

COMPILERS

Semantic Analysis

hussein suleman
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Semantic Analysis

- The compilation process is driven by the syntactic structure of the program as discovered by the parser.
- Semantic routines:
 - interpret meaning of the program based on its syntactic structure
 - it has two functions:
 - finish analysis by deriving context-sensitive information
 - begin synthesis by generating the IR or target code
- Associated with individual productions of a context free grammar or subtrees of a syntax tree.

Context Sensitive Analysis - Why

- What context-sensitive issues can be determined?
 - Is X declared before it is used?
 - Are any names declared but not used?
 - Which declaration of X does this reference?
 - Is an expression type-consistent?
 - Do the dimensions of a reference match the declaration?
 - Where can X be stored? (heap, stack, ...)
 - Does *p reference the result of a malloc()?
 - Is X defined before it is used?
 - Is an array reference in bounds?
 - Does function foo(...) produce a constant value?

Context Sensitive Analysis - How

- How to check symbols and their semantics at various points in the program?
 - Process program linearly (roughly, in-order tree traversal).
 - Maintain a list of currently defined symbols and what they mean as the program is processed – this is called a Symbol Table.

Symbol Tables

- Associate lexical names (symbols) with their attributes.
- Can contain:
 - variable names
 - defined constants
 - procedure/function/method names
 - literal constants and strings
 - source text labels
 - compiler-generated temporaries
 - subtables for structure layouts (types) (field offsets and lengths)

Symbol Table Attributes

- The following attributes would be kept in a symbol table:
 - textual name
 - data type
 - dimension information (for aggregates)
 - declaring procedure
 - lexical level of declaration
 - storage class (base address)
 - offset in storage
 - if record, pointer to structure table
 - if parameter, by-reference or by-value?
 - can it be aliased? to what other names?
 - number and type of arguments to functions/methods

Binding

- ❑ As the declarations of types, variables, and functions are processed, identifiers are bound to “meanings” in the symbol table.
- ❑ A symbol table is a set of bindings.
- ❑ ... But this binding is not static – it changes over the course of the program.

Scope

- ❑ An identifier has scope when it is visible and can be referenced.
- ❑ An out-of-scope identifier cannot be referenced.
- ❑ Identifiers in open scopes may override older/outer scopes temporarily.
- ❑ 2 Types of scope:
 - Static scope is when visibility is due to the lexical nesting of subprograms/blocks.
 - Dynamic scope is when visibility is due to the call sequence of subprograms.

Basic Static Scope

- Usually, a name begins life where it is declared and ends at the end of its block.

```
void foo() {  
    int k;  
    .....  
}
```

Why Scope?

- Scope is not necessary.
 - Languages such as assembler have exactly one scope: the whole program.
- Modern programming languages have more than one scope.
 - Information hiding and modularity.
- Goal of any language is to make the programmer's job simpler.
 - One way: keep things isolated.
 - Make each thing only affect a limited area.
 - Make it hard to break something far away.

Changing Scope

- Identifiers come into scope at the beginning of a subprogram/block and go out of scope at the end.

- Example (in C++):

```
void testfunc ()
{
  int a; // a enters scope;
  for ( int b=1; b<10; b++ ) // b in scope for for
  {
    int c; // c enters scope
    ...
  } // b,c leave scope
  ...
} // a leaves scope
```

Static Scope

- Consider the Pascal program (which uses static scoping):

```
program test;
var a : integer;

  procedure proc1;
  var b : integer;
  begin
  end; ← in scope: b (from proc1), a (from test)

  procedure proc2;
  var a, c : integer;
  begin
    proc1; ← in scope: a, c (from proc2)
  end;

begin
  proc2; ← in scope: a (from test)
end.
```

Dynamic Scope

- Consider the Pascal-like code (assume dynamic scoping):

```
program test;
var a : integer;

    procedure proc1;
    var b : integer;
    begin
    end; ← in scope: b (from proc1) a, c (from proc2)

    procedure proc2;
    var a, c : integer;
    begin
    proc1; ← in scope: a, c (from proc2)
    end;

begin
    proc2; ← in scope: a (from test)
end.
```

Static vs. Dynamic Scope

- Dynamic scope makes it easier to access variables with lifetime, but it is difficult to understand the semantics of code outside the context of execution.
- Static scope is more restrictive – therefore easier to read – but may force the use of more subprogram parameters or global identifiers to enable visibility when required.

