Course: Compiler Construction

Week 12: Symbol Table Management

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Learning outcomes Week 12: Symbol Table Management

At the end of the lecture, you will be able to:

i. Describe Symbol table information
ii. Describe the process of creating and managing symbol tables
iii. Describe how to build a symbol table

1. Introduction:

Definition: A symbol table is a central repository where a compiler stores essential information about every symbol contained in a program[1]. This information includes:-

- Keywords
- Variable names
- Constants
- Procedures
- Functions
- Operators
- Labels
- Data types among others.

✓ It is a data-structure maintained throughout all the phases of a compiler and is an integral part of the compilers Intermediate Representation (IR)

[1] Engineering a Compiler: 2nd edition; Keith D. Cooper and Linda Torczon; *Morgan Kaufmann Publishers* ISBN: 978-0-12-088478-0 (2003) page 279

- ✓ It stores all the identifier names along with their types making it easier for the compiler to quickly search and retrieve identifier records.
- ✓ It localizes information derived from various parts of the source code as well as aiding in scope management[2].

Roles of the Symbol Table

i. Enables easy and efficient access to information about symbols

ii. Simplifies the design and implementation of any code that must refer to information about variables derived earlier in compilation.

iii. Eliminates the need to represent the declarations directly in the IR, therefore doing away with the overhead of making each reference contain a pointer to the declaration[3].

- ✓ It uses a computed mapping from the *textual name* to *the stored information.*
- ✓ Symbol-table entries are created and used during the analysis phase by the lexical analyzer, the parser, and the semantic analyzer[4].

How a Symbol Table interacts with the phases of a compiler

- ✓ Every compiler phase uses the symbol table

1. *Initialization Phase* places keywords, operators and standard identifiers in it
2. *The scanner* places user-defined identifiers and literals in it and returns the corresponding token
3. *The parser* uses these tokens to create the parse tree which is the outcome from syntactic program analysis
4. *The semantic action* routines place the data type in its entries and uses this information to perform basic type-checking[5]
5. *Intermediate Code Generation phase* uses pointers to entries in the symbol table to create intermediate Representation (IR) of the program

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[2] Engineering a Compiler: 2nd edition; Keith D. Cooper and Linda Torczon; *Morgan Kaufmann Publishers* ISBN: 978-0-12-088478-0 (2003) page 286
[3] Engineering a Compiler: 2nd edition; Keith D. Cooper and Linda Torczon; *Morgan Kaufmann Publishers* ISBN: 978-0-12-088478-0 (2003) page 288
[4] Engineering a Compiler: 2nd edition; Keith D. Cooper and Linda Torczon; *Morgan Kaufmann Publishers* ISBN: 978-0-12-088478-0 (2003) page 297
[5] Engineering a Compiler: 2nd edition; Keith D. Cooper and Linda Torczon; *Morgan Kaufmann Publishers* ISBN: 978-0-12-088478-0 (2003) page 280

6. *The object code generation phase* uses pointers to entries in the symbol table for two functions:-
    i. *To allocate storage for its variables and constants*
    ii. *To store the addresses of its procedures and functions*[6]

Symbol Table Interaction with the Semantic Analyzer

- ✓ The symbol table contains the following information about the input strings in a source program[7]: -
    i. *Lexeme (input string) itself*
    ii. *Corresponding token*
    iii. *Its semantic component e.g. variable, operators, constant, function, procedure etc.*
    iv. *Data type*
    v. *Pointers to other entries (where necessary)*
- ✓ The semantic analyzer uses the syntax tree and the information in the symbol table to check the source program for semantic consistency with the language definition.
- ✓ It also gathers type information and saves it in either the syntax tree or the symbol table, for subsequent use during intermediate-code generation[8].
- ✓ Entries in the symbol table contain information about an identifier such as its character string (or lexeme), its type, its position in storage, and any other relevant information.
- ✓ Symbol tables typically need to support multiple declarations of the same identifier within a program[9].

Symbol Table Interaction with the Lexical Analyzer

- ✓ When the lexical analyzer discovers a lexeme constituting an identifier, it needs to enter that lexeme into the symbol table.
- ✓ In some cases, information regarding the kind of identifier may be read from the symbol table by the lexical analyzer. This helps in determining the proper token to be passed to the parser[10].

