Compilation Principle
编 译 原 理

第12讲：语义分析(2)

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Review Questions (1)

- How does LALR(1) improve LR(1)?

  Merge similar states to reduce space.

- How to merge states?

  Merge states with same core: all items are identical except lookahead

- What are the side effects of state merging?

  Introduce conflicts, delay error detection

- Why reduce-reduce conflict can happen in merging?

  Merging is the reverse of splitting, thus hurting LR(1) capability

- What are the advantages of LALR(1)?

  Higher parsing power than SLR(1), smaller parse table than LR(1)

Review Questions (2)

- What are LL and LR?

  LL=top-down (leftmost derivation)
  LR=bottom-up (reverse of rightmost derivation)

- At high level, why LR is easier or more powerful than LL?

  LR acts after seeing the entire RHS + lookahead, LR only guess with first few lookahead terminals of RHS

- Why context analysis is not performed in parsing stage?

  Parsing relies on CFG, which is context free.

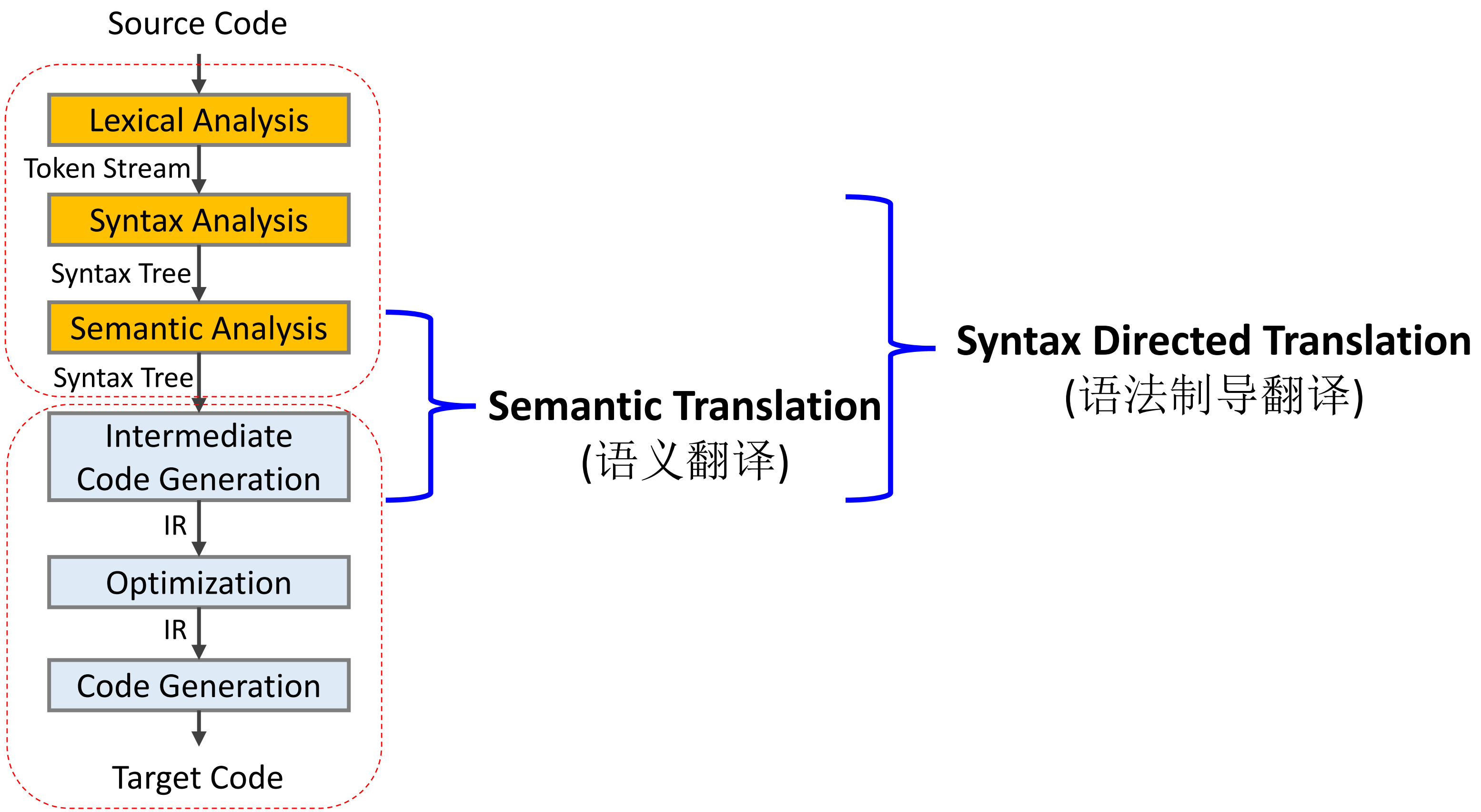
- Give some examples of semantic analysis.

