LECTURE 13

MORE ON LL PARSING

SUBJECTS

Error Recovery

Non LL(1) Grammar

LL(K) Parsers

LL(1) ERROR RECOVERY

What happens when the parser discovers an error?

- **Approach 1**: stop all parsing activity and return an error message

- **Approach 2**: try to continue parsing (if possible) and see if there are more errors along the way

At Nothing!

Which approach does your compiler take?

LL(1) ERROR RECOVERY

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An error is detected when:

- The terminal on top of the stack does not match the next input token
- The parsing table cell from which we are supposed to pull the next production is empty

What does the parser do?

- It enters the ***panic-mode*** error recovery
- Based on the idea of skipping symbols on the input until a token in the SYNCH set appears

LL(1) ERROR RECOVERY

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Let S be a set of tokens called a synchronization set (SYNCH)

Let s ∈ S ➔ s is called a synchronization token

Million dollar question: how to construct the synchronization set?

- Many heuristics have been proposed
- We will cover a simple method

Place all symbols in FOLLOW(A) into the SYNCH(A) set for nonterminal A

- If we skip tokens until an element of SYNCH(A) is seen and we pop A from the stack, it's likely that parsing can continue

LL(1) ERROR RECOVERY

The panic-mode error recovery can be implemented using the SYNCH set(s) as follows:

- **Scenario 1:** If there is a nonterminal at the top of the stack, discard input tokens until you find a synch token, then pop the non-terminal
- **Scenario 2:** If there is a terminal at the top of the stack, we could try popping it to see whether we can continue
  - Assume that the input string is actually missing that terminal

LL(1) ERROR RECOVERY EXAMPLE

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FIRST Sets

```
FIRST(expr)= {num, id}
FIRST(expr')= {+, -, ε}
FIRST(term)= {num, id}
FIRST(term')= {*, /, ε}
FIRST(factor)= {num, id}
```

FOLLOW Sets

```
FOLLOW(expr)={$}
FOLLOW(expr')={$}
FOLLOW(term)= {+, -, $}
FOLLOW(term')= {+, -, $}
FOLLOW(factor)= {*, /, +, -, $}
```

Grammar

$$
\begin{array}{lcl}
\langle \text{expr} \rangle & ::= & \langle \text{term} \rangle \langle \text{expr}' \rangle \\
\langle \text{expr}' \rangle & ::= & + \langle \text{expr} \rangle \\
 & | & - \langle \text{expr} \rangle \\
 & | & \varepsilon \\
\langle \text{term} \rangle & ::= & \langle \text{factor} \rangle \langle \text{term}' \rangle \\
\langle \text{term}' \rangle & ::= & * \langle \text{term} \rangle \\
 & | & / \langle \text{term} \rangle \\
 & | & \varepsilon \\
\langle \text{factor} \rangle & ::= & \texttt{num} \\
 & | & \texttt{id}
\end{array}
$$

	num	id	+	-	*	/	$
expr	<expr>→ <term><expr'>	<expr>→ <term><expr'>	-	-	-	-	-
expr'	-	-	<expr'>→ +<expr>	<expr'>→ -<expr>	-	-	<expr'>→ ε
term	<term>→ <factor><term'>	<term>→ <factor><term'>	-	-	-	-	-
term'	-	-	<term'>→ ε	<term'>→ ε	<term'>→ *<term>	<term'>→ /<term>	<term'>→ ε
factor	factor→ num	factor → id	-	-	-	-	-

LL(1) ERROR RECOVERY EXAMPLE

FIRST Sets

```
FIRST(expr)= {num, id}
FIRST(expr')= {+, -, ε}
FIRST(term)= {num, id}
FIRST(term')= {*, /, ε}
FIRST(factor)= {num, id}
```

FOLLOW Sets

```
FOLLOW(expr)={$}
FOLLOW(expr')={$}
FOLLOW(term)= {+, -, $}
FOLLOW(term')= {+, -, $}
FOLLOW(factor)= {*, /, +, -, $}
```

Grammar

$$
\begin{array}{lcl}
\langle expr\rangle & ::= & \langle term\rangle\langle expr'\rangle \\
\langle expr'\rangle & ::= & +\langle expr\rangle \\
 & | & -\langle expr\rangle \\
 & | & \varepsilon \\
\langle term\rangle & ::= & \langle factor\rangle\langle term'\rangle \\
\langle term'\rangle & ::= & *\langle term\rangle \\
 & | & /\langle term\rangle \\
 & | & \varepsilon \\
\langle factor\rangle & ::= & \texttt{num} \\
 & | & \texttt{id}
\end{array}
$$