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[6] Engineering a Compiler: 2nd edition; Keith D. Cooper and Linda Torczon; *Morgan Kaufmann Publishers* ISBN: 978-0-12-088478-0 (2003) page 280
[7] Engineering a Compiler: 2nd edition; Keith D. Cooper and Linda Torczon; *Morgan Kaufmann Publishers* ISBN: 978-0-12-088478-0 (2003) page 280
[8] Compilers: Principles, Techniques and Tools, Aho, Lam, Sethi, and Ullman; Addison- Wesley Pub Co, ISBN: 0201100886 (2007) page 33
[9] Compilers: Principles, Techniques and Tools, Aho, Lam, Sethi, and Ullman; Addison- Wesley Pub Co, ISBN: 0201100886 (2007) page 110
[10] Compilers: Principles, Techniques and Tools, Aho, Lam, Sethi, and Ullman; Addison- Wesley Pub Co, ISBN: 0201100886 (2007) page 134

2. Building a Symbol Table

- ✓ The symbol table defines two interface routines for the rest of the compiler.

  i. ***LookUp(name)*** returns the record stored in the table at *h(name)* if one exists. Otherwise, it returns a value indicating that name was not found.

  ii. ***Insert(name, record)*** stores the information in record in the table at *h.name*/. It may expand the table to accommodate the record for name[11].

- ✓ In processing declaration syntax, the compiler builds up a set of attributes for each variable.
- ✓ When the parser recognizes a production that declares some variable, it can enter the name and attributes into the symbol table using *Insert*.
- ✓ If a variable name can appear in only one declaration, the parser can call *LookUp* first to detect a repeated use of the name[12].
- ✓ The compiler *can use separate functions* for *LookUp* and *Insert*, or they can be combined by passing *LookUp* a flag that specifies whether or not to insert the name.
- ✓ This ensures that a *LookUp* of an undeclared variable will fail - a property useful for detecting a violation of the declare-before-use rule in Syntax-Directed Translation schemes or for supporting nested lexical scopes[13].
- ✓ When the parser encounters a variable name outside the declaration syntax, it uses *LookUp* to obtain the appropriate information from the symbol table.
- ✓ *LookUp* fails on any undeclared name[14].
- ✓ The compiler writer may need to add functions to initialize the table, to store it to and retrieve it from external media, and to finalize it.
- ✓ For a language with a single name space, this interface suffices[15].
- ✓ Symbol tables maintain *name entries* in the following format:

  <symbol name, type, attribute>

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[11] Engineering a Compiler: 2nd edition; Keith D. Cooper and Linda Torczon; *Morgan Kaufmann Publishers* ISBN: 978-0-12-088478-0 (2003) page 785

[12] Engineering a Compiler: 2nd edition; Keith D. Cooper and Linda Torczon; *Morgan Kaufmann Publishers* ISBN: 978-0-12-088478-0 (2003) page 255

[13] Engineering a Compiler: 2nd edition; Keith D. Cooper and Linda Torczon; *Morgan Kaufmann Publishers* ISBN: 978-0-12-088478-0 (2003) page 255

[14] Engineering a Compiler: 2nd edition; Keith D. Cooper and Linda Torczon; *Morgan Kaufmann Publishers* ISBN: 978-0-12-088478-0 (2003) page 281

[15] Engineering a Compiler: 2nd edition; Keith D. Cooper and Linda Torczon; *Morgan Kaufmann Publishers* ISBN: 978-0-12-088478-0 (2003) page 284

Example:-

- ✓ Consider a symbol table that stores information about the following variable declaration:

  static int interest;

- ✓ **then it should store the entry such as:**

  <interest, int, static>

- ✓ The attribute clause contains the entries related to the name[16].
- ✓ Symbol tables are created by the lexer and parser and later used by the code generator[17].
- ✓ The following is a symbol table generated for some code:-

Name	Class	Type
X1	Variable	Integer
X2	Variable	Integer
xR	Variable	Real

3. Symbol Table Implementation

- ✓ If a compiler is handling a small amount of data, then the symbol table can be implemented as an unordered list, which is easy to code, but it is only suitable for small tables only.
- ✓ A symbol table can be implemented in one of the following ways:
  - i. Linear (sorted or unsorted) list
  - ii. Binary Search Tree
  - iii. Hash table
- ✓ The most common method is hash tables, where the source code symbol itself is treated as a key for the hash function and the return value is the information about the symbol.
- ✓ A symbol table, whether linear or hash, should provide the Insert and Lookup operations[18].