  Def-before-use, no redefinition, same type, scoping …

LALR的一些解释

- LALR(1)是LR(1)和SLR(1)的平衡
  - 文法范围：LR > LALR > SLR
  - 状态数目：LR > LALR = SLR
- 假如一个文法G是LR而非SLR
  - 依靠Follow集进行归约不够精确 --> SLR产生了冲突
    - 而LR通过精确的lookahead解决了冲突
  - LALR对LR进行相似状态合并
    - 若合并后出现了冲突 --> 不是LALR文法
    - 若合并后没有冲突 --> 是LALR文法
      - LALR可以解析文法G，也即解决了SLR原有的冲突
      - 实际上LALR的状态数是SLR相同，但归约动作减少了（也即，对SLR解析表而言，多个移进/归约动作的单元格中的归约被消除了）
    - 如果没有相似状态，则LALR=LR
- 假如一个文法G是SLR
  - 那么G一定也是LR和LALR文法
  - LR的Follow集细分是不必要的，因此LALR合并回了SLR

Syntax Directed Translation[语法制导翻译]



Syntax Directed Translation[语法制导翻译]

- To translate based on the program's syntactic structure[语法结构]
  - Syntactic structure: structure of a program given by grammar
  - The parsing process and parse trees are used to direct semantic analysis and the translation of the program
    - i.e., **CFG-driven translation** [CFG驱动的翻译]
- How? Augment the grammar used in parser:
  - Attach **semantic attributes**[语义属性] to each grammar symbol
    - The attributes describe the symbol properties
    - An attribute has a name and an associated value: a string, a number, a type, a memory location, an assigned register …
  - For each grammar production, give **semantic rules or actions**[语义规则或动作]
    - The actions describe how to compute the attribute values associated with each symbol in a production

Attributes[语义属性]

- Attributes can represent anything depending on the task[属性可以表示任意含义]
  - If computing expression: *a number (value of expression)*
  - If building AST: *a pointer (pointer to AST for expression)*
  - If generating code: *a string (assembly code for expression)*
  - If type checking: *a type (type for expression)*
- Format: *X.a* (*X* is a symbol, *a* is one of its attributes)
- For Project 2 – Syntax Analysis
  - Semantic attributes
    - *intg*: string table index of integer constant value
    - *tptr*: “tree pointer” of a non-terminal symbol
  - Semantic actions
    - { … $$=makeTree(ProgramOp, leftChild, rightChild); …}

How to Specify Syntax Directed Translation

- **Syntax Directed Definitions** (SDD)[语法制导定义]
  - Attributes + semantic rules[语义规则]for computing them
    - Attributes for grammar symbols[文法符号和语义属性关联]
    - Semantic rules for productions[产生式和语义规则关联]
  - Example rules for computing the value of an expression

    $E \rightarrow E_1 + E_2$ RULE: {$E.val = E_1.val + E_2.val$}

    $E \rightarrow id$ RULE: {$E.val = id.lexval$}

- **Syntax Directed Translation scheme** (SDT)[语法制导翻译方案]
  - Attributes + semantic actions[语义动作] for computing them
  - Example actions for computing the value of an expression

    $E \rightarrow E_1 + E_2$ {$E.val = E_1.val + E_2.val$}

    $E \rightarrow id$ {$E.val = id.lexval$}

SDD vs. SDT

- SDD[语法制导定义]: 是CFG的推广，翻译的高层次规则说明
  - A CFG grammar together with attributes and semantic rules
    - A subset of them are also called **attribute grammars**[属性文法]
  - Semantic rules imply no order to attribute evaluation
- SDT[语法制导翻译方案]: SDD的补充，具体翻译实施方案
  - An executable specification of the SDD
    - Fragments of programs are attached to different points in the production rules
  - The order of execution is important

Grammar	SDD	SDT
D -> T L	L.*inh* = T.*type*	D -> T { L.*inh* = T.*type* } L
T -> int	T.*type* = int	T -> int { T.*type* = int }
T -> float	T.*type* = float	T -> real { T.*type* = float }
L -> L_1, id	L_1.*inh* = L.*inh*	L -> { L_1.*inh* = L.*inh* }L_1, id

SDD vs. SDT (cont.)