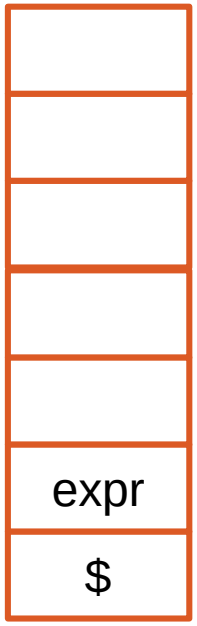
	num	id	+	-	*	/	$
expr	<expr>→ <term><expr'>	<expr>→ <term><expr'>	-	-	-	-	**(s)**
expr'	-	-	<expr'>→ +<expr>	<expr'>→ -<expr>	-	-	<expr'>→ ε **(s)**
term	<term>→ <factor><term'>	<term>→ <factor><term'>	**(s)**	**(s)**	-	-	**(s)**
term'	-	-	<term'>→ ε **(s)**	<term'>→ ε **(s)**	<term'>→ *<term>	<term'>→ /<term>	<term'>→ ε **(s)**
factor	factor→ num	factor → id	**(s)**	**(s)**	**(s)**	**(s)**	**(s)**

PARSING USING LL(1)

Example:

id	*	/	/	+	num	+	id	$

String of errors



	num	id	+	-	*	/	$
expr	<expr>→ <term><expr'>	<expr>→ <term><expr'>	-	-	-	-	**(s)**
expr'	-	-	<expr'>→ +<expr>	<expr'>→ -<expr>	-	-	<expr'>→ ε **(s)**
term	<term>→ <factor><term'>	<term>→ <factor><term'>	**(s)**	**(s)**	-	-	**(s)**
term'	-	-	<term'>→ ε **(s)**	<term'>→ ε **(s)**	<term'>→ *<term>	<term'>→ /<term>	<term'>→ ε **(s)**
factor	factor→ num	factor → id	**(s)**	**(s)**	**(s)**	**(s)**	**(s)**

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Example:

id	*	/	/	+	num	+	id	$

term
expr'
$

	num	id	+	-	*	/	$
expr	<expr>→ <term><expr'>	<expr>→ <term><expr'>	-	-	-	-	**(s)**
expr'	-	-	<expr'>→ +<expr>	<expr'>→ -<expr>	-	-	<expr'>→ ε **(s)**
term	<term>→ <factor><term'>	<term>→ <factor><term'>	**(s)**	**(s)**	-	-	**(s)**
term'	-	-	<term'>→ ε **(s)**	<term'>→ ε **(s)**	<term'>→ *<term>	<term'>→ /<term>	<term'>→ ε **(s)**
factor	factor→ num	factor → id	**(s)**	**(s)**	**(s)**	**(s)**	**(s)**

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Example:

id	*	/	/	+	num	+	id	$

factor
term'
expr'
$

	num	id	+	-	*	/	$
expr	<expr>→ <term><expr'>	<expr>→ <term><expr'>	-	-	-	-	**(s)**
expr'	-	-	<expr'>→ +<expr>	<expr'>→ -<expr>	-	-	<expr'>→ ε **(s)**
term	<term>→ <factor><term'>	<term>→ <factor><term'>	**(s)**	**(s)**	-	-	**(s)**
term'	-	-	<term'>→ ε **(s)**	<term'>→ ε **(s)**	<term'>→ *<term>	<term'>→ /<term>	<term'>→ ε **(s)**
factor	factor→ num	factor → id	**(s)**	**(s)**	**(s)**	**(s)**	**(s)**

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Example:

id	*	/	/	+	num	+	id	$

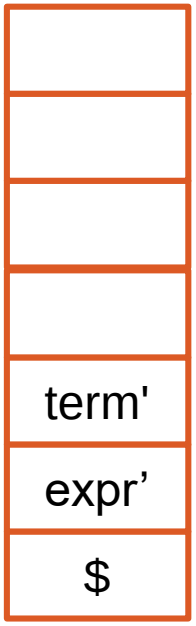
id
term'
expr'
$

	num	id	+	-	*	/	$
expr	<expr>→ <term><expr'>	<expr>→ <term><expr'>	-	-	-	-	**(s)**
expr'	-	-	<expr'>→ +<expr>	<expr'>→ -<expr>	-	-	<expr'>→ ε **(s)**
term	<term>→ <factor><term'>	<term>→ <factor><term'>	**(s)**	**(s)**	-	-	**(s)**
term'	-	-	<term'>→ ε **(s)**	<term'>→ ε **(s)**	<term'>→ *<term>	<term'>→ /<term>	<term'>→ ε **(s)**
factor	factor→ num	factor → id	**(s)**	**(s)**	**(s)**	**(s)**	**(s)**

PARSING USING LL(1)

Example:

