Compiler Design

Parse Table Construction

Amey Karkare
Department of Computer Science and Engineering
IIT Kanpur
karkare@iitk.ac.in

Constructing parse table

Augment the grammar

- G is a grammar with start symbol S
- The augmented grammar G' for G has a new start symbol S' and an additional production S' → S
- When the parser reduces by this rule it will stop with accept

Production to Use for Reduction

- How do we know which production to apply in a given configuration
- We can guess!
  - May require backtracking
- Keep track of “ALL” possible rules that can apply at a given point in the input string
  - But in general, there is no upper bound on the length of the input string
  - Is there a bound on the number of applicable rules?

Some hands on!

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

Strings to Parse

- id + id + id + id
- id * id * id * id
- id * id + id * id
- id * (id + id) * id

Parser states

- Goal is to know the valid reductions at any given point
- Summarize all possible stack prefixes α as a parser state
- Parser state is defined by a DFA state that reads in the stack α
- Accept states of DFA are unique reductions

Viable prefixes

- α is a viable prefix of the grammar if
  - $\exists w$ such that αw is a right sentential form
  - $\langle\alpha,w\rangle$ is a configuration of the parser
- As long as the parser has viable prefixes on the stack no parser error has been seen
- The set of viable prefixes is a regular language
- We can construct an automaton that accepts viable prefixes

LR(0) items

- An LR(0) item of a grammar G is a production of G with a special symbol "." at some position of the right side
- Thus production A→XYZ gives four LR(0) items

  A → .XYZ

  A → X.YZ

  A → XY.Z

  A → XYZ.

LR(0) items

- An item indicates how much of a production has been seen at a point in the process of parsing
  - Symbols on the left of "." are already on the stacks
  - Symbols on the right of "." are expected in the input

Start state

- Start state of DFA is an empty stack corresponding to $S' \rightarrow .S$ item
- This means no input has been seen
- The parser expects to see a string derived from S

Closure of a state

- **Closure** of a state adds items for all productions whose LHS occurs in an item in the state, just after "."
  - Set of possible productions to be reduced next
  - Added items have "." located at the beginning
  - No symbol of these items is on the stack as yet

Example

For the grammar

E' → E

E → E + T | T

T → T * F | F

F → (E) | id

If I is { E' → .E } then closure(I) is

E' → .E

E → .E + T

E → .T

T → .T * F

T → .F

F → .id

F → .(E)

Closure operation

- Let I be a set of items for a grammar G
- closure(I) is a set constructed as follows:
  - Every item in I is in closure (I)
  - If $A \rightarrow \alpha.B\beta$ is in closure(I) and $B \rightarrow \gamma$ is a production then $B \rightarrow .\gamma$ is in closure(I)
- Intuitively $A \rightarrow \alpha.B\beta$ indicates that we expect a string derivable from $B\beta$ in input
- If $B \rightarrow \gamma$ is a production then we might see a string derivable from γ at this point

Goto operation

- Goto(I,X) , where I is a set of items and X is a grammar symbol,
  - is closure of set of item $A \rightarrow \alpha X.\beta$
  - such that $A \rightarrow \alpha.X\beta$ is in I

- Intuitively if I is a set of items for some valid prefix α then goto(I,X) is set of valid items for prefix αX

Goto operation

If I is { E'→E. , E→E. + T } then goto(I,+) is

E → E + .T

T → .T * F

T → .F

F → .(E)

F → .id

Sets of items

C : Collection of sets of LR(0) items for grammar G'

C = { closure ({ S' → .S }) }

repeat

  for each set of items I in C

    for each grammar symbol X

      if goto (I,X) is not empty and not in C

        ADD goto(I,X) to C

until no more additions to C

Example

Grammar:

$E' \rightarrow E$
$E \rightarrow E+T \mid T$
$T \rightarrow T*F \mid F$
$F \rightarrow (E) \mid id$

I_0: closure($E' \rightarrow .E$)

$E' \rightarrow .E$
$E \rightarrow .E + T$
$E \rightarrow .T$
$T \rightarrow .T * F$
$T \rightarrow .F$
$F \rightarrow .(E)$
$F \rightarrow .id$

I_1: goto(I_0,E)