Scope in a symbol table

- Most modern programming languages have nested static scope.
 - The symbol table must reflect this.
- What additional information can reflect nested scope?
 - A name query must access the most recent declaration, from the current scope or some enclosing scope.
 - Innermost scope overrides declarations from outer scopes.

Scope and Symbol Table Operations

- What symbol table operations do we need?
 - void put (Symbol key, Object value)
 - binds key to value
 - Object get(Symbol key)
 - returns value bound to key
 - void beginScope()
 - remembers current state of table
 - void endScope()
 - restores table to state at most recent scope that has not been ended

Attribute Information

- Attributes are internal representations of declarations.
- Symbol table associates names with attributes.
- Names may have different attributes depending on their meaning:
 - variables: type, procedure level, frame offset
 - types: type descriptor, data size/alignment
 - constants: type, value
 - methods: formals (names/types), result type, block information (local decls.), frame size

Symbol Table Implementation

- Implemented as a collection of dictionaries in which each symbol is placed.
- Two operations:
 - insert adds a binding to a table and
 - lookup locates the binding for a name.
- Many different possible data structures:
 - linked list
 - hash table
 - binary tree

Symbol Table Lookup

- ❑ Basic operation is to find the entry for a given symbol.
- ❑ Each symbol table may have a pointer to its parent scope.
- ❑ Lookup: if symbol in current table, return it, otherwise look in parent.
- ❑ Hash tables and binary trees can be used more efficiently.

Types of Implementation

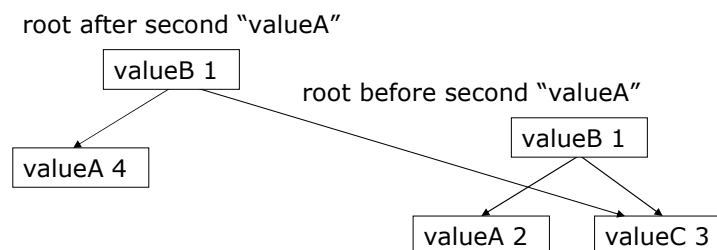
- ❑ Imperative
 - Auxiliary data structures are modified as the analysis progresses, always reflecting only the current state.
- ❑ Functional
 - Auxiliary data structures are maintained intact as the analysis progresses, with new versions created when needed – thus previous and current states are all available at any time.

Hash Table

- beginScope/put
 - Imperative - Chain new entries to beginning of table, thus overriding older entries.
 - Functional - Create copy of hash table array.
- endScope
 - Imperative - Remove entries from head of each linked list.
 - Each entry can point to the next one that should be removed.
 - Functional - Dispose of array.

Binary Tree

- put
 - Functional - Insert new entries into a new subtree, duplicating nodes up to the root.
- endScope
 - Functional - Delete all nodes in new subtree.



Symbols vs. Names

- Names are the textual entities found in the source code.
- Symbols are entities assigned to each name for more efficient processing during compilation.
- Example:
 - Name: valueA
 - Symbol: V001
 - Name: valueB
 - Symbol: V002
- Remember perfect hash functions?

Type Checking

- Static semantics should be checked after/as the symbol table is populated.
 - Is every name defined before it is used?
 - Does the type of each subexpression conform to what is expected?
 - Are the types on either side of an assignment compatible?
- The tree can be walked/visited to perform these checks.
 - May need multiple passes – so retain symbol table across passes.

Type Equivalence

□ Two approaches:

- Name equivalence: each type name is a distinct type.
- Structural equivalence: two types are equivalent iff. they have the same structure (after substituting type expressions for type names).

□ Example (structural):

```
typedef int bignumber;  
int c;  
bignumber b =c;
```

Error Handling

- If errors are detected, correct program representation and continue analysis to detect other errors.

□ Example:

```
int a, b;  
String c;  
c = a;  
b = a;
```