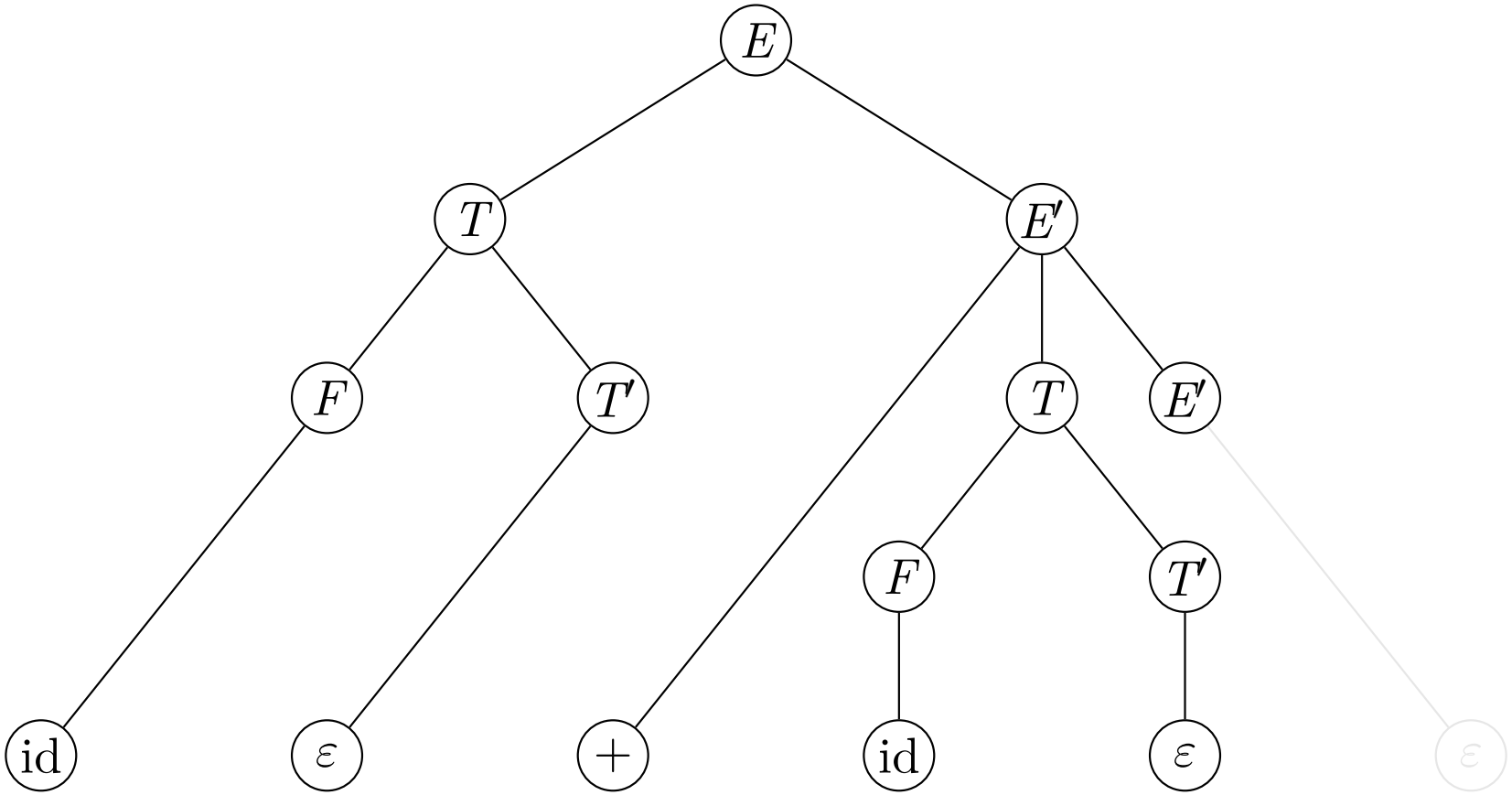

From the perspective of a parsing tree