- Syntax: A -> α {*action*$_1$} β {*action*$_2$} γ ...
- Actions are executed "at that point" in the RHS
  - *action1* executes after α have been produced but before β
  - action2 executes after α, *action1*, β but before γ

- Semantic rule vs. action[语义规则 vs. 语义动作]
  - Semantic rules are not associated with locations in RHS
    - SDD doesn't impose any order other than dependences
  - Location of action in RHS specifies when it should occur
    - SDT specifies the execution order and time of each action

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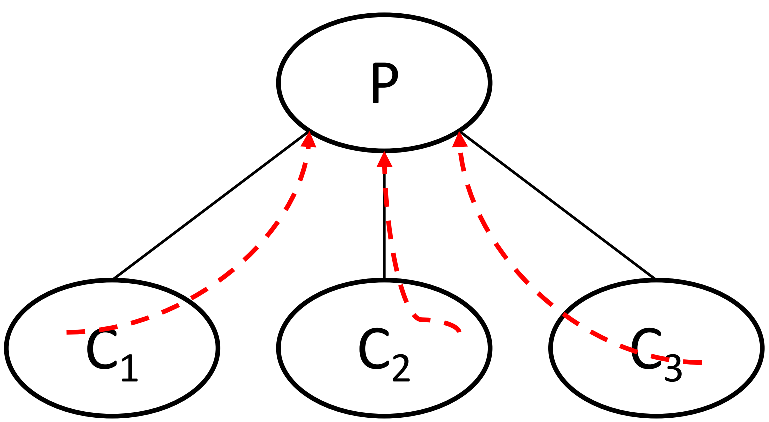
SDD[语法制导定义]

- SDD has two types of attributes[两种属性]
  - For a non-terminal *A* at a parse-tree node *N*

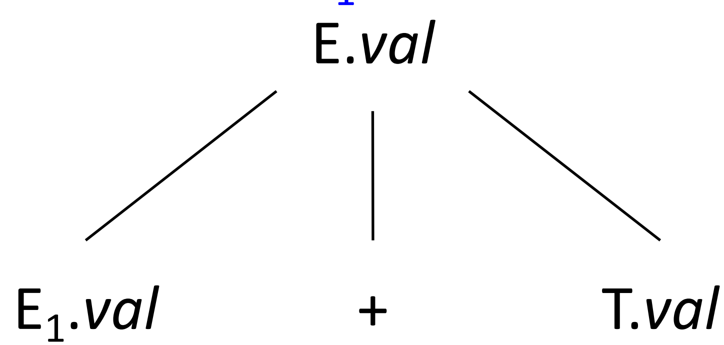
- **Synthesized attribute**[综合属性]
  - Defined by a semantic rule associated with the <u>production at *N*</u>
    - The production must have *A* as its head (i.e., A -> …)
  - A synthesized attribute of node *N* is defined only by attribute values at *N*'s children and *N* itself[子节点或自身]
- **Inherited attribute**[继承属性]
  - Defined by a semantic rule associated with the <u>production at the parent of *N*</u>
    - The production must have *A* as a symbol in its body (i.e., … -> …A…)
  - An inherited attributed at node *N* is defined only by attribute values at *N*'s parent, *N* itself, and *N*'s siblings [父节点、自身或兄弟节点]

Synthesized Attribute[综合属性]

- Synthesized attribute for <u>non-terminal</u> *A* of parse-tree node *N* [非终结符的综合属性]
  - Only defined by *N*'s children and *N* itself
    - Passed up the tree
  - P.syn_attr = f(P.attrs, C_1.attrs, C_2.attrs, C_3.attrs)
- <u>Terminals</u> can have synthesized attributes[终结符综合属性]
  - Lexical values supplied by the lexical analysis
  - Thus, no semantic rules in SDD for terminals

