CSL302: Compiler Design

Top Down Parsing - LL(1)

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Acknowledgement

- Today's slides are modified from that of
  - *Stanford University:*
    - *https://web.stanford.edu/class/archive/cs/cs143/cs143.1128/*

LL(1) Parse Tables

E → int
E → (E Op E)
Op → +
Op → *

	int	(	)	+	*
E	int	(E Op E)			
Op				+	*

LL(1) Parse Tables

$E \rightarrow AS$

$A \rightarrow a$

$S \rightarrow s$

FIRST(E) = {a}
FIRST(A) = {a}
FIRST(S) = {s}

	a	s
E	E → AS	
A	A → a	
S		S → s

LL(1) Parse Tables

$$E \rightarrow AS$$
$$A \rightarrow a \mid Tb$$
$$T \rightarrow t$$
$$S \rightarrow s$$

FIRST(E) = {a, t}

LL(1) Parse Tables

$$E \rightarrow AS$$
$$A \rightarrow \varepsilon$$
$$S \rightarrow s$$

FIRST(E) = {s}

FIRST Sets

- Algorithm to compute FIRST(X):
  1. If X is a terminal, then FIRST(X) = { X }.
  2. If $X \rightarrow \varepsilon$ is a production, then add ε to FIRST(X).
  3. If $X \rightarrow Y_1\ Y_2 \ldots Y_k$ is a production for $k \geq 1$, and
     for some $i \leq k$, $Y_1 Y_2 \ldots Y_{i-1}$ derives the empty string, and a is in FIRST(Y_i), then add a to FIRST(X).
     If $Y_1 Y_2 \ldots Y_k$ derives the empty string, then add ε to FIRST(X).

LL(1) Parse Tables

$$E \rightarrow AS$$
$$A \rightarrow a \mid Tb$$
$$T \rightarrow t$$
$$S \rightarrow s$$

FIRST(E) = FIRST(A)
= {a} U FIRST(T)
= {a, t}

LL(1) Parse Tables

$E \rightarrow AS$

$A \rightarrow \varepsilon$

$S \rightarrow s$

FIRST(E) = FIRST(AS)

FIRST(A) = {ε}

FIRST(S) = {s}

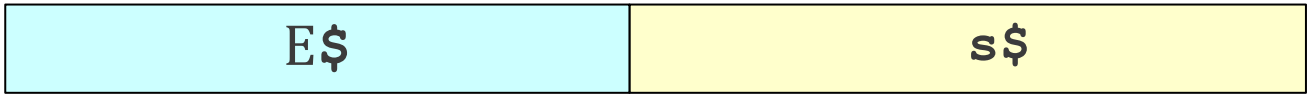
FIRST(E)= {s}

LL(1) Parsing

(1) E → AS

(2) A → ε

(3) S → s



LL(1) Parsing

(1) **E** → **AS**
(2) **A** → **ε**
(3) **S** → **s**

E$	**s$**
AS$	**s$**

Apply **A** → **ε**, **if s follows A**
FOLLOW(A) = FIRST(S)
= {s}

FOLLOW Sets

- Place $ in FOLLOW (S), where S is the start symbol, and $ is the input right endmarker.
- If there is a production $A \rightarrow \alpha B \beta$, then everything in FIRST(β) except for ε is placed in FOLLOW(B).
- If there is a production $A \rightarrow \alpha B$, or a production $A \rightarrow \alpha B \beta$ where FIRST(β) contains ε , then everything in FOLLOW(A) is in FOLLOW(B).

LL(1) Parse Tables

$E \rightarrow AS$

$A \rightarrow \varepsilon$

$S \rightarrow s$

FOLLOW(E) = {$}

FIRST(A) = FIRST(S) = {s}

FIRST(S) = FOLLOW(E)

= {$}

LL(1) Parse Tables

$E \rightarrow AS$

$A \rightarrow \varepsilon$

$S \rightarrow s$

FIRST(E) = {s}
FIRST(A) = {ε}
FIRST(S) = {s}

FOLLOW(E) = {$}
FOLLOW(A) = {s}
FOLLOW(S) = {$}

	s	$
E	E → AS	
A	A → ε	
S	S → s	

LL(1) Tables with ε

Num → Sign Digits

Sign → + | - | ε

Digits → Digit More

More → Digits | ε

Digit → 0 | 1 | … | 9

LL(1) Tables with ε

Num → Sign Digits

Sign → + | - | ε

Digits → Digit More

More → Digits | ε

Digit → 0 | 1 | … | 9

	+	-	#	$
Num				
Sign				
Digits				
More				
Digit				

LL(1) Tables with ε

Num → **Sign Digits**
Sign → **+** | **-** | **ε**
Digits → **Digit More**
More → **Digits** | **ε**
Digit → **0** | **1** | … | **9**