*	/	/	+	num	+	id	$

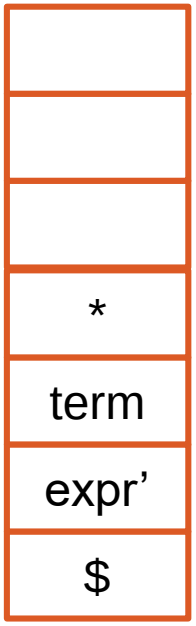


	num	id	+	-	*	/	$
expr	<expr>→ <term><expr'>	<expr>→ <term><expr'>	-	-	-	-	**(s)**
expr'	-	-	<expr'>→ +<expr>	<expr'>→ -<expr>	-	-	<expr'>→ ε **(s)**
term	<term>→ <factor><term'>	<term>→ <factor><term'>	**(s)**	**(s)**	-	-	**(s)**
term'	-	-	<term'>→ ε **(s)**	<term'>→ ε **(s)**	<term'>→ *<term>	<term'>→ /<term>	<term'>→ ε **(s)**
factor	factor→ num	factor → id	**(s)**	**(s)**	**(s)**	**(s)**	**(s)**

PARSING USING LL(1)

Example:

*	/	/	+	num	+	id	$



	num	id	+	-	*	/	$
expr	<expr>→ <term><expr'>	<expr>→ <term><expr'>	-	-	-	-	**(s)**
expr'	-	-	<expr'>→ +<expr>	<expr'>→ -<expr>	-	-	<expr'>→ ε **(s)**
term	<term>→ <factor><term'>	<term>→ <factor><term'>	**(s)**	**(s)**	-	-	**(s)**
term'	-	-	<term'>→ ε **(s)**	<term'>→ ε **(s)**	<term'>→ *<term>	<term'>→ /<term>	<term'>→ ε **(s)**
factor	factor→ num	factor → id	**(s)**	**(s)**	**(s)**	**(s)**	**(s)**

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Example:

/	/	+	num	+	id	$

term
expr'
$

Error: the cell corresponding to row term and column / is empty!

Start discarding tokens, until you find a synch token

	num	id	+	-	*	/	$
expr	<expr>→ <term><expr'>	<expr>→ <term><expr'>	-	-	-	-	**(s)**
expr'	-	-	<expr'>→ +<expr>	<expr'>→ -<expr>	-	-	<expr'>→ ε **(s)**
term	<term>→ <factor><term'>	<term>→ <factor><term'>	**(s)**	**(s)**	-	-	**(s)**
term'	-	-	<term'>→ ε **(s)**	<term'>→ ε **(s)**	<term'>→ *<term>	<term'>→ /<term>	<term'>→ ε **(s)**
factor	factor→ num	factor → id	**(s)**	**(s)**	**(s)**	**(s)**	**(s)**

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Example:

/	+	num	+	id	$

term
expr'
$

Error: the cell corresponding to row term and column / is empty!

Start discarding tokens, until you find a synch token

	num	id	+	-	*	/	$
expr	<expr>→ <term><expr'>	<expr>→ <term><expr'>	-	-	-	-	**(s)**
expr'	-	-	<expr'>→ +<expr>	<expr'>→ -<expr>	-	-	<expr'>→ ε **(s)**
term	<term>→ <factor><term'>	<term>→ <factor><term'>	**(s)**	**(s)**	-	-	**(s)**
term'	-	-	<term'>→ ε **(s)**	<term'>→ ε **(s)**	<term'>→ *<term>	<term'>→ /<term>	<term'>→ ε **(s)**
factor	factor→ num	factor → id	**(s)**	**(s)**	**(s)**	**(s)**	**(s)**

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Example:

+	num	+	id	$

term
expr'
$

Error: the cell corresponding to row term and column / is empty!

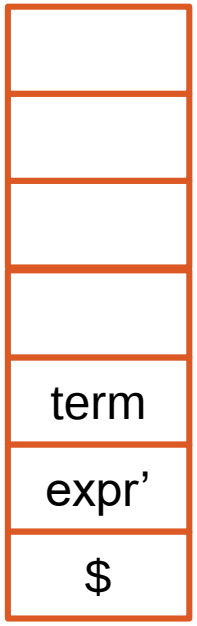
Start discarding tokens, until you find a synch token

	num	id	+	-	*	/	$
expr	<expr>→ <term><expr'>	<expr>→ <term><expr'>	-	-	-	-	**(s)**
expr'	-	-	<expr'>→ +<expr>	<expr'>→ -<expr>	-	-	<expr'>→ ε **(s)**
term	<term>→ <factor><term'>	<term>→ <factor><term'>	**(s)**	**(s)**	-	-	**(s)**
term'	-	-	<term'>→ ε **(s)**	<term'>→ ε **(s)**	<term'>→ *<term>	<term'>→ /<term>	<term'>→ ε **(s)**
factor	factor→ num	factor → id	**(s)**	**(s)**	**(s)**	**(s)**	**(s)**

PARSING USING LL(1)

Example:

+	num	+	id	$



We have found a synch token!