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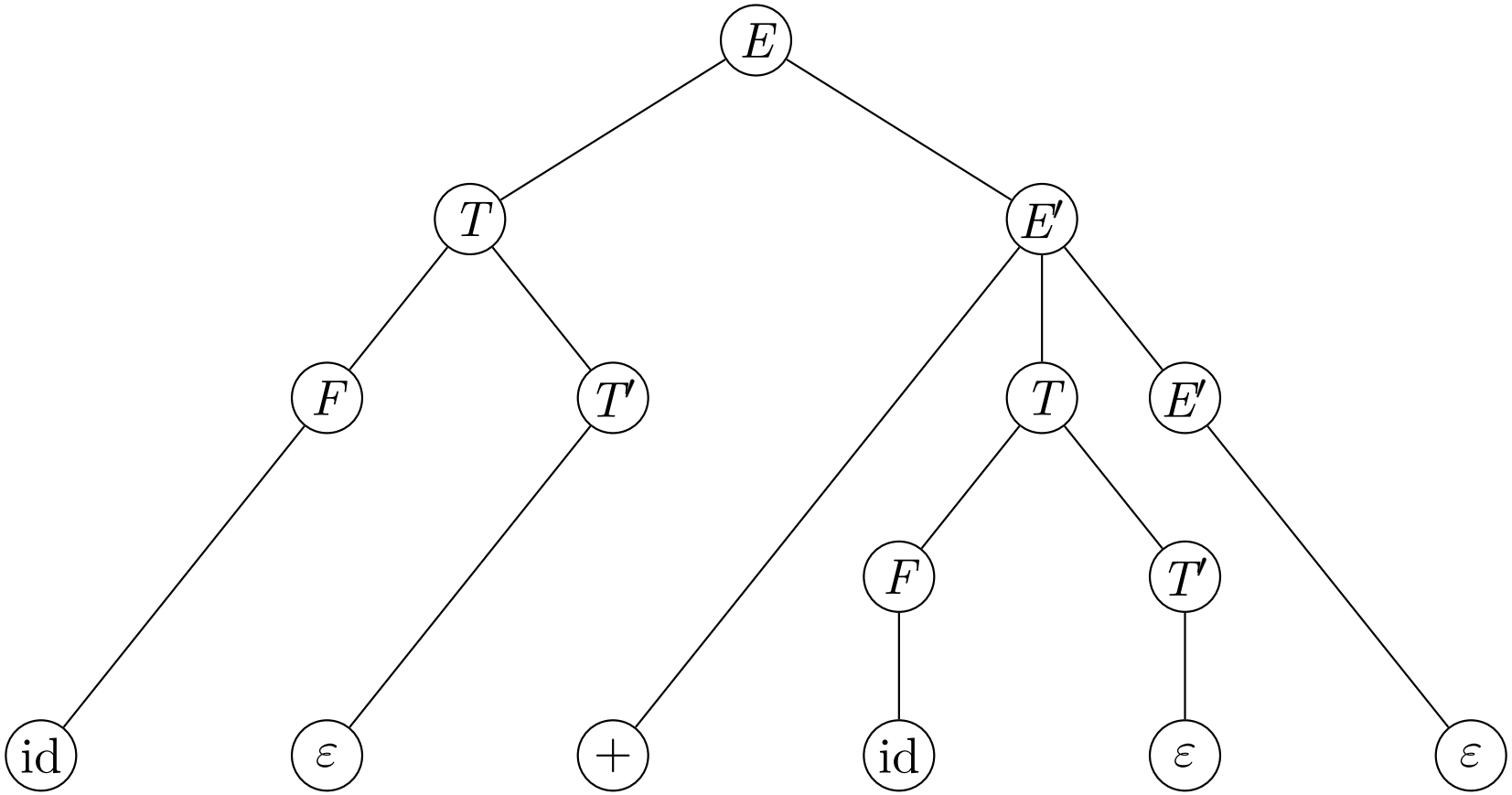

