

# CS536

## SDT For Top-Down Parsing

# Announcement: Midterm Prep

- List of topics
  - Up to and including all of last week
- Length 1hr 10min
- No extra materials allowed – just bring a pen
- Sample midterm
  - Recommended that you do this by Tuesday
  - We'll review it in class

# Last Time: Built LL(1) Predictive Parser

- FIRST and FOLLOW sets define the parse table
- If the grammar is LL(1), the table is unambiguous
- If the grammar is not LL(1) we can attempt a transformation sequence:
  1. Remove left recursion
  2. Left-factoring

# Today

- Review Parse Table Construction
  - 2 examples
- Show how to do Syntax-Directed Translation using an LL(1) parser

FIRST( $\alpha$ ) for  $\alpha = Y_1 Y_2 \dots Y_k$

Add FIRST( $Y_1$ ) -  $\{\epsilon\}$

If  $\epsilon$  is in FIRST( $Y_{1 \text{ to } i-1}$ ): add FIRST( $Y_i$ ) -  $\{\epsilon\}$

If  $\epsilon$  is in all RHS symbols, add  $\epsilon$

FOLLOW(A) for  $X \rightarrow \alpha A \beta$

If A is the start, add **eof**

Add FIRST( $\beta$ ) -  $\{\epsilon\}$

Add FOLLOW(X) if  $\epsilon$  in FIRST( $\beta$ ) or  $\beta$  empty

Table[X][t]

for each production  $X \rightarrow \alpha$

for each terminal **t** in FIRST( $\alpha$ )

put  $\alpha$  in Table[X][**t**]

if  $\epsilon$  is in FIRST( $\alpha$ ) {

for each terminal **t** in FOLLOW(X) {

put  $\alpha$  in Table[X][**t**]

FIRST(S) = { **a, c, d** }

FIRST(B) = { **a, c** }

FIRST(D) = { **d,  $\epsilon$**  }

FIRST(B c) = { **a, c** }

FIRST(D B) = { **d, a, c** }

FIRST(a b) = { **a** }

FIRST(c S) = { **c** }

FOLLOW(S) = { **eof, c** }

FOLLOW(B) = { **c, eof** }

FOLLOW(D) = { **a, c** }

CFG

S  $\rightarrow$  B c l D B

B  $\rightarrow$  a b l c S

D  $\rightarrow$  d l  $\epsilon$



	a	b	c	d	eof
S	B c D B		B c D B	D B	
B	a b		c S		
D	$\epsilon$		$\epsilon$		

FIRST( $\alpha$ ) for  $\alpha = Y_1 Y_2 \dots Y_k$

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if  $\epsilon$  is in FIRST( $\alpha$ ) {

for each terminal **t** in FOLLOW(X) {

put  $\alpha$  in Table[X][**t**]

CFG

$S \rightarrow (S) \mid \{S\} \mid \epsilon$

FIRST(S) =  $\{ \{, (, \epsilon \}$

FIRST((S)) =  $\{ ( \}$

FIRST({S}) =  $\{ \{ \}$

FIRST( $\epsilon$ ) =  $\{ \epsilon \}$

FOLLOW(S) =  $\{ \text{eof}, ), \} \}$

	(	)	{	}	eof
S	(S)	$\epsilon$	{S}	$\epsilon$	$\epsilon$

FIRST( $\alpha$ ) for  $\alpha = Y_1 Y_2 \dots Y_k$

Add FIRST( $Y_1$ ) -  $\{\epsilon\}$

If  $\epsilon$  is in FIRST( $Y_{1 \text{ to } i-1}$ ): add FIRST( $Y_i$ ) -  $\{\epsilon\}$

If  $\epsilon$  is in all RHS symbols, add  $\epsilon$

FOLLOW(A) for  $X \rightarrow \alpha A \beta$

If A is the start, add **eof**

Add FIRST( $\beta$ ) -  $\{\epsilon\}$

Add FOLLOW(X) if  $\epsilon$  in FIRST( $\beta$ ) or  $\beta$  empty

Table[X][t]

for each production  $X \rightarrow \alpha$

for each terminal **t** in FIRST( $\alpha$ )

put  $\alpha$  in Table[X][**t**]

if  $\epsilon$  is in FIRST( $\alpha$ ) {

for each terminal **t** in FOLLOW(X) {

put  $\alpha$  in Table[X][**t**]

