Bottom-Up Syntax Analysis

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Compiler Construction
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NYU Courant Institute

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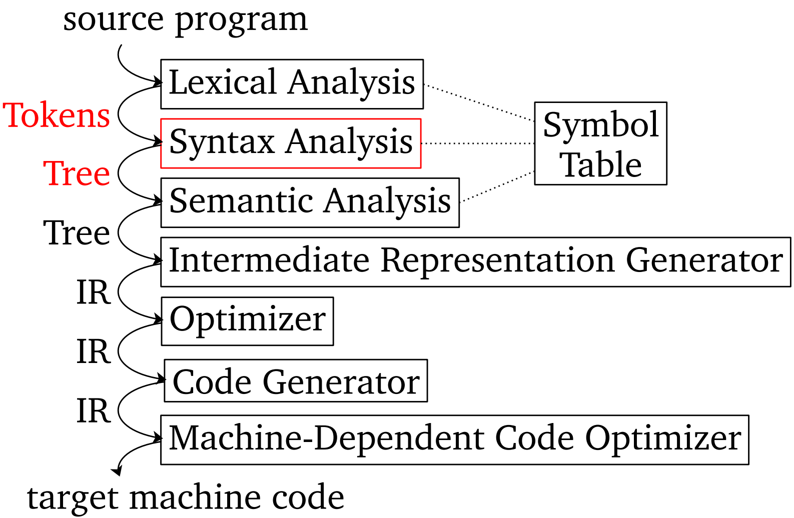
Outline

Second compilation phase



Outline

A Left Recursive Grammar

$$
\begin{aligned}
E &\to E + T \mid T \\
T &\to T * F \mid F \\
F &\to (\; E \;) \mid \mathbf{id}
\end{aligned} \tag{4.1}
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Bottom-Up Construction

Parser Categories

L Left (to right)
R (use) Rightmost derivation
k look-ahead count
LR(0) Easy parsers—include SLR, LALR.
LR(1) More powerful, less practical:

- most general non-backtracking method known
- detects errors early*
- handles grammar superset of predictive parsers
- hard to hand-code
- hard to debug
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$LR(k)$

$LR(k)$ automaton:

- 2 basic moves: shift token, reduce production
- 2 other moves: accept, error

Concepts:

- An $LR(0)$ item is a rule with a dot at some position: $A \to .BCD$, $A \to B.CD$, ...
- An $LR(0)$ state is a set of items.
- Canonical $LR(0)$ collection: FA used to make parsing decisions

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Closure Construction

For Grammar G need—

- Augmented grammar G'
  - Just add rules $S' \to S$
- closure function for set of items I, closure(I):
  1. add I to closure(I).
  2. if $A \to \alpha.B\beta$ in closure(I) then add $B \to .\gamma$ (for each possible γ)
- GOTO function

Example

1. $E' \to E$
2. $E \to E + T$
3. $E \to T$
4. $T \to T * F$
5. $T \to F$
6. $F \to (E)$
7. $F \to \mathbf{id}$

Construction (I)

$$
\begin{aligned}
I &= \{[E' \to .E]\} \\
I_0 &= \mathrm{closure}(I) \\
&= \{[E' \to .E], [E \to .E{+}T], [E \to .T], [T \to .T{*}F], [T \to .F], \\
&\qquad [F \to .\mathbf{(}E\mathbf{)}], [F \to .\mathbf{id}]\}
\end{aligned}
$$

Construction (II)

For items I, $\forall x$ in a set of symbols following dot.

$$\text{GOTO}(I, x) = \text{closure}(\{[A \rightarrow \alpha x.\beta] \mid [A \rightarrow \alpha.s\beta] \in I\})$$

gives

$$I_1 = \text{GOTO}(I_0, E) = \{[E' \rightarrow E.], [E' \rightarrow E. + T]\}$$
$$I_2 = \text{GOTO}(I_0, T) = \{[E \rightarrow T.], [T \rightarrow T. * F]\}$$
$$I_3 = \text{GOTO}(I_0, F) = \{[T \rightarrow F.]\}$$
$$I_4 = \text{GOTO}(I_0, \mathbf{(}) = \{[F \rightarrow \mathbf{(}.E\mathbf{)}], [E \rightarrow .E + T], [E \rightarrow .T], [T \rightarrow .T * F], [T \rightarrow .F], [F \rightarrow .\mathbf{(}E\mathbf{)}], [F \rightarrow .\mathbf{id}]\}$$
$$I_5 = \text{GOTO}(I_0, \mathbf{id}) = \{[F \rightarrow \mathbf{id}.]\}$$