$E' \rightarrow E.$
$E \rightarrow E. + T$

I_2: goto(I_0,T)

$E \rightarrow T.$
$T \rightarrow T. *F$

I_3: goto(I_0,F)

$T \rightarrow F.$

I_4: goto(I_0,( )

$F \rightarrow (.E)$
$E \rightarrow .E + T$
$E \rightarrow .T$
$T \rightarrow .T * F$
$T \rightarrow .F$
$F \rightarrow .(E)$
$F \rightarrow .id$

I_5: goto(I_0,id)

$F \rightarrow id.$

I_6: goto(I_1,+)

$E \rightarrow E + .T$

$T \rightarrow .T * F$

$T \rightarrow .F$

$F \rightarrow .(E)$

$F \rightarrow .id$

I_7: goto(I_2,*)

$T \rightarrow T * .F$

$F \rightarrow .(E)$

$F \rightarrow .id$

I_8: goto(I_4,E)

$F \rightarrow (E.)$

$E \rightarrow E. + T$

goto(I_4,T) is I_2
goto(I_4,F) is I_3
goto(I_4,( ) is I_4
goto(I_4,id) is I_5

I_9: goto(I_6,T)

$E \rightarrow E + T.$

$T \rightarrow T. * F$

goto(I_6,F) is I_3
goto(I_6,( ) is I_4
goto(I_6,id) is I_5

I_{10}: goto(I_7,F)