CFG

$S \rightarrow + S \mid \epsilon$

FIRST(S) = {**+**,  **$\epsilon$** }

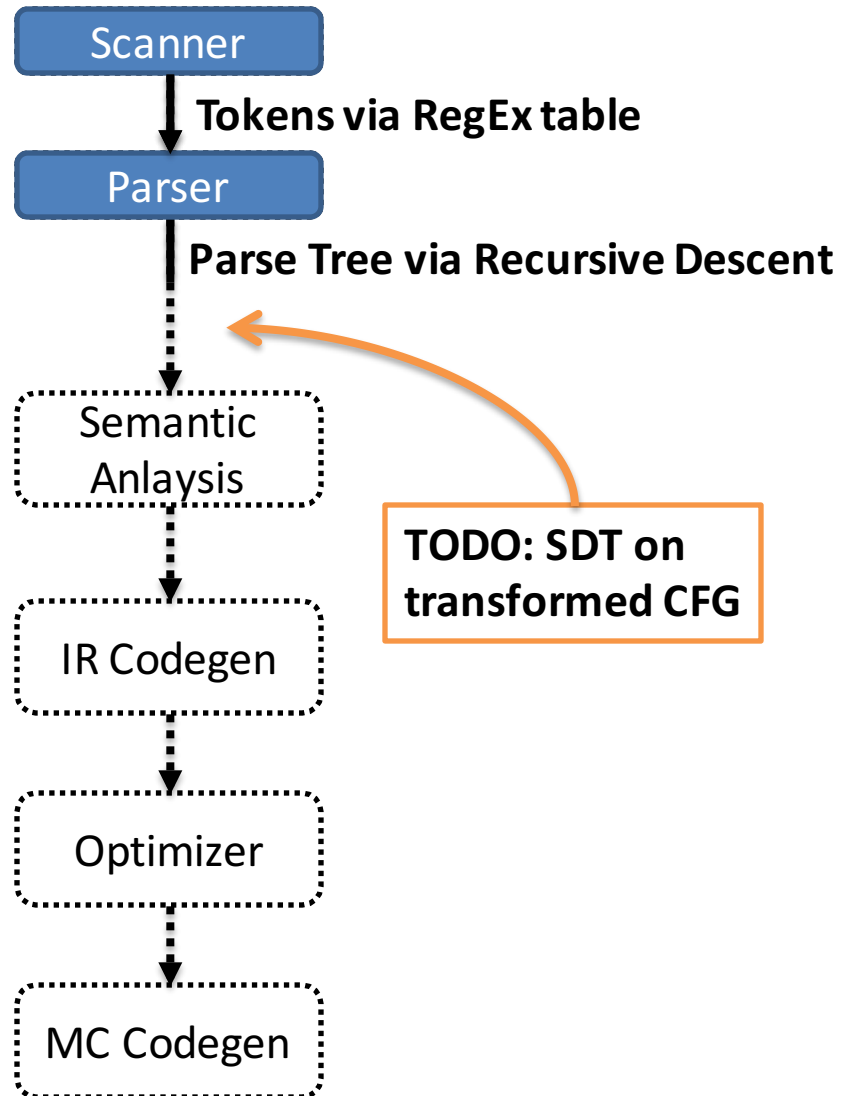
FIRST(+ S) = {**+**}

FIRST( $\epsilon$ ) = { $\epsilon$ }

FOLLOW(S) = {**eof**}

	<b>+</b>	<b>eof</b>
S	<b>+ S</b>	$\epsilon$

# How's that Compiler Looking?





# Implementing SDT for LL(1) Parser

- So far, SDT shown as second (bottom-up) pass over parse tree
- The LL(1) parser never needed to explicitly build the parse tree (implicitly tracked via stack)
- Naïve approach: build the parse tree

# Semantic Stack

- Instead of building the parse tree, give parser second, *semantic* stack
  - Holds nonterminals' translations
- SDT rules converted to SDT actions on semantic stack
  - Pop translations of RHS nonterms off
  - Push computed translation of LHS nonterm on

<u>CFG</u>	<u>SDT Rules</u>	<u>SDT Actions</u>
$Expr \rightarrow \epsilon$	$Expr.trans = 0$	push 0
$  ( Expr )$	$Expr.trans = Expr_2.trans + 1$	$Expr_2.trans = pop$ ; push $Expr_2.trans + 1$
$  [ Expr ]$	$Expr.trans = Expr_2.trans$	$Expr_2.trans = pop$ ; push $Expr_2.trans$

# Action Numbers

- Need to define *when* to fire the SDT Action
  - Not immediately obvious since SDT is bottom-up
- Solution
  - Number our actions and put them on the symbol stack!
  - Add action number symbols at end of the productions