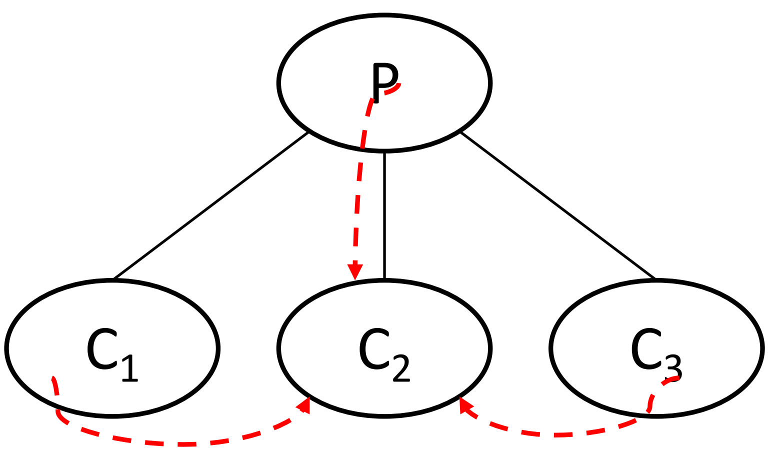


E.*val* = E_1.*val* + T.*val*

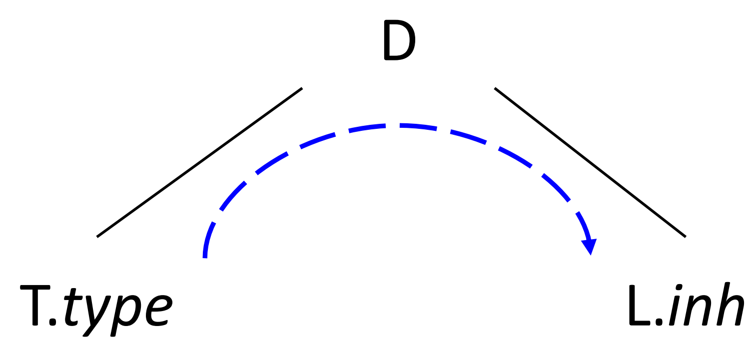


Inherited Attribute[继承属性]

- Inherited attribute for non-terminal *A* of parse-tree node *N*[非终结符继承属性]
  - Only defined by *N*'s parent, *N*'s siblings and *N* itself
    - Passed down a parse tree
  - C_2.inh_attr = f(P.attrs, C_1.attrs, C_2.attrs, C_3.attrs)
- Terminals cannot have inherited attributes[终结符无继承属性]
  - Only synthesized attributes from lexical analysis



D -> T L (L.*inh* = T.*type*)



SDD[语法制导定义]

- Attribute dependencies in a production rule[产生式中的属性依赖]

Inherited

A -> α β γ

Synthesized

- SDD has rule of the form for each grammar production

  b = f(A.attrs, α.attrs, β.attrs, γ.attrs)

- *b* is either an attribute in LHS (an attribute of A)
  - In which case *b* is a **synthesized** attribute
  - Why? From A's perspective α, β, γ are children
- Or, *b* is an attribute in RHS (e.g., of β)
  - In which case b is an **inherited** attribute
  - Why? From β's perspective A, α, γ are parent or siblings

Example: Synthesized Attribute[综合]

SDD:

Production Rules	**Semantic Rules**
(1) L -> E	print(E.*val*)
(2) E -> E_1 + T	E.*val* = E_1.*val* + T.*val*
(3) E -> T	E.*val* = T.*val*
(4) T -> T_1 * F	T.*val* = T_1.*val* x F.*val*
(5) T -> F	T.*val* = F.*val*
(6) F -> (E)	F.*val* = E.*val*
(7) F -> digit	F.*val* = digit.*lexval*

Each non-terminal has a single synthesized attribute val

Terminal *digit* has a synthesized attribute lexval

Arithmetic expressions with + and *

(1) Print the numerical value of the entire expression
(2) Compute value of summation
(3) Value copy
(4) Compute value of multiplication
(5) Value copy
(6) Value Copy

Example: Synthesized Attribute[综合]