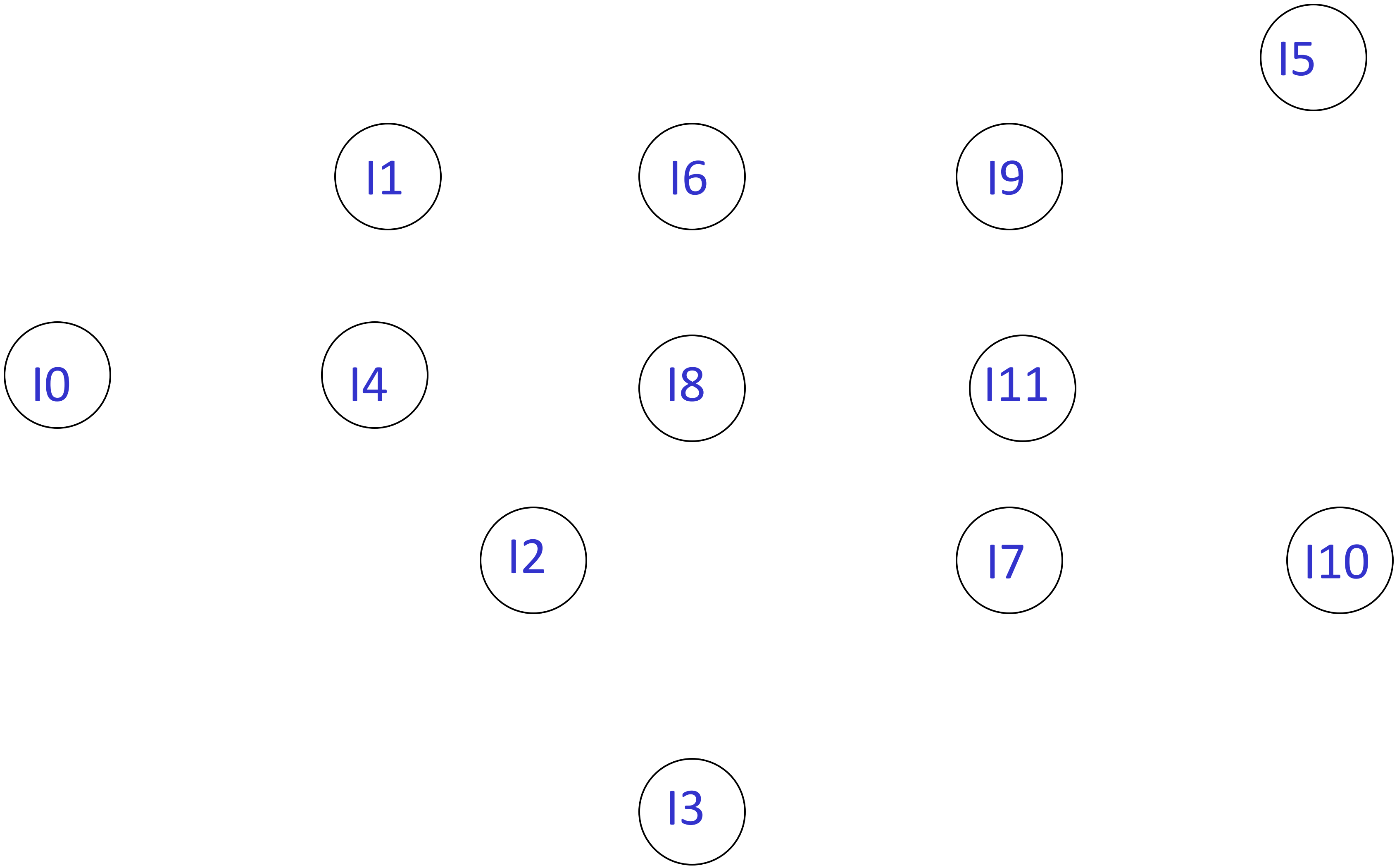
$T \rightarrow T * F.$

goto(I_7,( ) is I_4
goto(I_7,id) is I_5

I_{11}: goto(I_8,))