## CFG

$Expr \rightarrow \epsilon$  #1  
| ( Expr ) #2  
| [ Expr ] #3

## SDT Actions

#1 push 0  
#2  $Expr_2.trans = pop$ ; push  $Expr_2.trans + 1$   
#3  $Expr_2.trans = pop$ ; push  $Expr_2.trans$

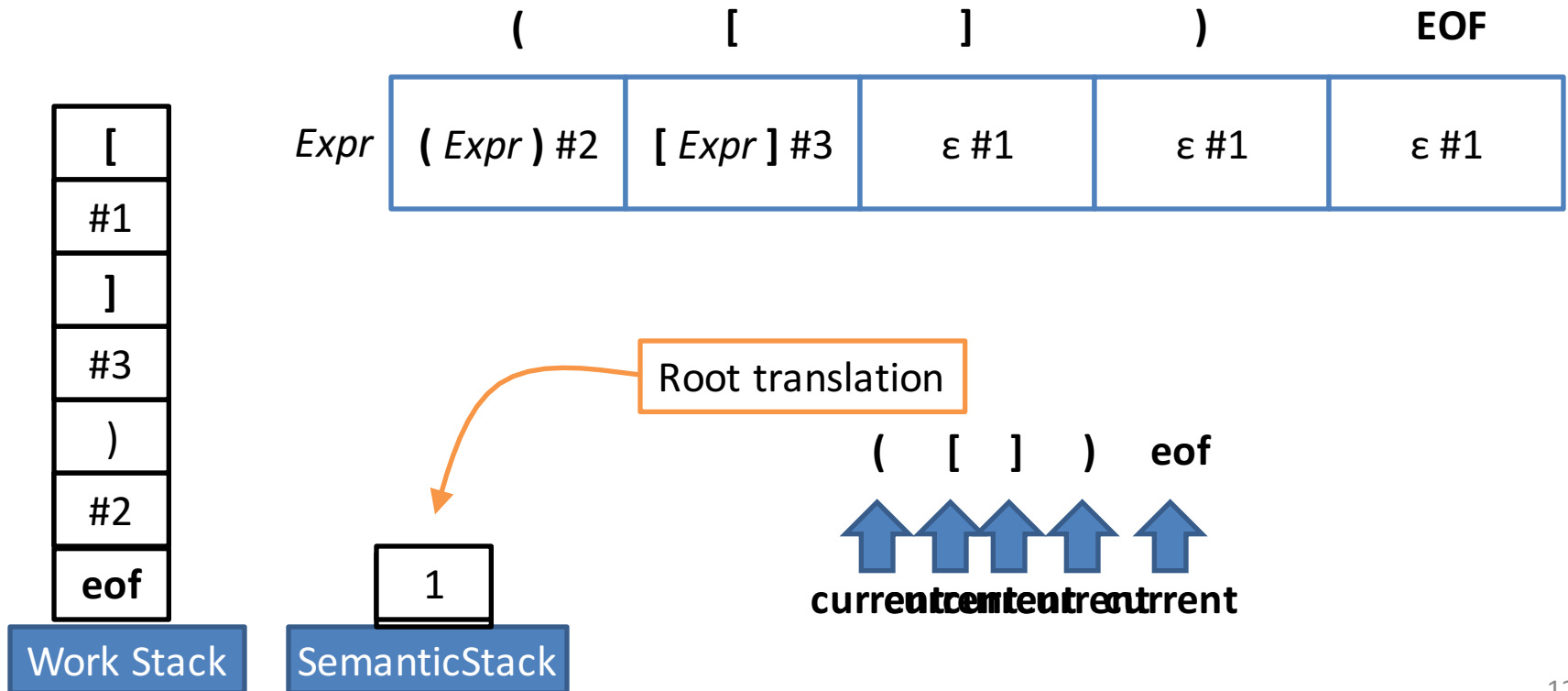
# Action Numbers: Example 1

## CFG

$Expr \rightarrow \epsilon \text{ \#1}$   
 $| ( Expr ) \text{ \#2}$   
 $| [ Expr ] \text{ \#3}$

## SDT Actions: Counting Max Parens Depth

$\text{\#1 push } 0$   
 $\text{\#2 } Expr_2.trans = \text{pop}; \text{push}(Expr_2.trans + 1)$   
 $\text{\#3 } Expr_2.trans = \text{pop}; \text{push}(Expr_2.trans)$