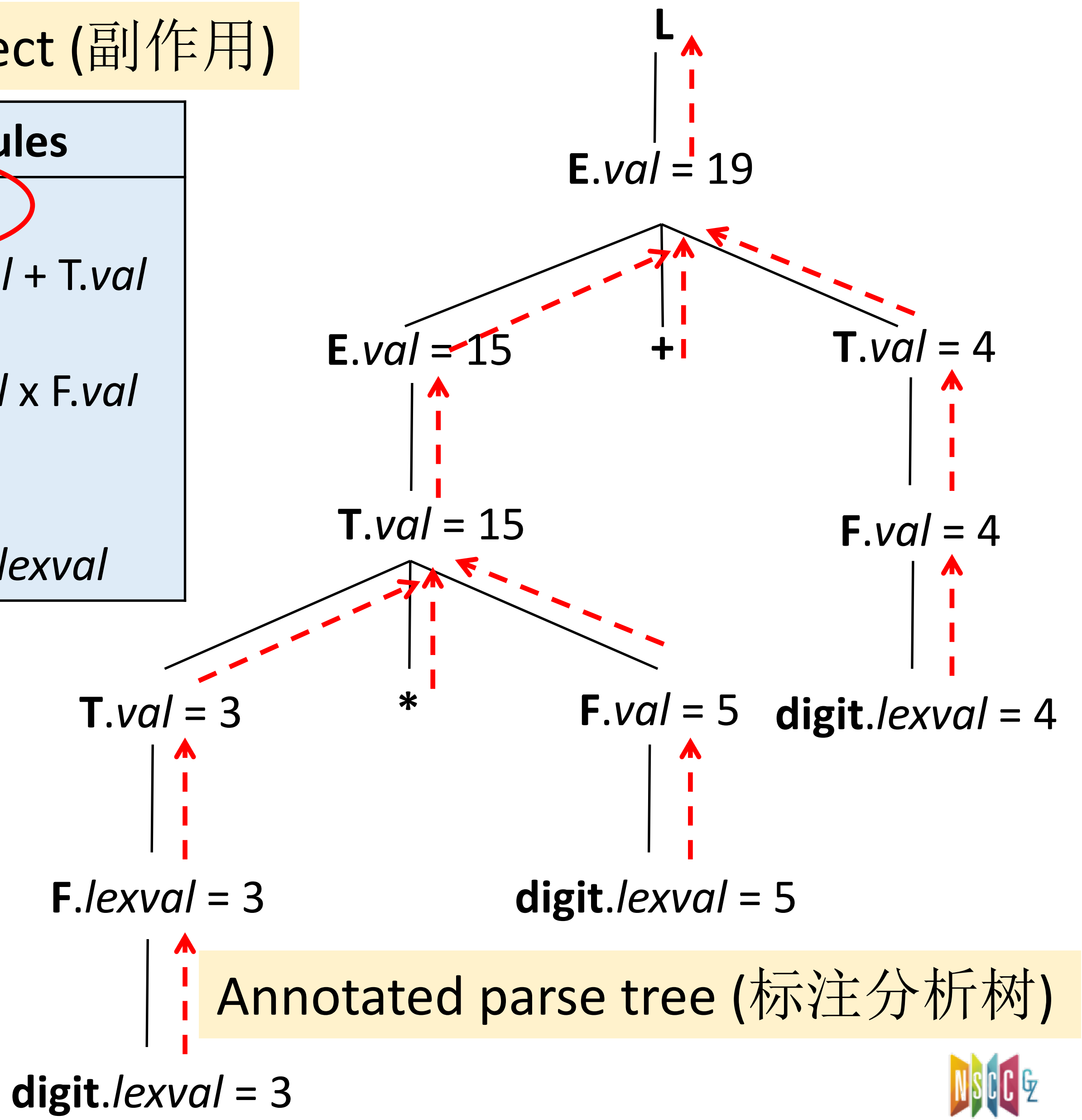
SDD:

Side effect (副作用)

Production Rules	Semantic Rules
(1) L -> E	print(E.*val*)
(2) E -> E_1 + T	E.*val* = E_1.*val* + T.*val*
(3) E -> T	E.*val* = T.*val*
(4) T -> T_1 * F	T.*val* = T_1.*val* x F.*val*
(5) T -> F	T.*val* = F.*val*
(6) F -> (E)	F.*val* = E.*val*
(7) F -> digit	F.*val* = digit.*lexval*

Input:

3 * 5 + 4



Annotated parse tree (标注分析树)

Example: Inherited Attribute[继承]

SDD:

Production Rules	**Semantic Rules**
(1) D -> T L	L.*inh* = T.*type*
(2) T -> int	T.*type* = int
(3) T -> float	T.*type* = float
(4) L -> L_1, id	L_1.*inh* = L.*inh* addtype(id.*entry*, L.*inh*)
(5) L -> id	addtype(id.*entry*, L.*inh*)

T has synthesized attribute *type*

L has inherited attribute *inh*

Pointing to a symbol-table object

Variable declaration of type int/float followed by a list of IDs:

(1) Declaration: a type *T* followed by a list of *L* identifiers

(2) Evaluate the synthesized attribute *T.type* (int)