Pop term from the stack and attempt to continue…

	num	id	+	-	*	/	$
expr	<expr>→ <term><expr'>	<expr>→ <term><expr'>	-	-	-	-	**(s)**
expr'	-	-	<expr'>→ +<expr>	<expr'>→ -<expr>	-	-	<expr'>→ ε **(s)**
term	<term>→ <factor><term'>	<term>→ <factor><term'>	**(s)**	**(s)**	-	-	**(s)**
term'	-	-	<term'>→ ε **(s)**	<term'>→ ε **(s)**	<term'>→ *<term>	<term'>→ /<term>	<term'>→ ε **(s)**
factor	factor→ num	factor → id	**(s)**	**(s)**	**(s)**	**(s)**	**(s)**

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Example:

+	num	+	id	$

expr'
$

	num	id	+	-	*	/	$
expr	<expr>→ <term><expr'>	<expr>→ <term><expr'>	-	-	-	-	**(s)**
expr'	-	-	<expr'>→ +<expr>	<expr'>→ -<expr>	-	-	<expr'>→ ε **(s)**
term	<term>→ <factor><term'>	<term>→ <factor><term'>	**(s)**	**(s)**	-	-	**(s)**
term'	-	-	<term'>→ ε **(s)**	<term'>→ ε **(s)**	<term'>→ *<term>	<term'>→ /<term>	<term'>→ ε **(s)**
factor	factor→ num	factor → id	**(s)**	**(s)**	**(s)**	**(s)**	**(s)**

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Example:

+	num	+	id	$

+
expr
$

	num	id	+	-	*	/	$
expr	<expr>→ <term><expr'>	<expr>→ <term><expr'>	-	-	-	-	**(s)**
expr'	-	-	<expr'>→ +<expr>	<expr'>→ -<expr>	-	-	<expr'>→ ε **(s)**
term	<term>→ <factor><term'>	<term>→ <factor><term'>	**(s)**	**(s)**	-	-	**(s)**
term'	-	-	<term'>→ ε **(s)**	<term'>→ ε **(s)**	<term'>→ *<term>	<term'>→ /<term>	<term'>→ ε **(s)**
factor	factor→ num	factor → id	**(s)**	**(s)**	**(s)**	**(s)**	**(s)**

PARSING USING LL(1)

Example:

num	+	id	$

expr
$

	num	id	+	-	*	/	$
expr	<expr>→ <term><expr'>	<expr>→ <term><expr'>	-	-	-	-	**(s)**
expr'	-	-	<expr'>→ +<expr>	<expr'>→ -<expr>	-	-	<expr'>→ ε **(s)**
term	<term>→ <factor><term'>	<term>→ <factor><term'>	**(s)**	**(s)**	-	-	**(s)**
term'	-	-	<term'>→ ε **(s)**	<term'>→ ε **(s)**	<term'>→ *<term>	<term'>→ /<term>	<term'>→ ε **(s)**
factor	factor→ num	factor → id	**(s)**	**(s)**	**(s)**	**(s)**	**(s)**

PARSING USING LL(1)

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Example:

num	+	id	$

term
expr'
$

	num	id	+	-	*	/	$
expr	<expr>→ <term><expr'>	<expr>→ <term><expr'>	-	-	-	-	**(s)**
expr'	-	-	<expr'>→ +<expr>	<expr'>→ -<expr>	-	-	<expr'>→ ε **(s)**
term	<term>→ <factor><term'>	<term>→ <factor><term'>	**(s)**	**(s)**	-	-	**(s)**
term'	-	-	<term'>→ ε **(s)**	<term'>→ ε **(s)**	<term'>→ *<term>	<term'>→ /<term>	<term'>→ ε **(s)**
factor	factor→ num	factor → id	**(s)**	**(s)**	**(s)**	**(s)**	**(s)**

PARSING USING LL(1)

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Example:

num	+	id	$

factor
term'
expr'
$

	num	id	+	-	*	/	$
expr	<expr>→ <term><expr'>	<expr>→ <term><expr'>	-	-	-	-	**(s)**
expr'	-	-	<expr'>→ +<expr>	<expr'>→ -<expr>	-	-	<expr'>→ ε **(s)**
term	<term>→ <factor><term'>	<term>→ <factor><term'>	**(s)**	**(s)**	-	-	**(s)**
term'	-	-	<term'>→ ε **(s)**	<term'>→ ε **(s)**	<term'>→ *<term>	<term'>→ /<term>	<term'>→ ε **(s)**
factor	factor→ num	factor → id	**(s)**	**(s)**	**(s)**	**(s)**	**(s)**

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Example:

num	+	id	$

num
term'
expr'
$

	num	id	+	-	*	/	$
expr	<expr>→ <term><expr'>	<expr>→ <term><expr'>	-	-	-	-	**(s)**
expr'	-	-	<expr'>→ +<expr>	<expr'>→ -<expr>	-	-	<expr'>→ ε **(s)**
term	<term>→ <factor><term'>	<term>→ <factor><term'>	**(s)**	**(s)**	-	-	**(s)**
term'	-	-	<term'>→ ε **(s)**	<term'>→ ε **(s)**	<term'>→ *<term>	<term'>→ /<term>	<term'>→ ε **(s)**
factor	factor→ num	factor → id	**(s)**	**(s)**	**(s)**	**(s)**	**(s)**