# No-op SDT Actions

## CFG

$Expr \rightarrow \varepsilon$  #1  
|  $( Expr )$  #2  
|  $[ Expr ]$  #3

## SDT Actions: Counting Max Parens Depth

#1 push 0  
#2  $Expr_2.trans = pop; push(Expr_2.trans + 1)$   
#3  $Expr_2.trans = pop; push(Expr_2.trans)$

Useless rule



## CFG

$Expr \rightarrow \varepsilon$  #1  
|  $( Expr )$  #2  
|  $[ Expr ]$

## SDT Actions: Counting Max Parens Depth

#1 push 0  
#2  $Expr_2.trans = pop; push(Expr_2.trans + 1)$

# Placing Action Numbers

- Action numbers go after their corresponding nonterminal, before their corresponding terminal
- Translations popped right to left in action

## CFG

$Expr \rightarrow Expr + Term \#1$   
          |  $Term$   
 $Term \rightarrow Term * Factor \#2$   
          |  $Factor$   
 $Factor \rightarrow \#3 \text{ intlit}$

## SDT Actions

#1  $tTrans = pop ; eTrans = pop ; push(tTrans + eTrans)$   
#2  $tTrans = pop ; eTrans = pop ; push(tTrans * eTrans)$   
#3  $push(\text{intlit.value})$

# Placing Action Numbers: Example

Write SDT Actions and place action numbers to get the **product** of a *ValList* (i.e. multiply all elements)

## CFG

*List*  $\rightarrow$  *Val List'* #1

*List'*  $\rightarrow$  *Val List'* #2

|  $\epsilon$  #3

*Val*  $\rightarrow$  #4 **intlit**

## SDT Actions

#1 LTrans = pop ; vTrans = pop ; push(LTrans \* vTrans)

#2 LTrans = pop; vTrans = pop ; push(LTrans \* vTrans)

#3 push(1)

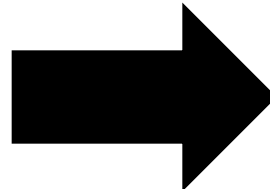
#4 push(**intlit**.value)

# Action Numbers: Benefits

- Plans SDT actions using the work stack
- Robust to previously introduced grammar transformations

## CFG

$Expr \rightarrow Expr + Term \#1$   
|  $Term$   
 $Term \rightarrow Term * Factor \#2$   
|  $Factor$   
 $Factor \rightarrow \#3 \text{ intlit}$



$Expr \rightarrow Term Expr'$   
|  $+ Term \#1 Expr'$   
|  $\epsilon$   
 $Term \rightarrow Factor Term'$   
|  $* Factor \#2 Term$   
|  $\epsilon$   
 $Factor \rightarrow \#3 \text{ intlit}$

## SDT Actions

#1  $tTrans = pop ; eTrans = pop ; push(tTrans + eTrans)$   
#2  $tTrans = pop ; eTrans = pop ; push(tTrans * eTrans)$   
#3  $push(\text{intlit.value})$



# Example: SDT on Transformed Grammar

## CFG

$Expr \rightarrow Term\ Expr'$   
          |  $+ Term\ \#1\ Expr'$   
          |  $\epsilon$   
 $Term \rightarrow Factor\ Term'$   
          |  $* Factor\ \#2\ Term$   
          |  $\epsilon$   
 $Factor \rightarrow \#3\ \text{intlit}$

## SDT Actions

#1  $tTrans = pop ; eTrans = pop ; push(tTrans + eTrans)$   
#2  $tTrans = pop ; eTrans = pop ; push(tTrans * eTrans)$   
#3  $push(\text{intlit.value})$

# What about ASTs?

- Push and pop nodes AST nodes on the stack
- Keep field references to nodes that we pop

## CFG

$Expr \rightarrow Expr + Term \#1$   
          |  $Term$   
 $Term \rightarrow \#2 \text{ intlit}$

## Transformed CFG

$Expr \rightarrow Term Expr'$   
 $Expr' \rightarrow + Term \#1 Expr'$   
          |  $\epsilon$   
 $Term \rightarrow \#2 \text{ intlit}$

## “Evaluation” SDT Actions

#1  $tTrans = pop ;$   
     $eTrans = pop ;$   
     $push(eTrans + tTrans)$   
#2  $push(\text{intlit.value})$

## “AST” SDT Actions

#1  $tTrans = pop ;$   
     $eTrans = pop ;$   
     $push(\text{new PlusNode}(tTrans, eTrans))$   
#2  $push(\text{new IntLitNode}(\text{intlit.value}))$