$F \rightarrow (E).$

goto(I_8,+) is I_6
goto(I_9,*) is I_7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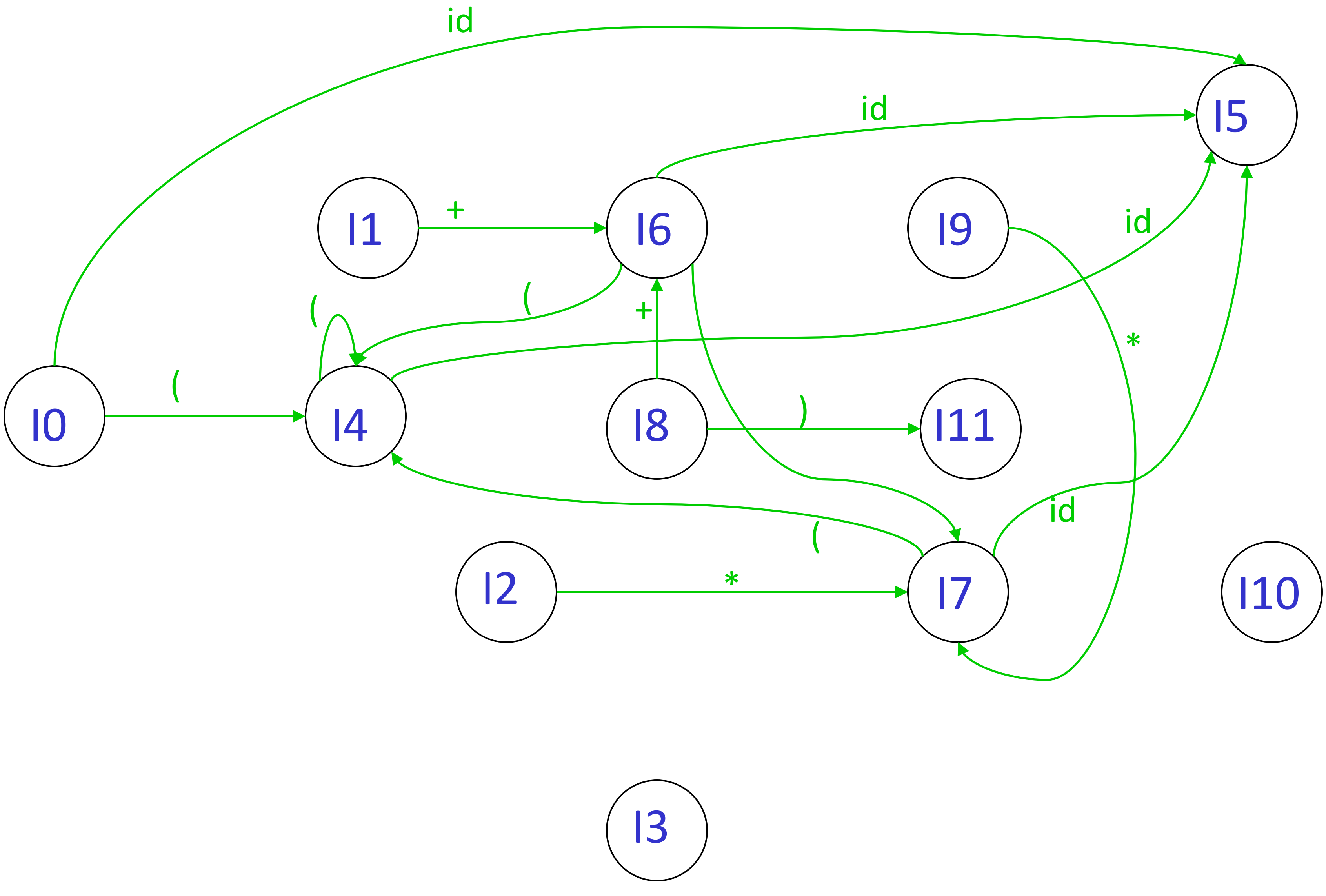
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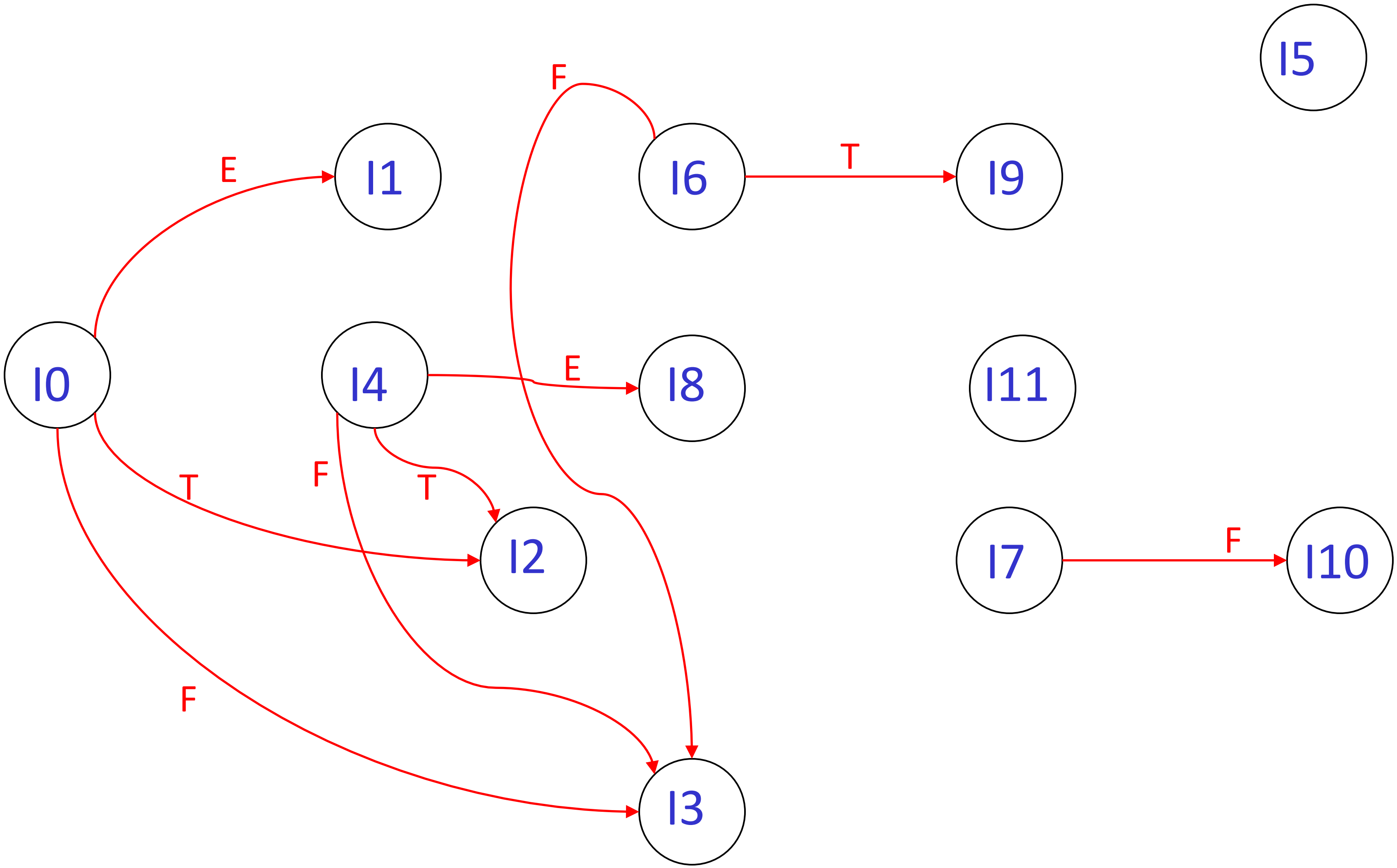
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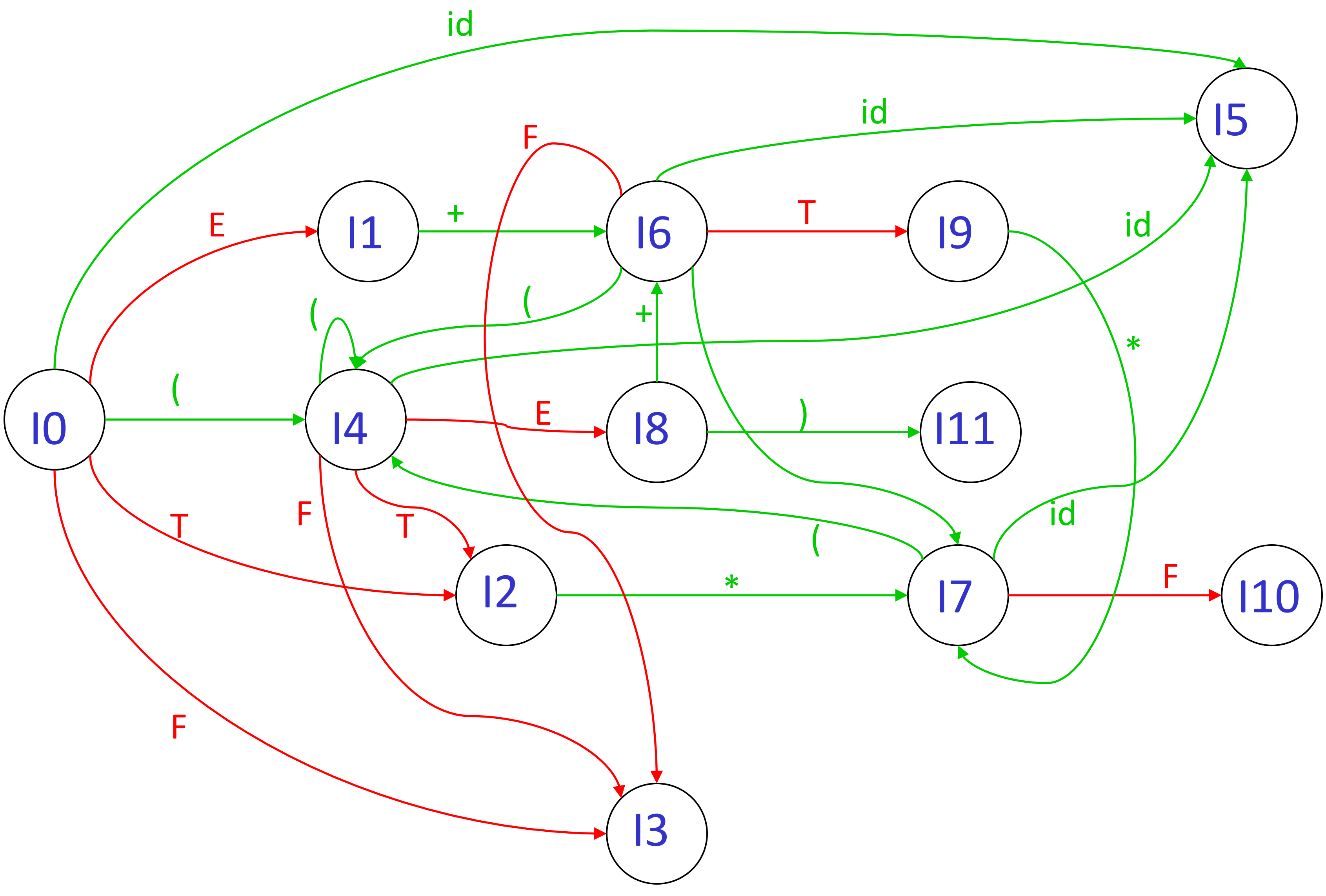
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LR(0) Parse Table (?)