[16] Engineering a Compiler: 2nd edition; Keith D. Cooper and Linda Torczon; *Morgan Kaufmann Publishers* ISBN: 978-0-12-088478-0 (2003) page 281
[17] Compilers: Principles, Techniques and Tools, Aho, Lam, Sethi, and Ullman; Addison- Wesley Pub Co, ISBN: 0201100886 (2007) page 27
[18] Engineering a Compiler: 2nd edition; Keith D. Cooper and Linda Torczon; *Morgan Kaufmann Publishers* ISBN: 978-0-12-088478-0 (2003) page 776

3.1. Symbol Table Operations

A. insert()

- ✓ The operation is frequently used in the analysis phase, i.e., the first half of the compiler where tokens are identified and names are stored in the table.
- ✓ The operation adds information in the symbol table about unique names present in the source code.
- ✓ The format or structure in which the names are stored depends upon the compiler being used
- ✓ A symbol attribute in the source code is the information associated with that symbol e.g. its value, state, scope, and type.
- ✓ The operation takes the symbol and its attributes as arguments e.g. *int a;* should be processed by the compiler as insert(a, int)[19] ;

B. lookup()

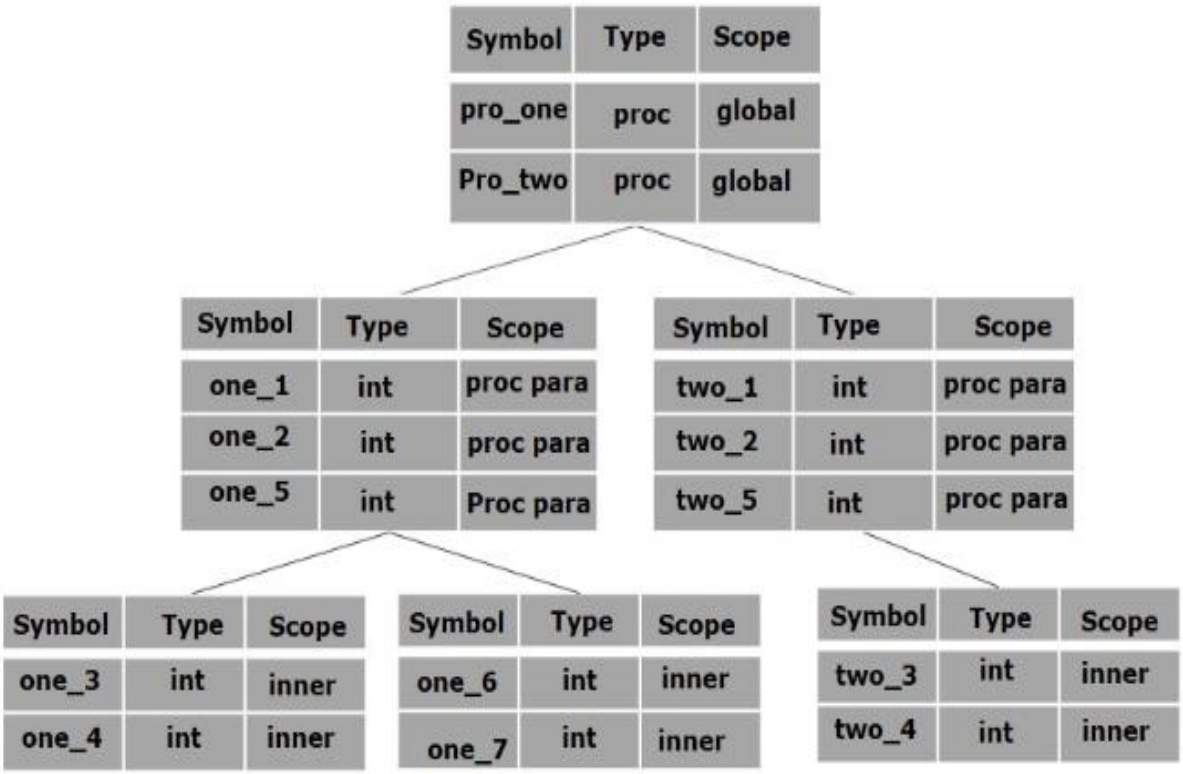
- ✓ The operation searches for a name in the symbol table to determine the following: -
  - i. Does the symbol exist in the table?
  - ii. Is it declared before use?
  - iii. Is the name used in the scope?
  - iv. Is the symbol initialized?
  - v. Is the symbol declared multiple times?
- ✓ The format of *lookup()* function varies according to the programming language. The basic format should be *lookup(symbol)*
- ✓ This method returns the symbol attributes if the symbol exists in the stored symbol table and zero (0) if the symbol *does not exist*[20].