Num		Sign		Digit		Digits		More	
+	-	+	-	0	5	0	5	0	5
0	5	ε		1	6	1	6	1	6
1	6			2	7	2	7	2	7
2	7			3	8	3	8	3	8
3	8			4	9	4	9	4	9
4	9							ε	

	+	-	#	$
Num				
Sign				
Digits				
More				
Digit				

LL(1) Tables with ε

Num → **Sign Digits**

Sign → + | - | ε

Digits → **Digit More**

More → **Digits** | ε

Digit → 0 | 1 | … | 9

Num		Sign		Digit		Digits		More	
+	-	+	-	0	5	0	5	0	5
0	5	ε		1	6	1	6	1	6
1	6			2	7	2	7	2	7
2	7			3	8	3	8	3	8
3	8			4	9	4	9	4	9
4	9							ε	

	+	-	#	$
Num				
Sign				
Digits				
More				
Digit				

LL(1) Tables with ε

Num	→ Sign Digits
Sign	→ + | - | ε
Digits	→ Digit More
More	→ Digits | ε
Digit	→ 0 | 1 | … | 9

Num		Sign		Digit		Digits		More	
+	-	+	-	0	5	0	5	0	5
0	5	ε		1	6	1	6	1	6
1	6			2	7	2	7	2	7
2	7			3	8	3	8	3	8
3	8			4	9	4	9	4	9
4	9							ε	

	+	-	#	$
Num	Sign Digits	Sign Digits	Sign Digits	
Sign				
Digits				
More				
Digit				

LL(1) Tables with ε

Num → Sign Digits
Sign → + | - | ε
Digits → Digit More
More → Digits | ε
Digit → 0 | 1 | … | 9

Num		Sign		Digit		Digits		More	
+	-	+	-	0	5	0	5	0	5
0	5	ε		1	6	1	6	1	6
1	6			2	7	2	7	2	7
2	7			3	8	3	8	3	8
3	8			4	9	4	9	4	9
4	9							ε	

	+	-	#	$
Num	Sign Digits	Sign Digits	Sign Digits	
Sign				
Digits				
More				
Digit				

LL(1) Tables with ε

Num → Sign Digits
Sign → + | - | ε
Digits → Digit More
More → Digits | ε
Digit → 0 | 1 | … | 9

Num		Sign		Digit		Digits		More	
+	-	+	-	0	5	0	5	0	5
0	5	ε		1	6	1	6	1	6
1	6			2	7	2	7	2	7
2	7			3	8	3	8	3	8
3	8			4	9	4	9	4	9
4	9							ε	

	+	-	#	$
Num	Sign Digits	Sign Digits	Sign Digits	
Sign	+	-		
Digits				
More				
Digit				

LL(1) Tables with ε

Num → **Sign Digits**

Sign → + | - | ε

Digits → **Digit More**

More → **Digits** | ε

Digit → 0 | 1 | … | 9

Num		Sign		Digit		Digits		More	
+	-	+	-	0	5	0	5	0	5
0	5	ε		1	6	1	6	1	6
1	6			2	7	2	7	2	7
2	7			3	8	3	8	3	8
3	8			4	9	4	9	4	9
4	9							ε	

	+	-	#	$
Num	Sign Digits	Sign Digits	Sign Digits	
Sign	+	-		
Digits				
More				
Digit				

LL(1) Tables with ε

Num → Sign Digits

Sign → + | - | ε

Digits → Digit More

More → Digits | ε

Digit → 0 | 1 | … | 9

Num		Sign		Digit		Digits		More	
+	-	+	-	0	5	0	5	0	5
0	5	ε		1	6	1	6	1	6
1	6			2	7	2	7	2	7
2	7			3	8	3	8	3	8
3	8			4	9	4	9	4	9
4	9							ε	

	+	-	#	$
Num	Sign Digits	Sign Digits	Sign Digits	
Sign	+	-		
Digits			Digits More	
More				
Digit				

LL(1) Tables with ε

Num → Sign Digits
Sign → + | - | ε
Digits → Digit More
More → Digits | ε
Digit → 0 | 1 | … | 9