(3) Evaluate the synthesized attribute *T.type* (float)

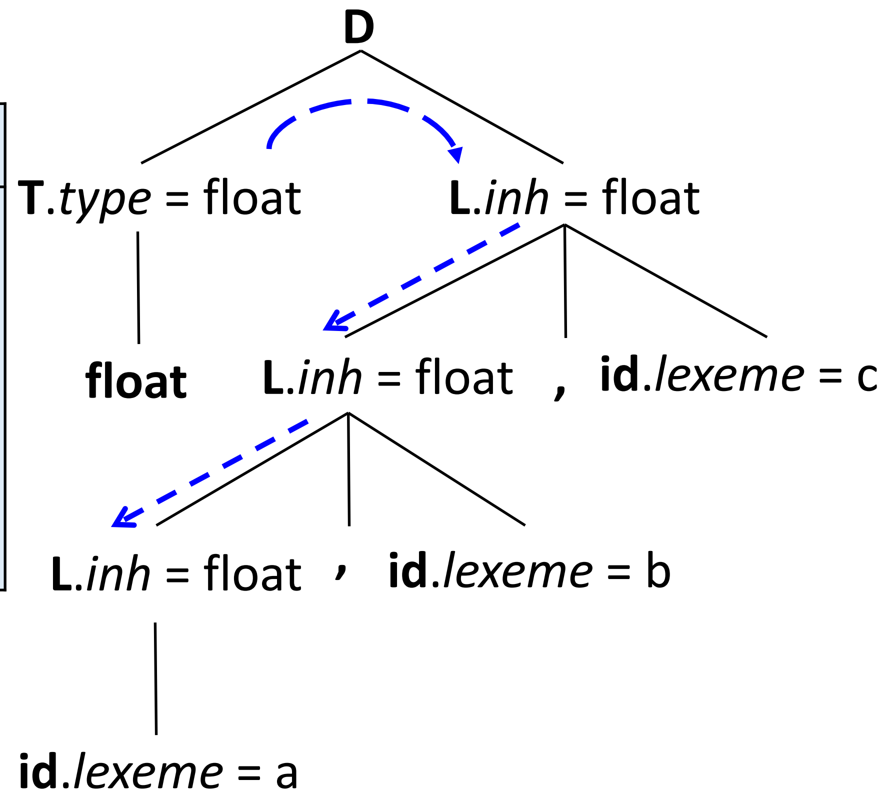
(4) Pass down type, and add type to symbol table entry for the identifier

(5) Add type to symbol table

Example: Inherited Attribute[继承]

SDD:

Production Rules	Semantic Rules
(1) D -> T L	L.*inh* = T.*type*
(2) T -> int	T.*type* = int
(3) T -> float	T.*type* = float
(4) L -> L_1, id	L_1.*inh* = L.*inh* addtype(id.*entry*, L.*inh*)
(5) L -> id	addtype(id.*entry*, L.*inh*)



Input:

float a, b, c

type depends on child
inh depends on sibling or parent

The Concepts

- **Side effect**[副作用]
  - 一般属性值计算（基于属性值或常量进行的）之外的功能
  - 例如：code generation, print results, modify symbol table ...
- **Attribute grammar**[属性文法]
  - 一个没有副作用的SDD
  - The rules define the value of an attribute purely in terms of the value of other attributes and constants[属性文法的规则仅仅通过其他属性值和常量来定义一个属性值]
- **Annotated parse-tree**[标注分析树]
  - 每个节点都带有属性值的分析树
    - A parse tree showing the value(s) of its attribute(s)
  - a.k.a., attribute parse tree[属性分析树]