[19] Engineering a Compiler: 2nd edition; Keith D. Cooper and Linda Torczon; *Morgan Kaufmann Publishers* ISBN: 978-0-12-088478-0 (2003) page 281

[20] Engineering a Compiler: 2nd edition; Keith D. Cooper and Linda Torczon; *Morgan Kaufmann Publishers* ISBN: 978-0-12-088478-0 (2003) page 281

3.2. Scope Management

- ✓ The symbol table data structure hierarchy is stored in the semantic analyzer
- ✓ The following algorithm is used to search for a name in a symbol table:-
  - i. Search a symbol in the current scope, i.e. current symbol table.
  - ii. The search is completed if a name is found, else it will be searched in the parent symbol table until,
  - iii. either the name is found or global symbol table has been searched for the name[21].
- ✓ A compiler maintains two types of symbol tables:
  - **i. A global symbol table** which can be accessed by *all* the procedures
  - ii. **A scope symbol table** created *for each* scope in the program[22].
- ✓ To determine the scope of a name, symbol tables are arranged in a hierarchy structure as demonstrated in the example below[23]:-



[21] Engineering a Compiler: 2nd edition; Keith D. Cooper and Linda Torczon; *Morgan Kaufmann Publishers* ISBN : 978-0-12-088478-0 (2003) page 281
[22] Engineering a Compiler: 2nd edition; Keith D. Cooper and Linda Torczon; *Morgan Kaufmann Publishers* ISBN : 978-0-12-088478-0 (2003) page 281
[23] Engineering a Compiler: 2nd edition; Keith D. Cooper and Linda Torczon; *Morgan Kaufmann Publishers* ISBN : 978-0-12-088478-0 (2003) page 281

Three Basic Operations of a Symbol Table

1. ***Adding Symbols***

- ✓ Reserved words , standard identifiers and operators are initialized while new lexemes, appropriate properties and attributes are *added* when the scanner encounters them.
- ✓ They are then assigned a token class[24].

2. ***Deleting Symbols***

- ✓ Upon finishing with a given scope of the program, the compiler *removes* all the symbols belonging to that scope effectively before processing a different program scope.
- ✓ This data may be hidden from the compilers' view or dumped into a temporary file[25]

3. ***Searching Symbols***

- ✓ Looking up a lexeme in the symbol table
- ✓ Retrieving any and all of the properties belonging to that symbol[26]

Summary: Symbol Table Management

- ✓ A symbol table is a data structure that holds information about all symbols held in the source program.
- ✓ Information stored includes variable names, their size, types, etc.
- ✓ It does not form part of the final code generated[27].

[24] Engineering a Compiler: 2nd edition; Keith D. Cooper and Linda Torczon; *Morgan Kaufmann Publishers* ISBN: 978-0-12-088478-0 (2003) page 760
[25] Engineering a Compiler: 2nd edition; Keith D. Cooper and Linda Torczon; *Morgan Kaufmann Publishers* ISBN: 978-0-12-088478-0 (2003) page 760
[26] Engineering a Compiler: 2nd edition; Keith D. Cooper and Linda Torczon; *Morgan Kaufmann Publishers* ISBN: 978-0-12-088478-0 (2003) page 760
[27] Engineering a Compiler: 2nd edition; Keith D. Cooper and Linda Torczon; *Morgan Kaufmann Publishers* ISBN: 978-0-12-088478-0 (2003) page 247

Content Covered in Week 12: Symbol Table Management

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Course Text Books

1. Compilers: Principles, Techniques and Tools, Aho, Lam, Sethi, and Ullman; *Addison-Wesley Pub Co*, ISBN: 0201100886 (2007))
2. Compiler Construction: Principles and practices; Kenneth C. Louden; *Cengage Learning*; 1st edition, ISBN-10 : 0534939724 (1997)
3. Basics of Compiler Design: Torben Mogensen; *DIKU University of Copenhagen Universitetsparken 1 DK-2100 Copenhagen DENMARK* (2007)
4. Engineering a Compiler: 2nd edition; Keith D. Cooper and Linda Torczon; *Morgan Kaufmann Publishers* ISBN: 978-0-12-088478-0 (2003)
5. Compiler Design: Santanu Chattopadhyay; *PHI Learning Publishers*, ISBN 812032725X, 9788120327252 (2005)