Num		Sign		Digit		Digits		More	
+	-	+	-	0	5	0	5	0	5
0	5	ε		1	6	1	6	1	6
1	6			2	7	2	7	2	7
2	7			3	8	3	8	3	8
3	8			4	9	4	9	4	9
4	9							ε	

	+	-	#	$
Num	Sign Digits	Sign Digits	Sign Digits	
Sign	+	-		
Digits			Digits More	
More				
Digit				

LL(1) Tables with ε

Num → Sign Digits
Sign → + | - | ε
Digits → Digit More
More → Digits | ε
Digit → 0 | 1 | … | 9

Num		Sign		Digit		Digits		More	
+	-	+	-	0	5	0	5	0	5
0	5	ε		1	6	1	6	1	6
1	6			2	7	2	7	2	7
2	7			3	8	3	8	3	8
3	8			4	9	4	9	4	9
4	9							ε	

	+	-	#	$
Num	Sign Digits	Sign Digits	Sign Digits	
Sign	+	-		
Digits			Digits More	
More			Digits	
Digit				

LL(1) Tables with ε

Num → **Sign Digits**
Sign → **+** | **-** | **ε**
Digits → **Digit More**
More → **Digits** | **ε**

Digit → **0** | **1** | … | **9**

Num		Sign		Digit		Digits		More	
+	-	+	-	0	5	0	5	0	5
0	5	ε		1	6	1	6	1	6
1	6			2	7	2	7	2	7
2	7			3	8	3	8	3	8
3	8			4	9	4	9	4	9
4	9							ε	

	+	-	#	$
Num	Sign Digits	Sign Digits	Sign Digits	
Sign	+	-		
Digits			Digits More	
More			Digits	
Digit				

LL(1) Tables with ε

Num → **Sign Digits**
Sign → **+** | **-** | **ε**
Digits → **Digit More**
More → **Digits** | **ε**

Digit → **0** | **1** | … | **9**

Num		Sign		Digit		Digits		More	
+	-	+	-	0	5	0	5	0	5
0	5	ε		1	6	1	6	1	6
1	6			2	7	2	7	2	7
2	7			3	8	3	8	3	8
3	8			4	9	4	9	4	9
4	9							ε	

	+	-	#	$
Num	Sign Digits	Sign Digits	Sign Digits	
Sign	+	-		
Digits			Digits More	
More			Digits	
Digit			#	

LL(1) Tables with ε

Num → **Sign Digits**
Sign → **+** | **-** | **ε**
Digits → **Digit More**
More → **Digits** | **ε**
Digit → **0** | **1** | … | **9**

Num	Sign	Digit	Digits	More
+ -	+ -	0 5	0 5	0 5
0 5	ε	1 6	1 6	1 6
1 6		2 7	2 7	2 7
2 7		3 8	3 8	3 8
3 8		4 9	4 9	4 9
4 9				ε

	+	-	#	$
Num	Sign Digits	Sign Digits	Sign Digits	
Sign	+	-		
Digits			Digits More	
More			Digits	
Digit			#	

LL(1) Tables with ε

Num → **Sign Digits**

Sign → + | - | ε

Digits → **Digit More**

More → **Digits** | ε

Digit → 0 | 1 | … | 9

Num		Sign		Digit		Digits		More	
+	-	+	-	0	5	0	5	0	5
0	5	ε		1	6	1	6	1	6
1	6			2	7	2	7	2	7
2	7			3	8	3	8	3	8
3	8			4	9	4	9	4	9
4	9							ε	

	+	-	#	$
Num	Sign Digits	Sign Digits	Sign Digits	
Sign	+	-		
Digits			Digits More	
More			Digits	
Digit			#	

LL(1) Tables with ε

Num → Sign Digits

Sign → + | - | ε

Digits → Digit More

More → Digits | ε

Digit → 0 | 1 | … | 9

Num		Sign		Digit		Digits		More	
+	-	+	-	0	5	0	5	0	5
0	5	ε		1	6	1	6	1	6
1	6			2	7	2	7	2	7
2	7			3	8	3	8	3	8
3	8			4	9	4	9	4	9
4	9							ε	

	+	-	#	$
Num	Sign Digits	Sign Digits	Sign Digits	
Sign	+	-		
Digits			Digits More	
More			Digits	
Digit			#	

