Topic 4: Abstract Syntax Semantic Analysis

COS 320

Compiling Techniques

Princeton University
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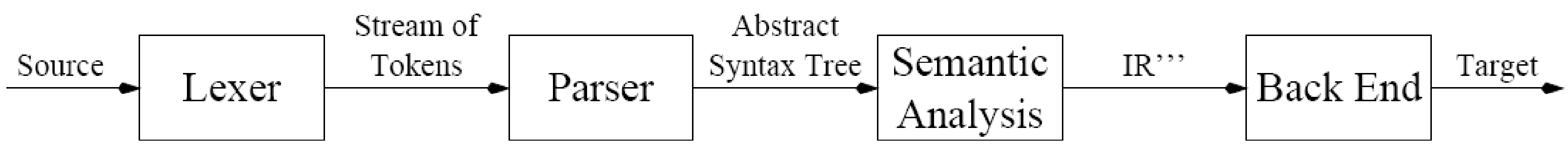
Abstract Syntax

Can write entire compiler in ML-YACC specification.

- Semantic actions would perform type checking and translation to assembly.
- Disadvantages:

1. File becomes too large, difficult to manage.
2. Program must be processed in order in which it is parsed. Impossible to do global/inter-procedural optimization.

Alternative: Separate parsing from remaining compiler phases.



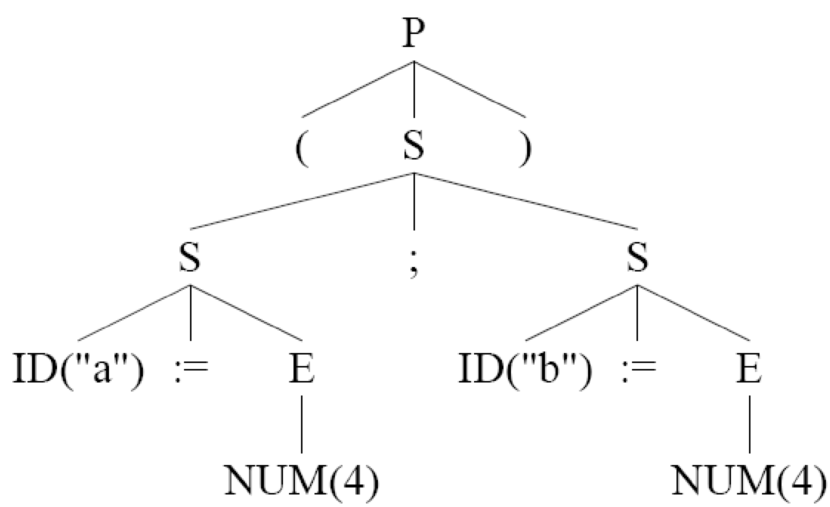
Parse Trees

- We have been looking at *concrete* parse trees.
  - Each internal node labeled with non-terminal.
  - Children labeled with symbols in RHS of production.
- Concrete parse trees inconvenient to use! Tree is cluttered with tokens containing no additional information.
  - Punctuation needed to specify structure when writing code, but
  - Tree structure itself cleanly describes program structure.

Parse Tree Example

$$P \rightarrow (\ S\ )$$
$$S \rightarrow S\ ;\ S$$
$$S \rightarrow \mathrm{ID} := E$$
$$E \rightarrow \mathrm{ID}$$
$$E \rightarrow \mathrm{NUM}$$
$$E \rightarrow E + E$$
$$E \rightarrow E\ \text{-}\ E$$
$$E \rightarrow E * E$$
$$E \rightarrow E\ /\ E$$

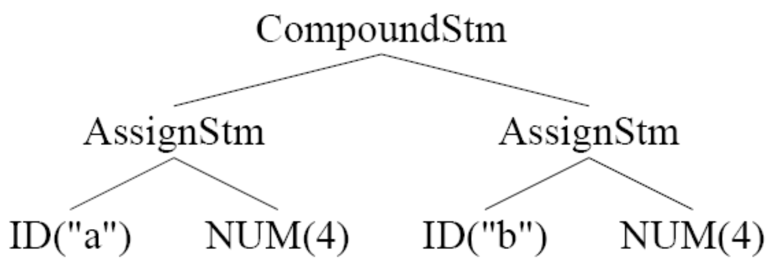
```
( a := 4 ; b := 5 )
```



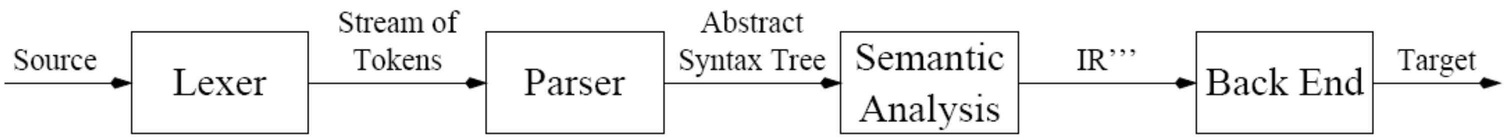
Type checker does not need "(" or ")" or ";"

Parse Tree Example

Solution: generate *abstract parse tree* (abstract syntax tree) - similar to concrete parse tree, except redundant punctuation tokens left out.