PARSING USING LL(1)

Example:

+	id	$

term’
expr'
$

	num	id	+	-	*	/	$
expr	<expr>→ <term><expr'>	<expr>→ <term><expr'>	-	-	-	-	**(s)**
expr’	-	-	<expr’>→ +<expr>	<expr’>→ -<expr>	-	-	<expr’>→ ε **(s)**
term	<term>→ <factor><term’>	<term>→ <factor><term’>	**(s)**	**(s)**	-	-	**(s)**
term’	-	-	<term’>→ ε **(s)**	<term’>→ ε **(s)**	<term’>→ *<term>	<term’>→ /<term>	<term’>→ ε **(s)**
factor	factor→ num	factor → id	**(s)**	**(s)**	**(s)**	**(s)**	**(s)**

PARSING USING LL(1)

Example:

+	id	$

expr'
$

	num	id	+	-	*	/	$
expr	<expr>→ <term><expr'>	<expr>→ <term><expr'>	-	-	-	-	**(s)**
expr'	-	-	<expr'>→ +<expr>	<expr'>→ -<expr>	-	-	<expr'>→ ε **(s)**
term	<term>→ <factor><term'>	<term>→ <factor><term'>	**(s)**	**(s)**	-	-	**(s)**
term'	-	-	<term'>→ ε **(s)**	<term'>→ ε **(s)**	<term'>→ *<term>	<term'>→ /<term>	<term'>→ ε **(s)**
factor	factor→ num	factor → id	**(s)**	**(s)**	**(s)**	**(s)**	**(s)**

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Example:

+	id	$

+
expr
$

	num	id	+	-	*	/	$
expr	<expr>→ <term><expr'>	<expr>→ <term><expr'>	-	-	-	-	**(s)**
expr'	-	-	<expr'>→ +<expr>	<expr'>→ -<expr>	-	-	<expr'>→ ε **(s)**
term	<term>→ <factor><term'>	<term>→ <factor><term'>	**(s)**	**(s)**	-	-	**(s)**
term'	-	-	<term'>→ ε **(s)**	<term'>→ ε **(s)**	<term'>→ *<term>	<term'>→ /<term>	<term'>→ ε **(s)**
factor	factor→ num	factor → id	**(s)**	**(s)**	**(s)**	**(s)**	**(s)**

PARSING USING LL(1)

Example:

id	$

expr
$

	num	id	+	-	*	/	$
expr	<expr>→ <term><expr'>	<expr>→ <term><expr'>	-	-	-	-	**(s)**
expr'	-	-	<expr'>→ +<expr>	<expr'>→ -<expr>	-	-	<expr'>→ ε **(s)**
term	<term>→ <factor><term'>	<term>→ <factor><term'>	**(s)**	**(s)**	-	-	**(s)**
term'	-	-	<term'>→ ε **(s)**	<term'>→ ε **(s)**	<term'>→ *<term>	<term'>→ /<term>	<term'>→ ε **(s)**
factor	factor→ num	factor → id	**(s)**	**(s)**	**(s)**	**(s)**	**(s)**

PARSING USING LL(1)

Example:

id	$

term
expr'
$

	num	id	+	-	*	/	$
expr	<expr>→ <term><expr'>	<expr>→ <term><expr'>	-	-	-	-	**(s)**
expr'	-	-	<expr'>→ +<expr>	<expr'>→ -<expr>	-	-	<expr'>→ ε **(s)**
term	<term>→ <factor><term'>	<term>→ <factor><term'>	**(s)**	**(s)**	-	-	**(s)**
term'	-	-	<term'>→ ε **(s)**	<term'>→ ε **(s)**	<term'>→ *<term>	<term'>→ /<term>	<term'>→ ε **(s)**
factor	factor→ num	factor → id	**(s)**	**(s)**	**(s)**	**(s)**	**(s)**

PARSING USING LL(1)

Example:

id	$

factor
term'
expr'
$

	num	id	+	-	*	/	$
expr	<expr>→ <term><expr'>	<expr>→ <term><expr'>	-	-	-	-	**(s)**
expr'	-	-	<expr'>→ +<expr>	<expr'>→ -<expr>	-	-	<expr'>→ ε **(s)**
term	<term>→ <factor><term'>	<term>→ <factor><term'>	**(s)**	**(s)**	-	-	**(s)**
term'	-	-	<term'>→ ε **(s)**	<term'>→ ε **(s)**	<term'>→ *<term>	<term'>→ /<term>	<term'>→ ε **(s)**
factor	factor→ num	factor → id	**(s)**	**(s)**	**(s)**	**(s)**	**(s)**