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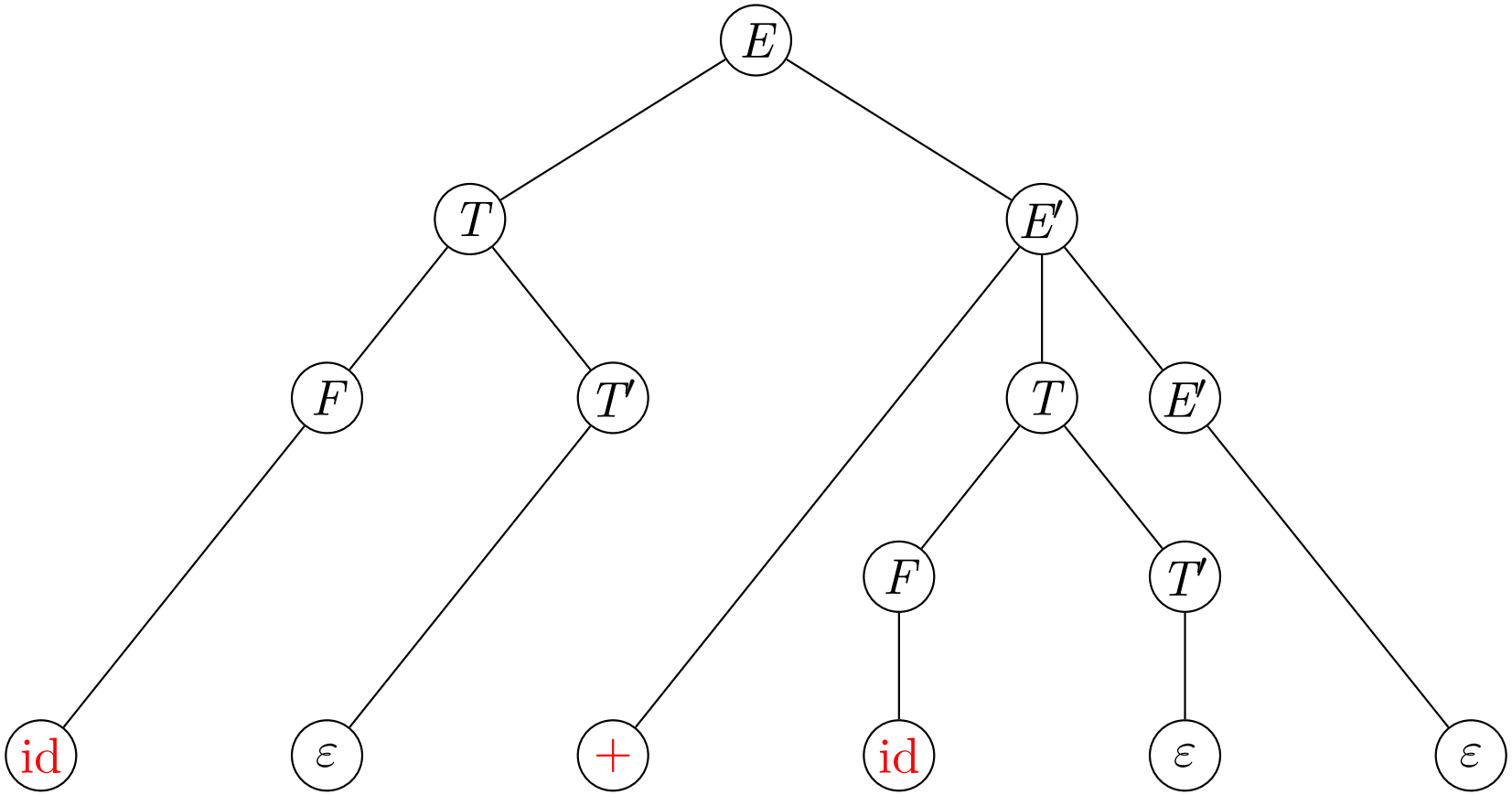

Tutorial: construction of a predicative parsing table

There are three steps:

1. construct FIRST sets;
2. construct FOLLOW sets;
3. construct the parsing table using the sets.

Tutorial: construction of a predicative parsing table

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Tutorial: construction of FIRST sets

Definition (FIRST sets)

FIRST(A) is a set of symbols (including ε) that can appear in the first position of any string derived from variable A.

- If there is a rule starting with variables on both sides, we will need to incorporate the FIRST set of the latter one into that of the former one.
- What if there is one more rule of $F \to \varepsilon$ and how would this affect FIRST(T)?