Algorithm

```
initialize C = { closure({[S'→.S]}) }
repeat for all I∈C, for all x,
  if GOTO(I,x) ≠ Ø and GOTO(I,x) ∉ C
    add GOTO(I,x) to C
```

In practice find repeating items, *i.e.*, `GOTO(I4,T) == I2`

- A final item is one with the . at the end.
- If all final items are in states by themselves then the grammar is $LR(0)$,
- otherwise there is a shift-reduce or reduce-reduce conflict in $LR(0)$.

SLR Trick

Use Follow Sets to decide when to reduce: $SLR(1)$.
If they overlap we can look 2 symbols ahead, *etc.*

Outline

Automaton

- 2 basic moves: shift, reduce
- 2 other moves: accept, error

Shift-Reduce

STACK	INPUT	ACTION
$\$$	$\mathbf{id}_1 * \mathbf{id}_2\ \$$	shift
$\$\ \mathbf{id}_1$	$* \mathbf{id}_2\ \$$	reduce by $F \to \mathbf{id}$
$\$\ F$	$* \mathbf{id}_2\ \$$	reduce by $T \to F$
$\$\ T$	$* \mathbf{id}_2\ \$$	shift
$\$\ T *$	$\mathbf{id}_2\ \$$	shift
$\$\ T * \mathbf{id}_2$	$\$$	reduce by $F \to \mathbf{id}$
$\$\ T * F$	$\$$	reduce by $T \to T * F$
$\$\ T$	$\$$	reduce by $E \to T$
$\$\ E$	$\$$	accept

LR components

- Input “pointer.”
- Driver.
- Action/GOTO table.
- Stack.

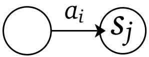
Configuration

Stack $s_0 \ldots s_m$ (both productions and tokens)

Input $a_1 \ldots a_n\$$

Moves. . .

shift j consume symbol a_i, push s_j.



reduce $A \to \beta$ pop $|\beta|$ states from stack
push GOTO$(s_{m-|\beta|}, A)$ on stack.
With $A \to .BCD$:

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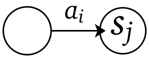

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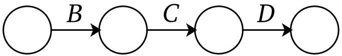

Example

Example.

Remark

Do you see the bottom-up?

Universal LR Driver

```
push S0 onto empty stack
read first input token
repeat:
  let s = state on top of stack
  if action(s,a) = shift t:
    push t onto stack
    a := next symbol
  else if action(s,a) = reduce A→β
    pop |β| states off stack
    let t be new top of stack
    push GOTO(t,A) onto stack
    synthesize attributes for A→β
  else if action(s,a) = accept
    break
  else
    call error recovery
```

Outline

LR(1) Items

- Extend LR(0) items with look-ahead: $[A \to \alpha.\beta, a]$
- Start with $[S' \to .S, \$]$
- Example: $[E' \to .E, \$]$
  closure:
  $[E \to .E{+}T, \$, +], [E \to .T, \$, +], [T \to .T{*}F, \$, +, *], \ldots$

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Algorithm (with Lookahead)

```
closure(I):
  repeat for all [A→α.Bβ,a] ∈ I,
         for all B→γ in G',
         for all b in FIRST(βa)
    add [B→.γ,b] to I
  until no more items can be added

goto(I,x):
  J = ∅
  for all [A→α.xβ,a] ∈ I
    add [A→αx.β,a] to J
  return closure(J)
```

Remarks

- Unlike LR(0)→SLR step no need to deal with ambiguous states of LR(1)
- For LALR(1), systematically *merge* certain LR(1) states ⇒ compact tables
- To build LALR from LR(0) consider *path that led to it* ⇒ efficient table construction

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Summary

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- LR(0) is efficient, LR($k > 0$) is not.
- SLR and LALR improve LR(0) in important ways but remain efficient.
- SLR(k) and LALR(k) are both less than LR(k).
- The main source of conflicts are shift-reduce and reduce-reduce conflicts; resolving in nonstandard ways allows for (some) ambiguous grammars

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