PARSING USING LL(1)

Example:

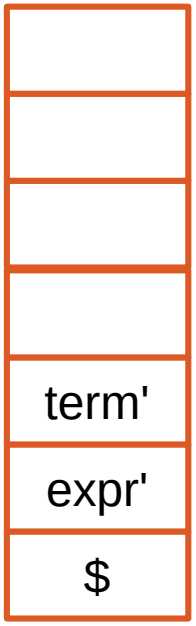
id	$

id
term'
expr'
$

	num	id	+	-	*	/	$
expr	<expr>→ <term><expr'>	<expr>→ <term><expr'>	-	-	-	-	**(s)**
expr'	-	-	<expr'>→ +<expr>	<expr'>→ -<expr>	-	-	<expr'>→ ε **(s)**
term	<term>→ <factor><term'>	<term>→ <factor><term'>	**(s)**	**(s)**	-	-	**(s)**
term'	-	-	<term'>→ ε **(s)**	<term'>→ ε **(s)**	<term'>→ *<term>	<term'>→ /<term>	<term'>→ ε **(s)**
factor	factor→ num	factor → id	**(s)**	**(s)**	**(s)**	**(s)**	**(s)**

PARSING USING LL(1)

Example:



$

	num	id	+	-	*	/	$
expr	<expr>→ <term><expr'>	<expr>→ <term><expr'>	-	-	-	-	**(s)**
expr'	-	-	<expr'>→ +<expr>	<expr'>→ -<expr>	-	-	<expr'>→ ε **(s)**
term	<term>→ <factor><term'>	<term>→ <factor><term'>	**(s)**	**(s)**	-	-	**(s)**
term'	-	-	<term'>→ ε **(s)**	<term'>→ ε **(s)**	<term'>→ *<term>	<term'>→ /<term>	<term'>→ ε **(s)**
factor	factor→ num	factor → id	**(s)**	**(s)**	**(s)**	**(s)**	**(s)**

PARSING USING LL(1)

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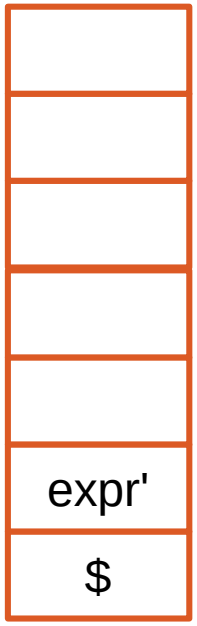
Example:

$



	num	id	+	-	*	/	$
expr	<expr>→ <term><expr'>	<expr>→ <term><expr'>	-	-	-	-	**(s)**
expr'	-	-	<expr'>→ +<expr>	<expr'>→ -<expr>	-	-	<expr'>→ ε **(s)**
term	<term>→ <factor><term'>	<term>→ <factor><term'>	**(s)**	**(s)**	-	-	**(s)**
term'	-	-	<term'>→ ε **(s)**	<term'>→ ε **(s)**	<term'>→ *<term>	<term'>→ /<term>	<term'>→ ε **(s)**
factor	factor→ num	factor → id	**(s)**	**(s)**	**(s)**	**(s)**	**(s)**

PARSING USING LL(1)

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Example:

$

$

We did our best to continue parsing…

	num	id	+	-	*	/	$
expr	<expr>→ <term><expr'>	<expr>→ <term><expr'>	-	-	-	-	**(s)**
expr'	-	-	<expr'>→ +<expr>	<expr'>→ -<expr>	-	-	<expr'>→ ε **(s)**
term	<term>→ <factor><term'>	<term>→ <factor><term'>	**(s)**	**(s)**	-	-	**(s)**
term'	-	-	<term'>→ ε **(s)**	<term'>→ ε **(s)**	<term'>→ *<term>	<term'>→ /<term>	<term'>→ ε **(s)**
factor	factor→ num	factor → id	**(s)**	**(s)**	**(s)**	**(s)**	**(s)**

A NON LL(1) GRAMMAR

Consider the grammar:

```
<stmt> ::= if <expr> then <stmt>
         | if <expr> then <stmt> else <stmt>
```

Needs left factoring, which gives:

```
<stmt> ::= if <expr> then <stmt><stmt'>
<stmt'> ::= else <stmt> | ε
```

Let's get the FIRST and FOLLOW sets

FIRST(stmt) = {if}

FIRST(stmt')={else, ε}

1) FIRST(terminal) is {terminal}

2) If A→aα, and a is a terminal:
{a}∈FIRST(A)

3) If A→Bα, and rule B→ε does **NOT** exist:
FIRST(B)∈FIRST(A)

4) If A→Bα, and rule B→ε **DOES** exist:
{(FIRST(B) − ε) ∪ FIRST(α)}∈FIRST(A)