1. $E \to TE'$
2. $E' \to +TE'$
3. $E' \to \varepsilon$
4. $T \to FT' \Rightarrow T'$
5. $T' \to *FT'$
6. $T' \to \varepsilon$
7. $F \to (E)$
8. $F \to \text{id}$

FIRST sets	
E	(, id
E'	+, ε
T	(, id
T'	*, ε
F	(, id

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Tutorial: construction of FIRST sets

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7. $F \to (E)$
8. $F \to \mathrm{id}$

FIRST sets	
E	(, id
E'	$+$, ε
T	FIRST(F)
T'	$*$, ε
F	(, id

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FIRST sets	
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FIRST sets

E	FIRST(T)
E'	$+, \varepsilon$
T	(, id
T'	$*, \varepsilon$
F	(, id

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FIRST sets	
E	(, id
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FIRST sets	
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E'	+, ε
T	(, id
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5. $T' \to *FT'$
6. $T' \to \varepsilon$
7. $F \to (E)$
8. $F \to \text{id}$

FIRST sets	
E	(, id
E'	+, ε
T	(, id
T'	*, ε
F	(, id

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6. $T' \to \varepsilon$
7. $F \to (E)$
8. $F \to \text{id}$

FIRST sets	
E	(, id
E'	+, ε
T	(, id
T'	*, ε
F	(, id

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Tutorial: construction of FIRST sets

Definition (FIRST sets)

FIRST(A) is a set of symbols (including ε) that can appear in the first position of any string derived from variable A.

a If there is a rule starting with variables on both sides, we will need to incorporate the FIRST set of the latter one into that of the former one.

b What if there is one more rule of $F \to \varepsilon$ and how would this affect FIRST(T)?

1. $E \to TE'$
2. $E' \to +TE'$
3. $E' \to \varepsilon$
4. $T \to FT' \Rightarrow T'$
5. $T' \to *FT'$
6. $T' \to \varepsilon$
7. $F \to (E)$
8. $F \to \text{id}$

	FIRST sets
E	(, id
E'	$+$, ε
T	(, id, FIRST(T')
T'	$*$, ε
F	(, id

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Tutorial: construction of FOLLOW sets

Definition (FOLLOW sets)

FOLLOW(A) is a set of symbols (not including ε) that can appear immediately after variable A in any derivation of the grammar.

1. We always incorporate \$ into the FOLLOW set of the start variable.
2. If there is a rule ending with variables on both sides, we will need to incorporate the FOLLOW set of the former one into that of the latter one.
3. If there is a rule involving two consecutive variables, we will need to incorporate the FIRST set of the latter one into the FOLLOW set of the former one.

1. $E \to TE'$
2. $E' \to +TE' \Rightarrow +T$
3. $E' \to \varepsilon$
4. $T \to FT' \Rightarrow F$
5. $T' \to *FT' \Rightarrow *F$
6. $T' \to \varepsilon$
7. $F \to (E)$
8. $F \to \mathrm{id}$

FIRST sets	
E	(, id
E'	+, ε
T	(, id
T'	*, ε
F	(, id

FOLLOW sets	
E	\$,)
E'	\$,)
T	+, \$,)
T'	+, \$,)
F	*, +, \$,)

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Tutorial: construction of FOLLOW sets

Definition (FOLLOW sets)

FOLLOW(A) is a set of symbols (not including ε) that can appear immediately after variable A in any derivation of the grammar.

a. We always incorporate $ into the FOLLOW set of the start variable.

b. If there is a rule ending with variables on both sides, we will need to incorporate the FOLLOW set of the former one into that of the latter one.

c. If there is a rule involving two consecutive variables, we will need to incorporate the FIRST set of the latter one into the FOLLOW set of the former one. Caution if ε is in the set!