# AST Example

## Transformed CFG

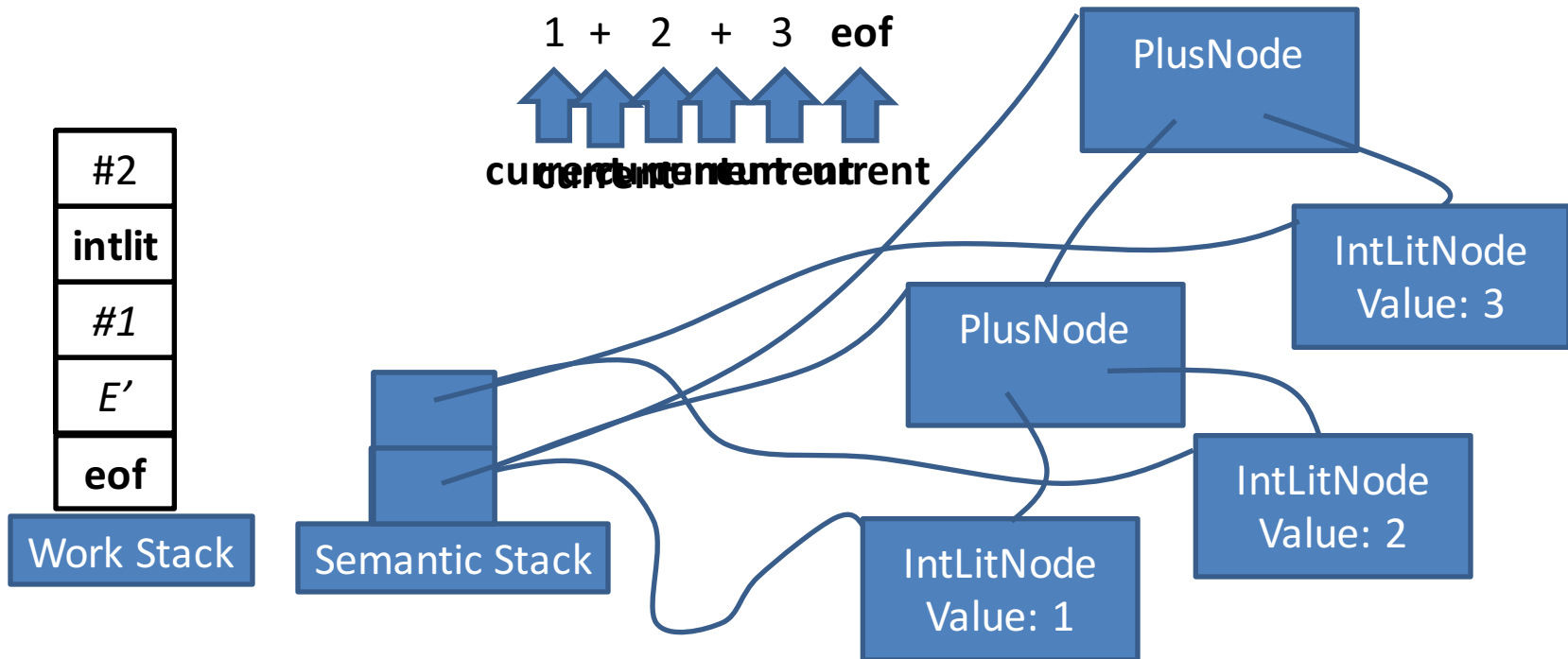
$$\begin{aligned}
 E &\rightarrow T E' \\
 E' &\rightarrow + T \#1 E' \\
 &\quad | \quad \varepsilon \\
 T &\rightarrow \#2 \text{intlit}
 \end{aligned}$$

## "AST" SDT Actions

```

#1 tTrans = pop ;
   eTrans = pop ;
   push(new PlusNode(tTrans, eTrans))
#2 push(new IntLitNode(intlit.value))
    
```

	intlrit	+	EOF
$E$	$T E'$		
$E'$		$+ T$ $\#1 E'$	$\varepsilon$
$T$	<b>#2</b> <b>intlrit</b>		



# We now have an AST

- At this point, we have completed the frontend for (a) compiler
  - Only recognize LL(1)
- LL(1) is not a great class of languages

```
if (e1)
    stmt1
if (e2)
    stmt2
else
    stmt3
```

## Grammar Snippet

```
IfStmt -> if lparens Exp rparens Stmts
        | if lparens Exp rparens Stmts else Stmts
```