LL(1) Tables with ε

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Sign → + | - | ε

Digits → Digit More

More → Digits | ε

Digit → 0 | 1 | … | 9

Num		Sign		Digit		Digits		More	
+	-	+	-	0	5	0	5	0	5
0	5	ε		1	6	1	6	1	6
1	6			2	7	2	7	2	7
2	7			3	8	3	8	3	8
3	8			4	9	4	9	4	9
4	9							ε	

	+	-	#	$
Num	Sign Digits	Sign Digits	Sign Digits	
Sign	+	-	ε	
Digits			Digits More	
More			Digits	
Digit			#	

LL(1) Tables with ε

Num → Sign Digits

Sign → + | - | ε

Digits → Digit More

More → Digits | ε

Digit → 0 | 1 | … | 9

Num		Sign		Digit		Digits		More	
+	-	+	-	0	5	0	5	0	5
0	5	ε		1	6	1	6	1	6
1	6			2	7	2	7	2	7
2	7			3	8	3	8	3	8
3	8			4	9	4	9	4	9
4	9							ε	

	+	-	#	$
Num	Sign Digits	Sign Digits	Sign Digits	
Sign	+	-	ε	
Digits			Digits More	
More			Digits	
Digit			#	

LL(1) Tables with ε

Num → **Sign Digits**

Sign → **+** | **-** | **ε**

Digits → **Digit More**

More → **Digits** | **ε**

Digit → **0** | **1** | … | **9**

Num		Sign		Digit		Digits		More	
+	-	+	-	0	5	0	5	0	5
0	5	ε		1	6	1	6	1	6
1	6			2	7	2	7	2	7
2	7			3	8	3	8	3	8
3	8			4	9	4	9	4	9
4	9							ε	

	+	-	#	$
Num	Sign Digits	Sign Digits	Sign Digits	
Sign	+	-	ε	
Digits			Digits More	
More			Digits	
Digit			#	

LL(1) Tables with ε

Num → **Sign Digits**

Sign → **+** | **-** | **ε**

Digits → **Digit More**

More → **Digits** | **ε**

Digit → **0** | **1** | … | **9**

Num		Sign		Digit		Digits		More	
+	-	+	-	0	5	0	5	0	5
0	5	ε		1	6	1	6	1	6
1	6			2	7	2	7	2	7
2	7			3	8	3	8	3	8
3	8			4	9	4	9	4	9
4	9							ε	

	+	-	#	$
Num	Sign Digits	Sign Digits	Sign Digits	
Sign	+	-	ε	
Digits			Digits More	
More			Digits	ε
Digit			#	

LL(1) Tables with ε

Num → **Sign Digits**
Sign → **+** | **-** | **ε**
Digits → **Digit More**
More → **Digits** | **ε**

Digit → **0** | **1** | … | **9**

Num		Sign		Digit		Digits		More	
+	-	+	-	0	5	0	5	0	5
0	5	ε		1	6	1	6	1	6
1	6			2	7	2	7	2	7
2	7			3	8	3	8	3	8
3	8			4	9	4	9	4	9
4	9							ε	

	+	-	#	$
Num	Sign Digits	Sign Digits	Sign Digits	
Sign	+	-	ε	
Digits			Digits More	
More			Digits	ε
Digit			#	

LL(1) Tables with ε

Num → **Sign Digits**
Sign → + | - | ε
Digits → **Digit More**
More → **Digits** | ε
Digit → 0 | 1 | … | 9

Num	Sign	Digit	Digits	More
+ -	+ -	0 5	0 5	0 5
0 5	ε	1 6	1 6	1 6
1 6		2 7	2 7	2 7
2 7		3 8	3 8	3 8
3 8		4 9	4 9	4 9
4 9				ε

	+	-	#	$
Num	Sign Digits	Sign Digits	Sign Digits	
Sign	+	-	ε	
Digits			Digits More	
More			Digits	ε
Digit			#	

The Final LL(1) Table Algorithm

- Compute FIRST(**A**) and FOLLOW(**A**) for all nonterminals **A**.
- For each rule **A** → ω, for each terminal **t** ∈ FIRST*(ω), set T[**A**, **t**] = ω.
  - Note that **ε** is not a terminal.
- For each rule **A** → ω, if **ε** ∈ FIRST*(ω), set T[**A**, **t**] = ω for each **t** ∈ FOLLOW(**A**).

A Formal Characterization of LL(1)

- A grammar is LL(1) if there are no conflicts in the table.
  - Every entry in the LL(1) table is unique

Questions?