Semantic Analysis: Symbol Tables



- Semantic Analysis Phase:
  - Type check AST to make sure each expression has correct type
  - Translate AST into IR trees
- Main data structure used by semantic analysis: *symbol table*
  - Contains entries mapping identifiers to their bindings (e.g. type)
  - As new type, variable, function declarations encountered, symbol table augmented with entries mapping identifiers to bindings.
  - When identifier subsequently used, symbol table consulted to find info about identifier.
  - When identifier goes out of scope, entries are removed.

Symbol Table Example

```
function f(b:int,
           c:int) =
  (print_int(b+c);
   let
     var j := b
     var a := "x"
   in
     print(a)
     print(j)
   end
   print_int(a)
  )
```

$$\sigma_0 = \{a \mapsto int\}$$

$$\sigma_1 = \{b \mapsto int, c \mapsto int, a \mapsto int\}$$

$$\sigma_2 = \{j \mapsto int, b \mapsto int, c \mapsto int, a \mapsto int\}$$

$$\sigma_3 = \{a \mapsto string, j \mapsto int, b \mapsto int, c \mapsto int, a \mapsto int\}$$

$$\sigma_1 = \{b \mapsto int, c \mapsto int, a \mapsto int\}$$

$$\sigma_0 = \{a \mapsto int\}$$

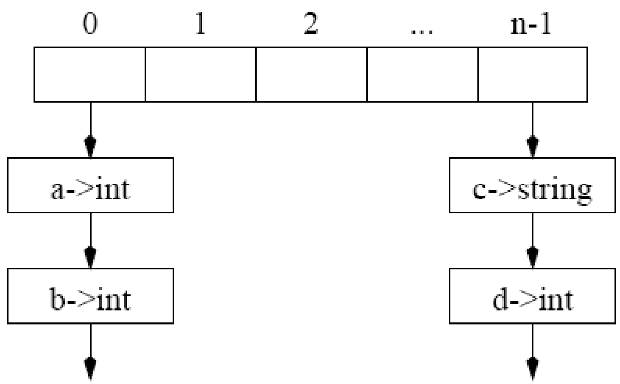
Symbol Table Implementation

- Imperative Style: (side effects)
  - Global symbol table
  - When beginning-of-scope entered, entries added to table using side-effects. (old table destroyed)
  - When end-of-scope reached, auxiliary info used to remove previous additions. (old table reconstructed)
- Functional Style: (no side effects)
  - When beginning-of-scope entered, *new* environment created by adding to old one, but old table remains intact.
  - When end-of-scope reached, retrieve old table.

Imperative Symbol Tables

Symbol tables must permit fast lookup of identifiers.

- *Hash Tables* - an array of *buckets*
- *Bucket* - linked list of entries (each entry maps identifier to binding)