A NON LL(1) GRAMMAR

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Consider the grammar:

```
<stmt> ::= if <expr> then <stmt>
         | if <expr> then <stmt> else <stmt>
```

Needs left factoring, which gives:

```
<stmt> ::= if <expr> then <stmt><stmt'>
<stmt'> ::= else <stmt> | ε
```

Let's get the FIRST and FOLLOW sets

FIRST(stmt) = {if}

FIRST(stmt')={else, ε}

FOLLOW(stmt) = {$, else}

FOLLOW(stmt')={$, else}

1) $\{\$\} \in FOLLOW(S)$

2) If $A \rightarrow \alpha B$:
$FOLLOW(A) \in FOLLOW(B)$

3) If $A \rightarrow \alpha B\gamma$, and rule $\gamma \rightarrow \varepsilon$ does **NOT** exist:
$FIRST(\gamma) \in FOLLOW(B)$

4) If $A \rightarrow \alpha B\gamma$, and rule $\gamma \rightarrow \varepsilon$ **DOES** exist:
$\{(FIRST(\gamma) - \varepsilon) \cup FOLLOW(A)\} \in FOLLOW(B)$

***Note**: This is a partial grammar (used to demonstrate a concept), therefore we did not specify the production rules associated with expr. Consequently, its FIRST and FOLLOW sets will not be calculated.*

A NON LL(1) GRAMMAR

FIRST(stmt) = {if}
FIRST(stmt')={else, ε}
…

FOLLOW(stmt) = {$, else}
FOLLOW(stmt')={$, else}
…

```
<stmt> ::= if <expr> then <stmt><stmt'>

<stmt'> ::= else <stmt> | ε
```

	if	then	else	$
stmt				
stmt'				

A NON LL(1) GRAMMAR

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FIRST(stmt) = {if}
FIRST(stmt')={else, ε}
…

FOLLOW(stmt) = {$, else}
FOLLOW(stmt')={$, else}
…

```
<stmt> ::= if <expr> then <stmt><stmt'>

<stmt'> ::= else <stmt> | ε
```

	if	then	else	$
stmt	<stmt>→ if <expr> then <stmt><stmt'>	-	-	-
stmt'				

A NON LL(1) GRAMMAR

FIRST(stmt) = {if}
FIRST(stmt')={else, ε}
…

FOLLOW(stmt) = {$, else}
FOLLOW(stmt')={$, else}
…

```
<stmt> ::= if <expr> then <stmt><stmt'>

<stmt'> ::= else <stmt> | ε
```

	if	then	else	$
stmt	<stmt>→ if <expr> then <stmt><stmt'>	-	-	-
stmt'			<stmt'>→ else <stmt>	

A NON LL(1) GRAMMAR

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FIRST(stmt) = {if}
FIRST(stmt')={else, ε}
…

FOLLOW(stmt) = {$, else}
FOLLOW(stmt')={$, else}
…

```
<stmt> ::= if <expr> then <stmt><stmt'>

<stmt'> ::= else <stmt> | ε
```

	if	then	else	$
stmt	<stmt>→ if <expr> then <stmt><stmt'>	-	-	-
stmt'			<stmt'>→ else <stmt>	<stmt'>→ ε

A NON LL(1) GRAMMAR

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FIRST(stmt) = {if}
FIRST(stmt')={else, ε}
…

FOLLOW(stmt) = {$, else}
FOLLOW(stmt')={$, else}
…

```
<stmt> ::= if <expr> then <stmt><stmt'>

<stmt'> ::= else <stmt> | ε
```

	if	then	else	$
stmt	<stmt>→ if <expr> then <stmt><stmt'>	-	-	-
stmt'	-	-	<stmt'>→ else <stmt>, <stmt'>→ ε	<stmt'>→ ε

A NON LL(1) GRAMMAR

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The problem arises because for an input token `else` and stack top of `stmt'`, we do not know which production to choose:

- `<stmt'>→else <stmt>`
- `<stmt'>→ε`

Therefore, this is not an LL(1) grammar

	if	then	else	$
stmt	`<stmt>→ if <expr> then <stmt><stmt'>`	-	-	-
stmt'	-	-	`<stmt'>→ else <stmt>,` `<stmt'>→ ε`	`<stmt'>→ ε`

LL(K) PARSERS

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We have already studied LL(1) parser

- With 1 token look-ahead

We will touch briefly on LL(k) parsers

- With "k" tokens look-ahead
- This is useful since not all grammars are LL(1) compatible

LL(K) PARSERS

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Consider the following grammar:

<Z> ::= <X><Y><Z>| ab

<Y> ::= cb | ε

<X> ::= ac | b<Y>c

First and Follow sets:

FIRST(Z)={a,b}

FIRST(Y)={c, ε}

FIRST(X)={a,b}

FOLLOW(Z)={$}

FOLLOW(Y)={a,b,c}

FOLLOW(X)={a,b,c}

First Rules

1) FIRST(terminal) is {terminal}

2) If A→aα, and a is a terminal:
{a}∈FIRST(A)

3) If A→Bα, and rule B→ε does **NOT** exist:
FIRST(B)∈FIRST(A)

4) If A→Bα, and rule B→ε **DOES** exist:
{(FIRST(B)- ε)∪FIRST(α)}∈FIRST(A)

Follow Rules

1) {$}∈FOLLOW(S)

2) If A→ αB:
FOLLOW(A) ∈ FOLLOW(B)

3) If A→αBγ, and rule γ→ε does **NOT** exist:
FIRST(γ) ∈ FOLLOW(B)

4) If A→αBγ, and rule γ→ε **DOES** exist:
{(FIRST(γ)-ε)∪FOLLOW(A)}∈FOLLOW(B)

LL(K) PARSERS

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Grammar	FIRST	FOLLOW
<Z> ::= <X><Y><Z>| ab	FIRST(Z)={a,b}	FOLLOW(Z)={$}
<Y> ::= cb | ε	FIRST(Y)={c, ε}	FOLLOW(Y)={a,b,c}
<X> ::= ac | b<Y>c	FIRST(X)={a,b}	FOLLOW(X)={a,b,c}

	a	b	c	$
X				
Y				
Z				

LL(K) PARSERS

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Grammar	FIRST	FOLLOW
<Z> ::= <X><Y><Z>| ab	FIRST(Z)={a,b}	FOLLOW(Z)={$}
<Y> ::= cb | ε	FIRST(Y)={c, ε}	FOLLOW(Y)={a,b,c}
<X> ::= ac | b<Y>c	FIRST(X)={a,b}	FOLLOW(X)={a,b,c}

	a	b	c	$
X	X→ac	X→bYc	-	-
Y				
Z				

LL(K) PARSERS

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Grammar

```
<Z> ::= <X><Y><Z>| ab
<Y> ::= cb | ε
<X> ::= ac | b<Y>c
```

FIRST

FIRST(Z)={a,b}

FIRST(Y)={c, ε}

FIRST(X)={a,b}

FOLLOW

FOLLOW(Z)={$}

FOLLOW(Y)={a,b,c}

FOLLOW(X)={a,b,c}

	a	b	c	$
X	X→ac	X→bYc	-	-
Y	Y→ε	Y→ε	Y→cb, Y→ε	-
Z				

LL(K) PARSERS

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Grammar

```
<Z> ::= <X><Y><Z>| ab
<Y> ::= cb | ε
<X> ::= ac | b<Y>c
```

FIRST

FIRST(Z)={a,b}

FIRST(Y)={c, ε}

FIRST(X)={a,b}

FOLLOW

FOLLOW(Z)={$}

FOLLOW(Y)={a,b,c}

FOLLOW(X)={a,b,c}

	a	b	c	$
X	X→ac	X→bYc	-	-
Y	Y→ε	Y→ε	Y→cb, Y→ε	-
Z	Z→ab	Z→XYZ	-	-

Not an LL(1) Grammar

LL(K) PARSERS

Grammar

```
<Z> ::= <X><Y><Z>| ab

<Y> ::= cb | ε

<X> ::= ac | b<Y>c
```

We have shown that the above grammar is not LL(1)

Maybe it is an LL(2) grammar

- Re-create the sets **FIRST(A)** while considering **TWO** terminals appearing **first** in a string derived from A
- Re-create the sets **FOLLOW (A)** while considering **TWO** terminals appearing **after A** in a sentential form

- Make sure that a single production exists in every table cell

LL(2) PARSING TABLE

```
<Z> ::= <X><Y><Z>| ab
<Y> ::= cb | ε
<X> ::= ac | b<Y>c
```

FIRST(Z)={ab, ac,bc}
FIRST(Y)={cb, ε}
FIRST(X)={ac, bc}

FOLLOW(Z)={a$, b$, c$}
FOLLOW(Y)={ab, ac,bc}
FOLLOW(X)={cb,ab,ac,bc}

	aa	ab	ac	a$	ba	bb	bc	b$	ca	cb	cc	c$
X												
Y												
Z												

LL(2) PARSING TABLE

```
<Z> ::= <X><Y><Z>| ab
<Y> ::= cb | ε
<X> ::= ac | b<Y>c
```

FIRST(Z)={ab, ac,bc}
FIRST(Y)={cb, ε}
FIRST(X)={ac, bc}

FOLLOW(Z)={a$, b$, c$}
FOLLOW(Y)={ab, ac,bc}
FOLLOW(X)={cb,ab,ac,bc}

	aa	ab	ac	a$	ba	bb	bc	b$	ca	cb	cc	c$
X			X→ ac				X→bYc					
Y		Y→ε	Y→ε				Y→ε			Y→cb		
Z		Z→ab	Z→XYZ				Z→XYZ					

THANK YOU!

QUESTIONS?