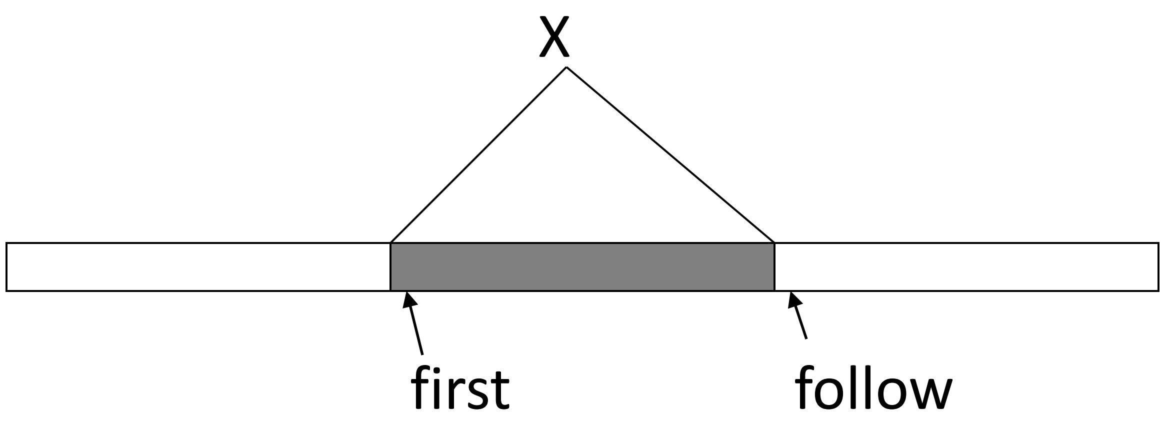
- The information is still not sufficient to help us resolve shift-reduce conflict. For example, the state has potential *conflict*:

$$I_1: E' \rightarrow E.$$
$$E \rightarrow E. + T$$

- We need some more information to take decisions.

Constructing parse table

- First(α) for a string of terminals and non terminals α is
  - Set of symbols that might begin the fully expanded (made of only tokens) version of α
- Follow(X) for a non terminal X is
  - set of symbols that might follow the derivation of X in the input stream



Compute first sets

- If X is a terminal symbol then $first(X) = \{X\}$
- If $X \rightarrow \epsilon$ is a production then ϵ is in $first(X)$
- If X is a non terminal and $X \rightarrow Y_l Y_2 \ldots Y_k$ is a production, then

  if for some i, a is in $first(Y_i)$

  and ϵ is in all of $first(Y_j)$ (such that $j<i$)

  then a is in $first(X)$
- If ϵ is in $first\ (Y_1) \ldots first(Y_k)$ then ϵ is in $first(X)$
- Now generalize to a string α of terminals and non-terminals

Example

- For the expression grammar

  $E \rightarrow T\ E'$ $\quad$ $E' \rightarrow +T\ E' \mid \epsilon$

  $T \rightarrow F\ T'$ $\quad$ $T' \rightarrow *\ F\ T' \mid \epsilon$

  $F \rightarrow (\ E\ ) \mid id$

  First(E) = First(T) = First(F)

  = { (, id }

  First(E')

  = {+, Є}

  First(T')

  = { *, Є}

Compute follow sets

1. Place $ in follow(S) // S is the start symbol
2. If there is a production $A \rightarrow \alpha B \beta$ then everything in first(β) (except ε) is in follow(B)
3. If there is a production $A \rightarrow \alpha B \beta$ and first(β) contains ε then everything in follow(A) is in follow(B)
4. If there is a production $A \rightarrow \alpha B$ then everything in follow(A) is in follow(B)

Last two steps have to be repeated until the follow sets converge.

Example

- For the expression grammar

  E → T E'

  E' → + T E' | ϵ

  T → F T'

  T' → * F T' | ϵ

  F → (E) | id

follow(E) = follow(E') = ?
follow(T) = follow(T') = ?
follow(F) = ?