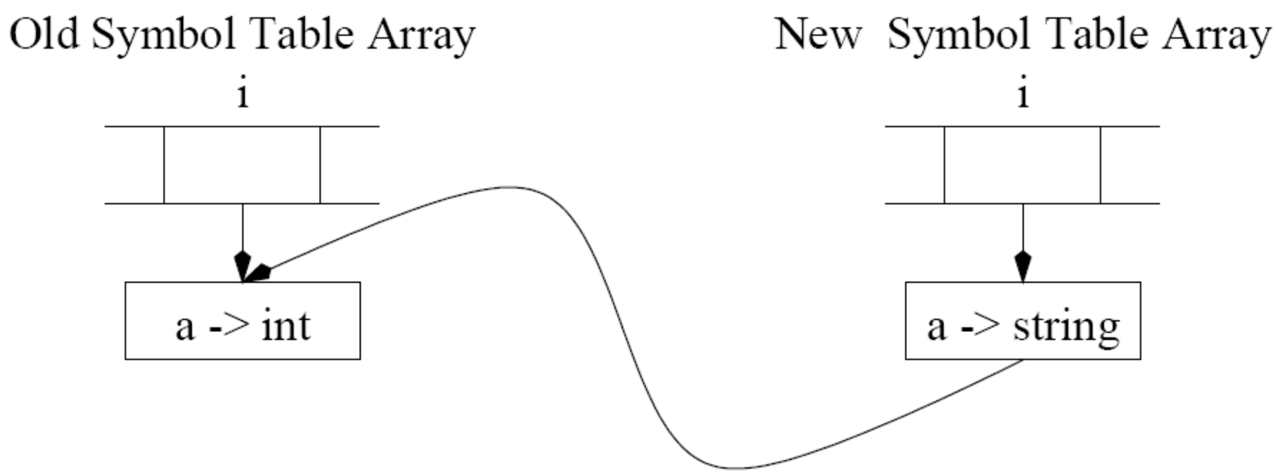


- Suppose we with to lookup entry for id i in symbol table:
  1. Apply *hash function* to key i to get array element $j \in [0, n-1]$.
  2. Traverse bucket in table[j] in order to find binding b.
     (table[x]: all entries whose keys hash to x)

Functional Symbol Tables

Hash tables not efficient for functional symbol tables.

Insert `a` $\mapsto$ `string` $\Rightarrow$ copy array, share buckets:

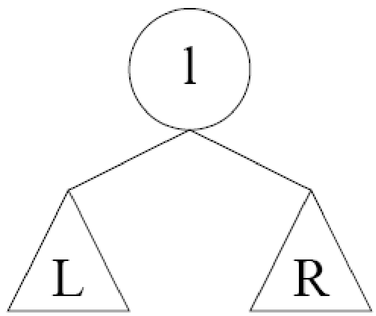


Not feasible to copy array each time entry added to table.

Functional Symbol Tables

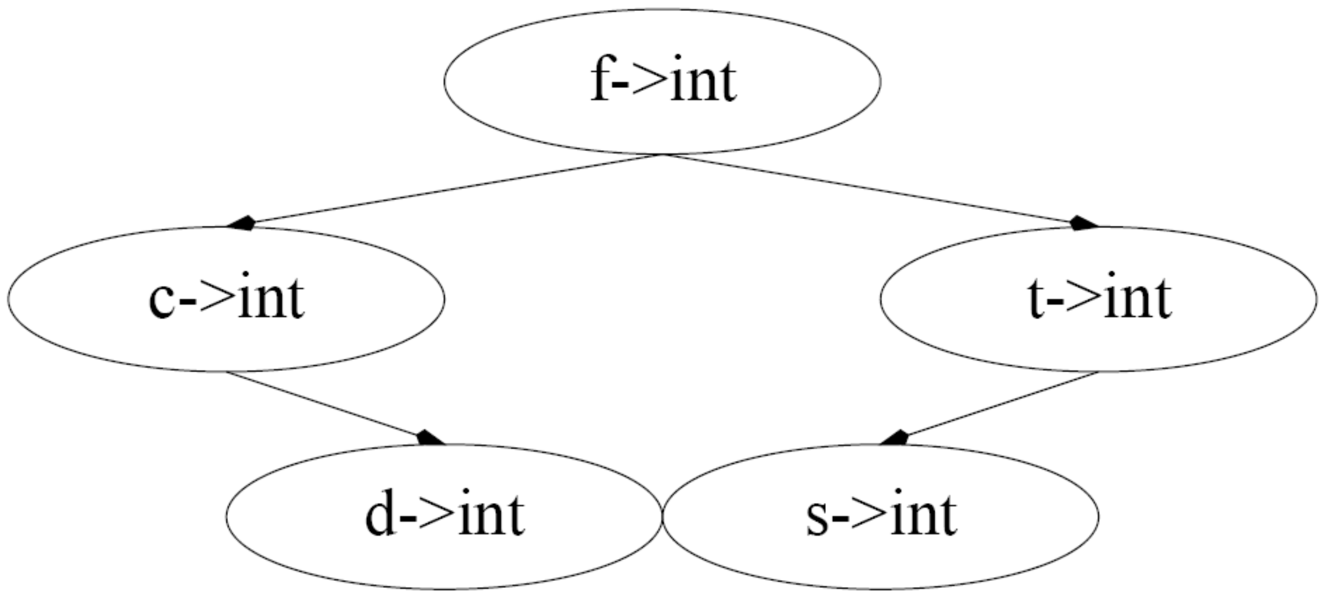
Better method: use *binary search trees (BSTs)*.

- Functional additions easy.
- Need "less than" ordering to build tree.
  - Each node contains mapping from identifier (key) to binding.
  - Use string comparison for "less than" ordering.
  - For all nodes $n \in L$, key(n) $<$ key(l)
    For all nodes $n \in R$, key(n) $>=$ key(l)



Functional Symbol Table Example

Lookup:



Functional Symbol Table Example

Insert:

insert $z \mapsto$ `int`, create node `z`, copy all ancestors of `z`: