Name Equivalence

- Two types are name equivalent if they have same name or label

```
typedef int Value
typedef int Total
...
Value var1, var2
Total var3, var4
```

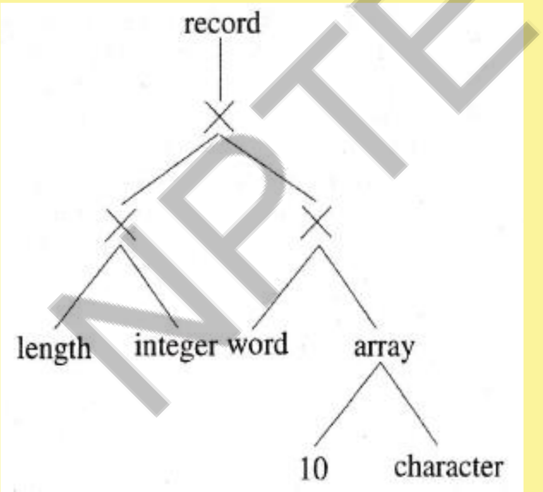
- Variables var1, var2 are name equivalent, so are var3 and var4
- Variables var1 and var4 are not name equivalent, as their type names are different

Structural Equivalence

- Checks the structure of the type
- Determines equivalence by checking whether they have same constructor applied to structurally equivalent types
- Checked recursively
- Types array(I1, T1) and array(I2, T2) are structurally equivalent if I1 and I2 are equal and T1 and T2 are structurally equivalent

Directed Acyclic Graph Representation

- Type expressions can be represented as a DAG or a tree
- “record((length × integer) × (word × array(10, character)))”



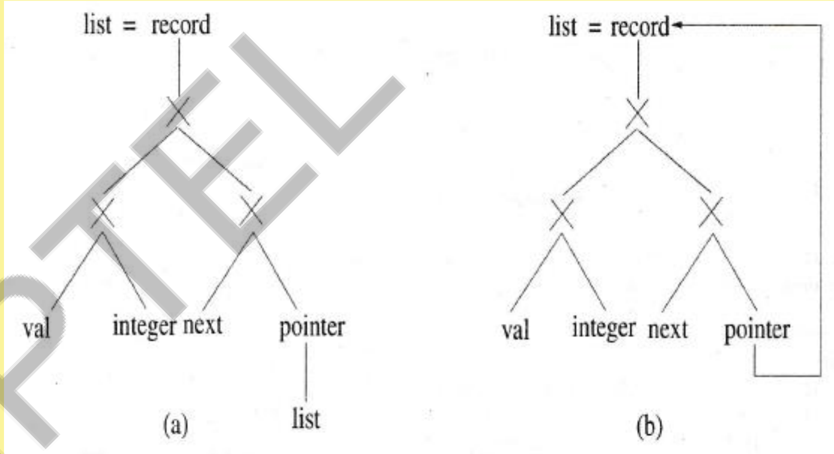
Function dag_equivalence

```
function dag-equivalence(s,t: type-DAGs): boolean
begin
    if s and t represents the same basic type then return true
    if s represents array(I1, T1) and t represents array(I2, T2) then
        if I1 = I2 then return dag-equivalence(T1, T2)
        else return false
    if s represents s1 × s2 and t represents t1 × t2 then
        return dag-equivalence(s1, t1) and dag-equivalence(s2, t2)
    if s represents pointer(s1) and t represents pointer(t1) then
        return dag-equivalence(s1, t1)
    if s = s1 → s2 and t = t1 → t2 then
        return dag-equivalence(s1, t1) and dag-equivalence(s2, t2)
    return false
end.
```

Cycles in Type Representation

- Some languages allow types to be defined in a cyclical fashion

```
struct list
{
        int val;
        struct list *next;
}
```



- (a) Acyclic representation (b) Cyclic representation

Cycles in Type Representation

- Most programming languages, including C, uses acyclic one
- Type names are to be declared before using it, excepting pointers
- Name of the structure is also part of the type
- Equivalence test stops when a structure is reached
- At this point, type expressions are equivalent if they point to the same structure name, nonequivalent otherwise

Type Conversion

- Refers to local modification of type for a variable or subexpression
- For example, it may be necessary to add an integer quantity to a real variable, however, the language may require both the operands to be of same type
- Modifying integer variable to real will require more space
- Solution: to treat integer operand as really operand locally and perform the operation
- May be done explicitly or implicitly
- Implicit conversion ➔ type coercion

```
int x;
float y;
...
y = ((float)x)/14.0
```

```
int x;
float y;
...
y = x/14.0
```

Conclusion

- Compilers usually perform static type checking
- Dynamic type checking is costly
- Types are normally represented as type expressions
- Type checking can be performed by syntax directed techniques
- Type graphs may be compared to check type equivalence

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Thank you!

Compiler Design

Symbol Tables

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Electronics and Electrical Communication Engineering

- Information in Symbol Table
- Features of Symbol Table
- Simple Symbol Table
- Scoped Symbol Table
- Conclusion

Introduction

- Essential data structure used by compilers to remember information about identifiers in the source program
- Usually lexical analyzer and parser fill up the entries in the table, later phases like code generator and optimizer make use of table information
- Types of symbols stored in the symbol table include variables, procedures, functions, defined constants, labels, structures etc.
- Symbol tables may vary widely from implementation to implementation, even for the same language

Information in Symbol Table

- Name
  - Name of the identifier
  - May be stored directly or as a pointer to another character string in an associated string table – names can be arbitrarily long
- Type
  - Type of the identifier: variable, label, procedure name etc.
  - For variables, its type: basic types, derived types etc.
- Location
  - Offset within the program where the identifier is defined
- Scope
  - Region of the program where the current definition is valid
- Other attributes: array limits, fields of records, parameters, return values etc.

Usage of Symbol Table Information

- Semantic Analysis – check correct semantic usage of language constructs, e.g. types of identifiers
- Code Generation – Types of variables provide their sizes during code generation
- Error Detection – Undefined variables. Recurrence of error messages can be avoided by marking the variable type as undefined in the symbol table
- Optimization – Two or more temporaries can be merged if their types are same

Operations on Symbol Table

- Lookup – Most frequent, whenever an identifier is seen it is needed to check its type, or create a new entry
- Insert – Adding new names to the table, happens mostly in lexical and syntax analysis phases
- Modify – When a name is defined, all information may not be available, may be updated later
- Delete – Not very frequent. Needed sometimes, such as when a procedure body ends

Issues in Symbol Table Design

- Format of entries – Various formats from linear array to tree structured table
- Access methodology – Linear search, Binary search, Tree search, Hashing, etc.
- Location of storage – Primary memory, partial storage in secondary memory
- Scope Issues – In block-structured language, a variable defined in upper blocks must be visible to inner blocks, not the other way

Simple Symbol Table

- Works well for languages with a single scope
- Commonly used techniques are
  - Linear table
  - Ordered list
  - Tree
  - Hash table

Linear Table

- Simple array of records with each record corresponding to an identifier in the program
- Example:

```
int x, y
real z
...
procedure abc
...
L1:...
...
```

Name	Type	Location
x	integer	Offset of x
y	integer	Offset of y
z	real	Offset of z
abc	procedure	Offset of abc
L1	label	Offset of L1

Linear Table

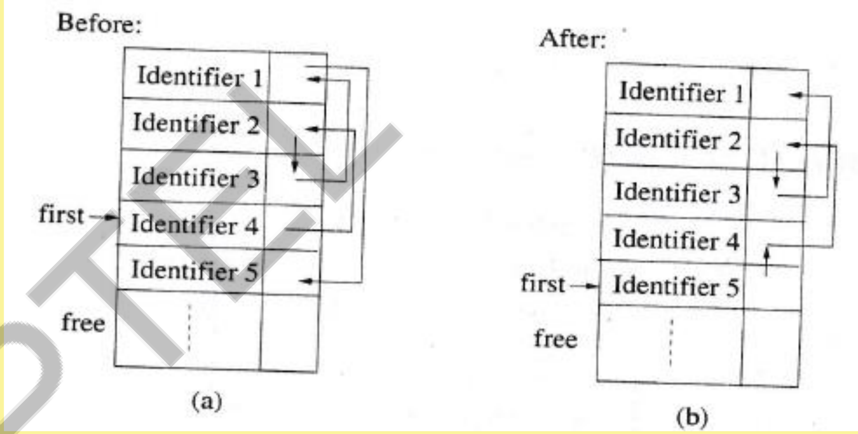
- If there is no restriction in the length of the string for the name of an identifier, string table may be used, with name field holding pointers
- Lookup, insert, modify take O(n) time
- Insertion can be made O(1) by remembering the pointer to the next free index
- Scanning most recent entries first may probably speed up the access – due to program locality – a variable defined just inside a block is expected to be referred to more often than some earlier variables

Ordered List

- Variation of linear tables in which list organization is used
- List is sorted in some fashion , then binary search can be used with O(log n) time
- Insertion needs more time
- A variant – self-organizing list: neighbourhood of entries changed dynamically

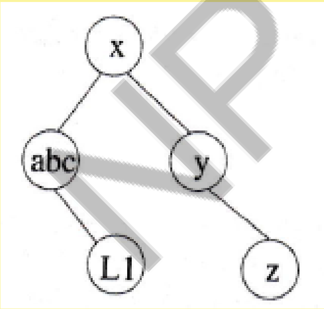
Self-Organizing List

- In Fig (a), Identifier4 is the most recently used symbol, followed by Identifier2, Identifier3 and so on
- In Fig (b), Identifier5 is accessed next, accordingly the order changes
- Due to program locality, it is expected that during compilation, entries near the beginning of the ordered list will be accessed more frequently
- This improves lookup time



Tree

- Each entry represented by a node of the tree
- Based on string comparison of names, entries lesser than a reference node are kept in its left subtree, otherwise in the right subtree
- Average lookup time O(log n)
- Proper height balancing techniques need to be utilized



Hash Table

- Useful to minimize access time
- Most common method for implementing symbol tables in compilers
- Mapping done using Hash function that results in unique location in the table organized as array
- Access time O(1)
- Imperfection of hash function results in several symbols mapped to the same location – collision resolution strategy needed
- To keep collisions reasonable, hash table is chosen to be of size between n and 2n for n keys

Desirable Properties of Hash Functions

- Should depend on the name of the symbol. Equal emphasis be given to each part
- Should be quickly computable
- Should be uniform in mapping names to different parts of the table. Similar names (such as, data1 and data2) should not cluster to the same address
- Computed value must be within the range of table index

Scoped Symbol Table

- Scope of a symbol defines the region of the program in which a particular definition of the symbol is valid – definition is *visible*
- Block structured languages permit different types of scopes for the identifiers – *scope rules* for the language
  - Global scope: visibility throughout the program, global variables
  - File-wide scope: visible only within the file
  - Local scope within a procedure: visible only to the points inside the procedure, local variables
  - Local scope within a block: visible only within the block in which it is defined

Scoping Rules

- Two categories depending on the time at which the scope gets defined
- Static or Lexical Scoping
  - Scope defined by syntactic nesting
  - Can be used efficiently by the compiler to generate correct references
- Dynamic or Runtime Scoping
  - Scoping depends on execution sequence of the program
  - Lot of extra code needed to dynamically decide the definition to be used

Nested Lexical Scoping

- To reach the definition of a symbol, apart from the current block, the blocks that contain this innermost one, also have to be considered
- Current scope is the innermost one
- There exists a number of open scopes – one corresponding to the current scope and others to each of the blocks surrounding it

```
Procedure P1
…
  Procedure P2
  …
  end procedure
Procedure P3
  x =
  …
```

Current scope of x is P3, it has another open scope P1

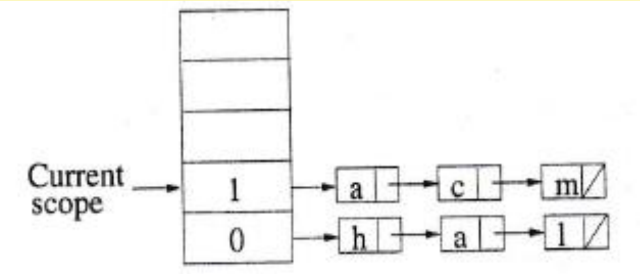
Visibility Rules

- Used to resolve conflicts arising out of same variable being defined more than once
- If a name is defined in more than one scope, the innermost declaration closest to the reference is used to interpret
- When a scope is exited all declared variables in that scope are deleted and the scope is thus *closed*
- Two methods to implement symbol tables with nested scope
  - One table for each scope
  - A single global table