Construct SLR parse table

- Construct $C=\{I_0, \ldots, I_n\}$ the collection of sets of LR(0) items
- If $A \rightarrow \alpha.a\beta$ is in I_i and $goto(I_i, a) = I_j$
  then action[i,a] = shift j
- If $A \rightarrow \alpha.$ is in I_i
  then action[i,a] = reduce $A \rightarrow \alpha$ for all a in follow(A)
- If $S' \rightarrow S.$ is in I_i then action[i,$] = accept
- If $goto(I_i, A) = I_j$
  then goto[i,A]=j for all non terminals A
- All entries not defined are errors

Practice Assignment

Construct SLR parse table for following grammar

$E \rightarrow E + E \mid E - E \mid E * E \mid E / E \mid (E) \mid digit$

Show steps in parsing of string
9*5+(2+3*7)

- Steps to be followed
  - Augment the grammar
  - Construct set of LR(0) items
  - Construct the parse table
  - Show states of parser as the given string is parsed

Notes

- This method of parsing is called SLR (Simple LR)
- LR parsers accept LR(k) languages
  - L stands for left to right scan of input
  - R stands for rightmost derivation
  - k stands for number of lookahead token
- SLR is the simplest of the LR parsing methods. SLR is too weak to handle most languages!
- If an SLR parse table for a grammar does not have multiple entries in any cell then the grammar is unambiguous
- All SLR grammars are unambiguous
- Are all unambiguous grammars in SLR?

Does Conflict => Ambiguity?

Example

- Consider following grammar and its SLR parse table:

  $S' \rightarrow S$

  $S \rightarrow L = R$

  $S \rightarrow R$

  $L \rightarrow *R$

  $L \rightarrow id$

  $R \rightarrow L$

I_0: $S' \rightarrow .S$

$S \rightarrow .L=R$

$S \rightarrow .R$

$L \rightarrow .*R$

$L \rightarrow .id$

$R \rightarrow .L$

I_1: goto(I_0, S)

$S' \rightarrow S.$

I_2: goto(I_0, L)

$S \rightarrow L.=R$

$R \rightarrow L.$

Assignment (not to be submitted): Construct rest of the items and the parse table.

SLR parse table for the grammar

	=	*	id	$	S	L	R
0		s4	s5		1	2	3
1				acc			
2	s6,r6			r6			
3				r3			
4		s4	s5			8	7
5	r5			r5			
6		s4	s5			8	9
7	r4			r4			
8	r6			r6			
9				r2			

The table has multiple entries in action[2,=]

- There is both a shift and a reduce entry in action[2,=]. Therefore state 2 has a shift-reduce conflict on symbol "=", However, the grammar is not ambiguous.
- Parse id=id assuming reduce action is taken in [2,=]

Stack	**input**	**action**
0	id=id	shift 5
0 id 5	=id	reduce by L→id
0 L 2	=id	reduce by R→L
0 R 3	=id	error

- if shift action is taken in [2,=]

Stack	**input**	**action**
0	id=id$	shift 5
0 id 5	=id$	reduce by L→id
0 L 2	=id$	shift 6
0 L 2 = 6	id$	shift 5
0 L 2 = 6 id 5	$	reduce by L→id
0 L 2 = 6 L 8	$	reduce by R→L
0 L 2 = 6 R 9	$	reduce by S→L=R
0 S 1	$	ACCEPT

Another look at the grammar

S' → S
S → L = R
S → R
L → *R
L → id
R → L

- No sentential form of this grammar can start with R=…
- However, the reduce action in action[2,=] generates a sentential form starting with R=
- Therefore, the reduce action is incorrect

Problems in SLR parsing

- In SLR parsing method state i calls for reduction on symbol "a", by rule $A \rightarrow \alpha$ if I_i contains $[A \rightarrow \alpha.]$ and "a" is in follow(A)
- However, when state I appears on the top of the stack, the viable prefix $\beta\alpha$ on the stack may be such that βA can not be followed by symbol "a" in any right sentential form
- Thus, the reduction by the rule $A \rightarrow \alpha$ on symbol "a" is invalid
- SLR parsers cannot remember the left context