1. $E \to TE'$
2. $E' \to +TE' \Rightarrow +T$
3. $E' \to \varepsilon$
4. $T \to FT' \Rightarrow F$
5. $T' \to *FT' \Rightarrow *F$
6. $T' \to \varepsilon$
7. $F \to (E)$
8. $F \to \mathrm{id}$

FIRST sets	
E	(, id
E'	+, ε
T	(, id
T'	*, ε
F	(, id

FOLLOW sets	
E	$,)
E'	$,)
T	+, $,)
T'	+, $,)
F	*, +, $,)

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Tutorial: construction of FOLLOW sets

Definition (FOLLOW sets)

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1. $E \to TE'$
2. $E' \to +TE' \Rightarrow +T$
3. $E' \to \varepsilon$
4. $T \to FT' \Rightarrow F$
5. $T' \to *FT' \Rightarrow *F$
6. $T' \to \varepsilon$
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FIRST sets	
E	(, id
E'	+, ε
T	(, id
T'	*, ε
F	(, id

FOLLOW sets	
E	\$,)
E'	\$,)
T	+, \$,)
T'	+, \$,)
F	*, +, \$,)

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6. $T' \to \varepsilon$
7. $F \to (E)$
8. $F \to \mathrm{id}$

	FIRST sets
E	$($, id
E'	$+$, ε
T	$($, id
T'	$*$, ε
F	$($, id

	FOLLOW sets
E	\$, $)$
E'	FOLLOW(E)
T	$+$, \$, $)$
T'	$+$, \$, $)$
F	$*$, $+$, \$, $)$

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6. $T' \to \varepsilon$
7. $F \to (E)$
8. $F \to \mathrm{id}$

FIRST sets	
E	$($, id
E'	$+$, ε
T	$($, id
T'	$*$, ε
F	$($, id

FOLLOW sets	
E	\$, $)$
E'	\$, $)$
T	$+$, \$, $)$
T'	$+$, \$, $)$
F	$*$, $+$, \$, $)$

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6. $T' \to \varepsilon$
7. $F \to (E)$
8. $F \to \text{id}$

FIRST sets	
E	(, id
E'	+, ε
T	(, id
T'	*, ε
F	(, id

FOLLOW sets	
E	\$,)
E'	\$,)
T	+, \$,)
T'	+, \$,)
F	*, +, \$,)

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7. $F \to (E)$
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FIRST sets	
E	(, id
E'	+, ε
T	(, id
T'	*, ε
F	(, id

FOLLOW sets	
E	\$,)
E'	\$,)
T	+, \$,)
T'	+, \$,)
F	*, +, \$,)

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6. $T' \to \varepsilon$
7. $F \to (E)$
8. $F \to \text{id}$

FIRST sets	
E	(, id
E'	+, ε
T	(, id
T'	*, ε
F	(, id

FOLLOW sets	
E	\$,)
E'	\$,)
T	+, \$,)
T'	+, \$,)
F	*, +, \$,)

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6. $T' \to \varepsilon$
7. $F \to (E)$
8. $F \to \mathrm{id}$

FIRST sets	
E	(, id
E'	+, ε
T	(, id
T'	*, ε
F	(, id

FOLLOW sets	
E	\$,)
E'	\$,)
T	+, FOLLOW(E')
T'	+, \$,)
F	*, +, \$,)

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7. $F \to (E)$
8. $F \to \text{id}$

FIRST sets	
E	(, id
E'	+, ε
T	(, id
T'	*, ε
F	(, id

FOLLOW sets	
E	\$,)
E'	\$,)
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T'	+, \$,)
F	*, +, \$,)

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7. $F \to (E)$
8. $F \to \text{id}$

FIRST sets

E	(, id
E'	+, ε
T	(, id
T'	*, ε
F	(, id

FOLLOW sets

E	\$,)
E'	\$,)
T	+, \$,)
T'	FOLLOW(T)
F	*, +, \$,)

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FIRST sets	
E	(, id
E'	+, ε
T	(, id
T'	*, ε
F	(, id

FOLLOW sets	
E	\$,)
E'	\$,)
T	+, \$,)
T'	+, \$,)
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FIRST sets	
E	(, id
E'	+, ε
T	(, id
T'	*, ε
F	(, id

FOLLOW sets	
E	\$,)
E'	\$,)
T	+, \$,)
T'	+, \$,)
F	*, +, \$,)

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FIRST sets	
E	(, id
E'	+, ε
T	(, id
T'	*, ε
F	(, id

FOLLOW sets	
E	\$,)
E'	\$,)
T	+, \$,)
T'	+, \$,)
F	*, +, \$,)

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6. $T' \to \varepsilon$
7. $F \to (E)$
8. $F \to \text{id}$