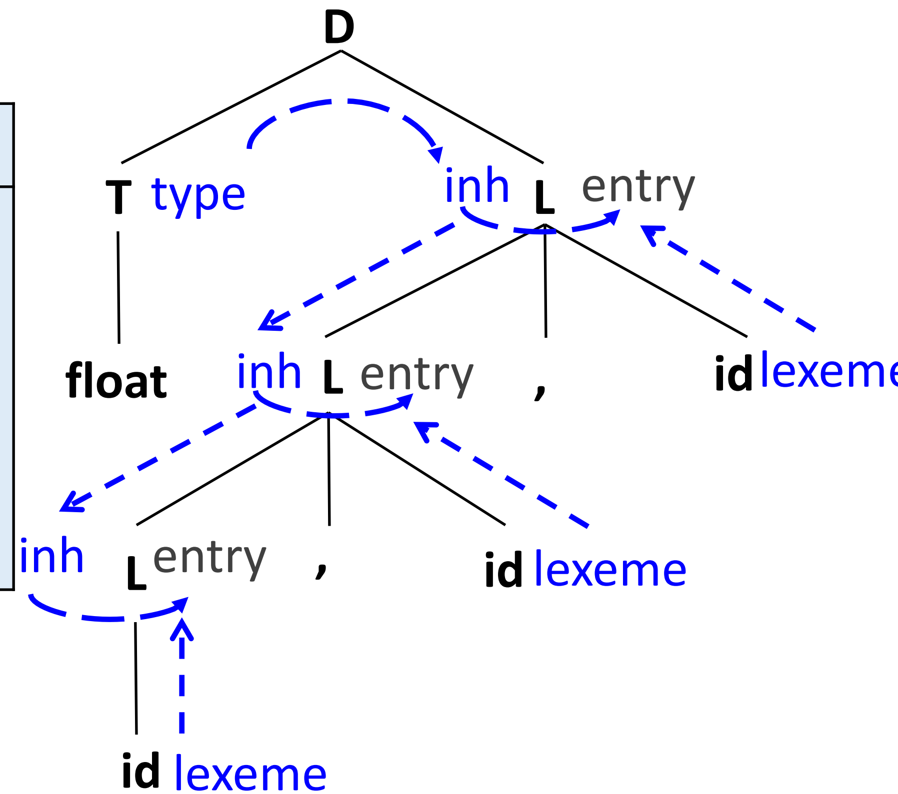
Dependence Graph[依赖图]

- Dependence relationship[依赖关系]
  - Before evaluating an attribute at a node of a parse tree, we must evaluate all attributes it depends on
- **Dependency graph**[依赖图]
  - While the annotated parse tree shows the values of attributes, a dependency graph helps determine how those values can be computed[依赖图决定属性值的计算]
  - Depicts the flow of info among the attribute instances in a particular parse tree[描绘了分析树的属性信息流]
    - **Directed graph** where edges are dependence relationships between attributes
    - For each parse-tree node *X*, there's a graph node for each attr of *X*
    - If attr *X.a* depends on attr *Y.b*, then there's one directed edge from *X.a* to *Y.b*

Example: Dependency Graph

SDD:

Production Rules	Semantic Rules
(1) D -> T L	L.*inh* = T.*type*
(2) T -> int	T.*type* = int
(3) T -> float	T.*type* = float
(4) L -> L_1, id	L_1.*inh* = L.*inh* addtype(id.*entry*, L.*inh*)
(5) L -> id	addtype(id.*entry*, L.*inh*)



Input:

float a, b, c

‘entry’ is dummy attribute for the *addtype()*

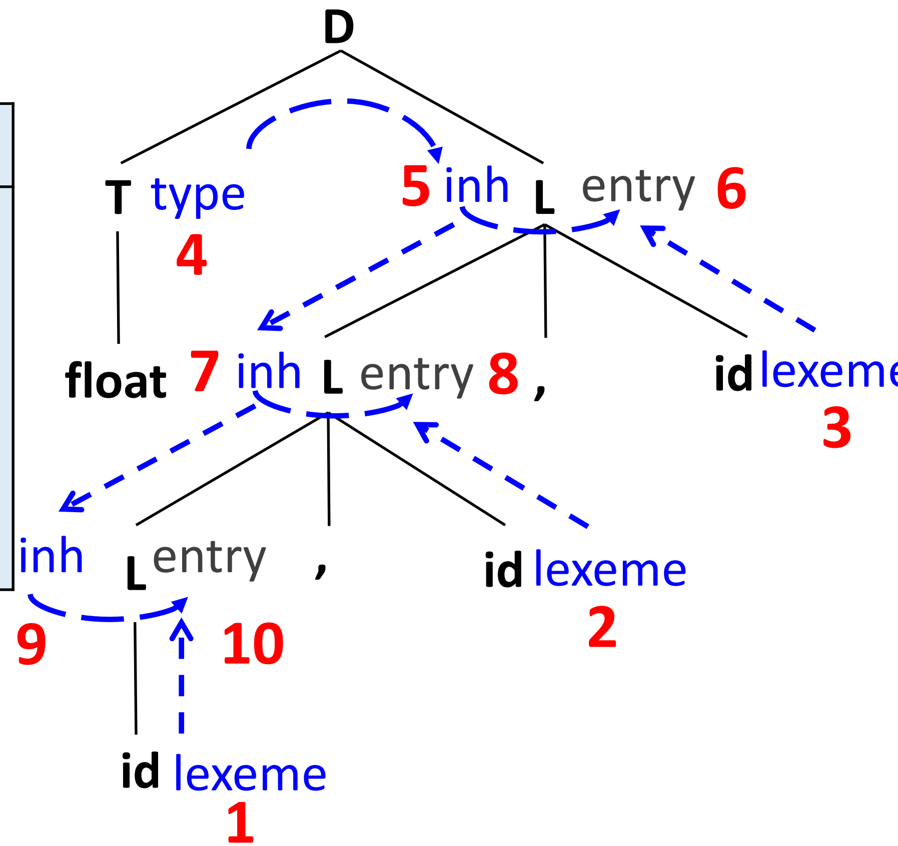
Evaluation Order[属性值计算顺序]