FIRST sets	
E	(, id
E'	+, ε
T	(, id
T'	*, ε
F	(, id

FOLLOW sets	
E	\$,)
E'	\$,)
T	+, \$,)
T'	+, \$,)
F	*, +, \$,)

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5. $T' \to *FT' \Rightarrow *F$
6. $T' \to \varepsilon$
7. $F \to (E)$
8. $F \to \mathrm{id}$

FIRST sets	
E	(, id
E'	+, ε
T	(, id
T'	*, ε
F	(, id

	FOLLOW sets
E	\$,)
E'	\$,)
T	+, \$,)
T'	+, \$,)
F	*, FOLLOW(T, T')

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3. $E' \to \varepsilon$
4. $T \to FT' \Rightarrow F$
5. $T' \to *FT' \Rightarrow *F$
6. $T' \to \varepsilon$
7. $F \to (E)$
8. $F \to \mathrm{id}$

FIRST sets	
E	$($, id
E'	$+$, ε
T	$($, id
T'	$*$, ε
F	$($, id

FOLLOW sets	
E	\$, $)$
E'	\$, $)$
T	$+$, \$, $)$
T'	$+$, \$, $)$
F	$*$, $+$, \$, $)$

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5. $T' \to *FT' \Rightarrow *F$
6. $T' \to \varepsilon$
7. $F \to (E)$
8. $F \to \mathrm{id}$

FIRST sets	
E	(, id
E'	+, ε
T	(, id
T'	*, ε
F	(, id

FOLLOW sets	
E	\$,)
E'	\$,)
T	+, \$,)
T'	+, \$,)
F	*, +, \$,)

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Tutorial: construction of parsing table using the sets

	id	+	*	(	)	$
E	1			1		
E'		2			3	3
T	4			4		
T'		6	5		6	6
F	8			7		

1. $E \to TE'$
2. $E' \to +TE'$
3. $E' \to \varepsilon$
4. $T \to FT'$
5. $T' \to *FT'$
6. $T' \to \varepsilon$
7. $F \to (E)$
8. $F \to \text{id}$

FIRST sets	
E	(, id
E'	+, ε
T	(, id
T'	*, ε
F	(, id

FOLLOW sets	
E	\$,)
E'	\$,)
T	+, \$,)
T'	+, \$,)
F	*, +, \$,)

Tutorial: construction of parsing table using the sets

$E \to TE'$ means E can go to the terminals in FIRST(T).

	id	+	*	(	)	$
E	1			1		
E'		2			3	3
T	4			4		
T'		6	5		6	6
F	8			7		

1. $E \to TE'$
2. $E' \to +TE'$
3. $E' \to \varepsilon$
4. $T \to FT'$
5. $T' \to *FT'$
6. $T' \to \varepsilon$
7. $F \to (E)$
8. $F \to \text{id}$

FIRST sets	
E	(, id
E'	+, ε
T	(, id
T'	*, ε
F	(, id

FOLLOW sets	
E	\$,)
E'	\$,)
T	+, \$,)
T'	+, \$,)
F	*, +, \$,)

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Tutorial: construction of parsing table using the sets

$E \to TE'$ means E can go to the terminals in FIRST(T).

	id	+	*	(	)	$
E	1			1		
E'		2			3	3
T	4			4		
T'		6	5		6	6
F	8			7		

1. $E \to TE'$
2. $E' \to +TE'$
3. $E' \to \varepsilon$
4. $T \to FT'$
5. $T' \to *FT'$
6. $T' \to \varepsilon$
7. $F \to (E)$
8. $F \to \text{id}$

FIRST sets	
E	(, id
E'	+, ε
T	(, id
T'	*, ε
F	(, id

FOLLOW sets	
E	\$,)
E'	\$,)
T	+, \$,)
T'	+, \$,)
F	*, +, \$,)

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Tutorial: construction of parsing table using the sets

$E' \to +TE'$ means E' can go to terminal $+$.

	id	$+$	$*$	(	)	$
E	1			1		
E'		2			3	3
T	4			4		
T'		6	5		6	6
F	8			7		

1. $E \to TE'$
2. $E' \to +TE'$
3. $E' \to \varepsilon$
4. $T \to FT'$
5. $T' \to *FT'$
6. $T' \to \varepsilon$
7. $F \to (E)$
8. $F \to \text{id}$

FIRST sets	
E	(, id
E'	$+$, ε
T	(, id
T'	$*$, ε
F	(, id

FOLLOW sets	
E	\$,)
E'	\$,)
T	$+$, \$,)
T'	$+$, \$,)
F	$*$, $+$, \$,)

Tutorial: construction of parsing table using the sets

$E' \to \varepsilon$ means E' can go to the terminals in FOLLOW(E').

	id	+	*	(	)	$
E	1			1		
E'		2			3	3
T	4			4		
T'		6	5		6	6
F	8			7		

1. $E \to TE'$
2. $E' \to +TE'$
3. $E' \to \varepsilon$
4. $T \to FT'$
5. $T' \to *FT'$
6. $T' \to \varepsilon$
7. $F \to (E)$
8. $F \to \text{id}$

FIRST sets	
E	(, id
E'	+, ε
T	(, id
T'	*, ε
F	(, id

FOLLOW sets	
E	\$,)
E'	\$,)
T	+, \$,)
T'	+, \$,)
F	*, +, \$,)

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Tutorial: construction of parsing table using the sets

$E' \to \varepsilon$ means E' can go to the terminals in FOLLOW(E').

	id	+	*	(	)	$
E	1			1		
E'		2			3	3
T	4			4		
T'		6	5		6	6
F	8			7		

1. $E \to TE'$
2. $E' \to +TE'$
3. $E' \to \varepsilon$
4. $T \to FT'$
5. $T' \to *FT'$
6. $T' \to \varepsilon$
7. $F \to (E)$
8. $F \to \text{id}$

FIRST sets	
E	(, id
E'	+, ε
T	(, id
T'	*, ε
F	(, id

FOLLOW sets	
E	\$,)
E'	\$,)
T	+, \$,)
T'	+, \$,)
F	*, +, \$,)

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Tutorial: construction of parsing table using the sets

$T \to FT'$ means T can go to the terminals in FIRST(F).

	id	+	*	(	)	$
E	1			1		
E'		2			3	3
T	4			4		
T'		6	5		6	6
F	8			7		

1. $E \to TE'$
2. $E' \to +TE'$
3. $E' \to \varepsilon$
4. $T \to FT'$
5. $T' \to *FT'$
6. $T' \to \varepsilon$
7. $F \to (E)$
8. $F \to \text{id}$

FIRST sets	
E	(, id
E'	+, ε
T	(, id
T'	*, ε
F	(, id

FOLLOW sets	
E	\$,)
E'	\$,)
T	+, \$,)
T'	+, \$,)
F	*, +, \$,)

Tutorial: construction of parsing table using the sets

$T \to FT'$ means T can go to the terminals in FIRST(F).

	id	+	*	(	)	$
E	1			1		
E'		2			3	3
T	4			4		
T'		6	5		6	6
F	8			7		

1. $E \to TE'$
2. $E' \to +TE'$
3. $E' \to \varepsilon$
4. $T \to FT'$
5. $T' \to *FT'$
6. $T' \to \varepsilon$
7. $F \to (E)$
8. $F \to \text{id}$

FIRST sets	
E	(, id
E'	+, ε
T	(, id
T'	*, ε
F	(, id

FOLLOW sets	
E	\$,)
E'	\$,)
T	+, \$,)
T'	+, \$,)
F	*, +, \$,)

Tutorial: construction of parsing table using the sets

$T' \to *FT'$ means T' can go to terminal $*$.

	id	+	*	(	)	$
E	1			1		
E'		2			3	3
T	4			4		
T'		6	5		6	6
F	8			7		

1. $E \to TE'$
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Tutorial: construction of parsing table using the sets

$T' \to \varepsilon$ means T' can go to the terminals in FOLLOW(T').

	id	+	*	(	)	$
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Tutorial: construction of parsing table using the sets

$F \to (E)$ means F can go to terminal (.

	id	+	*	(	)	$
E	1			1		
E'		2			3	3
T	4			4		
T'		6	5		6	6
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Tutorial: construction of parsing table using the sets

$F \to \text{id}$ means F can go to terminal id.

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