- Ordering the evaluation of attributes[计算顺序]
  - Dependency graph characterizes possible orders in which we can evaluate the attributes at the various nodes of a parse-tree
- If the graph has an edge from node *M* to node *N*, then the attribute associated with *M* must be evaluated before *N*[用图的边来确定计算顺序]
  - Thus, the only allowable orders of evaluation are those sequences of nodes N_1, N_2, …, N_k such that if there is an edge of the graph from N_i to N_j, then i < j
  - Such an ordering embeds a directed graph into a linear order, and is called a **topological sort**[拓扑排序] of the graph
    - If there's any cycle in the graph, then there are no topological sorts, i.e., no way to evaluate the SDD on this parse tree
    - If there are no cycles, then there is always at least one topological sort

Example: Evaluation Order

SDD:

Production Rules	Semantic Rules
(1) D -> T L	L.*inh* = T.*type*
(2) T -> int	T.*type* = int
(3) T -> float	T.*type* = float
(4) L -> L_1, id	L_1.*inh* = L.*inh* addtype(id.*lexeme*, L.*inh*)
(5) L -> id	addtype(id.*lexeme*, L.*inh*)



Input:

float a, b, c

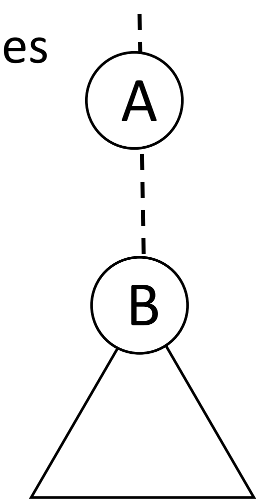
Topological sort:

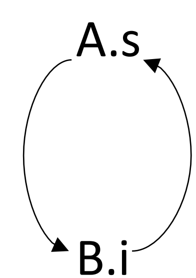
1, 2, 3, 4, 5, 6, 7, 8, 9, 10

Evaluation Order (cont.)

- Before evaluating an attribute at a node of a parse tree, we must evaluate all attributes it depends on [依赖关系]
  - Synthesized: evaluate children first, then the node itself
    - Any bottom-up order is fine
  - For SDD's with both inherited and synthesized attributes, there's no guarantee that there is even one evaluation order
- Difficult to determine whether exist any circularities[非常难确定是否有循环依赖]
  - But, there are useful subclasses of SDD's that are sufficient to guarantee that an evaluation order exists
    - Such classes do not permit graphs with cycles

Production	Semantic Rules
A -> B	A.*s* = B.*i*;
	B.*i* = A.*s* + 1;





S-Attributed Definitions[S-属性定义]

- An SDD is S-attributed if every attribute is synthesized[只具有综合属性]
- If an SDD is S-attributed (S-SDD)
  - We can evaluate its attributes in any bottom-up order of the nodes of the parse-tree[任何自底向上的顺序计算属性值]
  - Can be implemented during bottom-up parsing

Production Rules	**Semantic Rules**
(1) L -> E	print(E.*val*)
(2) E -> E_1 + T	E.*val* = E_1.*val* + T.*val*
(3) E -> T	E.*val* = T.*val*
(4) T -> T_1 * F	T.*val* = T_1.*val* x F.*val*
(5) T -> F	T.*val* = F.*val*
(6) F -> (E)	F.*val* = E.*val*
(7) F -> digit	F.*val* = digit.*lexval*