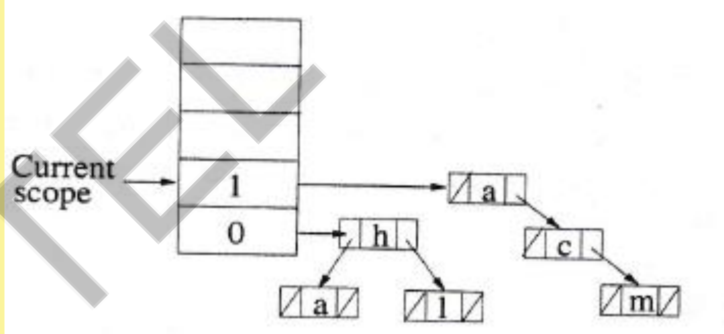
One Table Per Scope

- Maintain a different table for each scope
- A stack is used to remember the scopes of the symbol tables
- Drawbacks:
  - For a single-pass compiler, table can be popped out and destroyed when a scope is closed, not for a multi-pass compiler
  - Search may be expensive if variable is defined much above in the hierarchy
  - Table size allotted to each block is another issue
- Lists, Trees, Hash Tables can be used

One Table Per Scope



Scoped Symbol Table – Lists

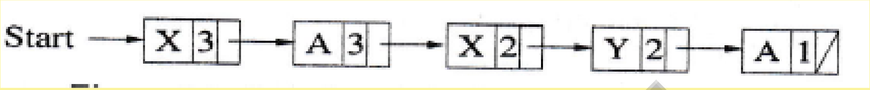


Scoped Symbol Table – Trees

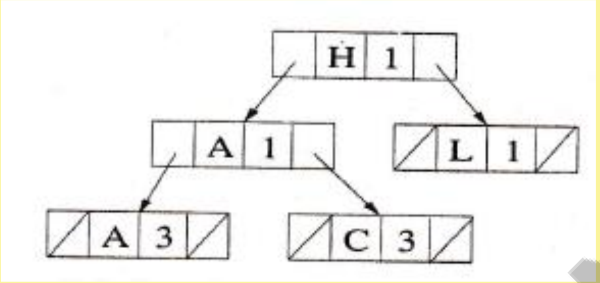
One Table for All Scopes

- All identifiers are stored in a single table
- Each entry in the symbol table has an extra field identifying the scope
- To search for an identifier, start with the highest scope number, then try out the entries having next lesser scope number, and so on
- When a scope gets closed, all identifiers with that scope number are removed from the table
- Suitable particularly for single-pass compilers
- List, Tree and Hash Table can be used

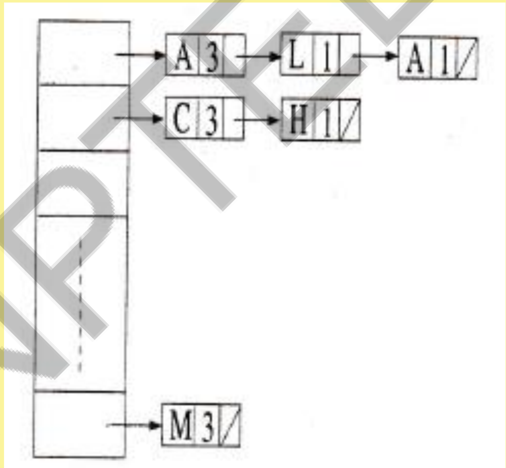
One Table for All Scopes



Single List



Tree



Hash Table

Conclusions

- Symbol table, though not part of code generated by the compiler, helps in the compilation process
- Phases like Lexical Analysis and Syntax Analysis produce the symbol table, while other phases use its content
- Depending upon the scope rules of the language, symbol table needs to be organized in various different manners
- Data structures commonly used for symbol table are linear table, ordered list, tree, hash table, etc.

Thank you

Compiler Design

Runtime Environment Management

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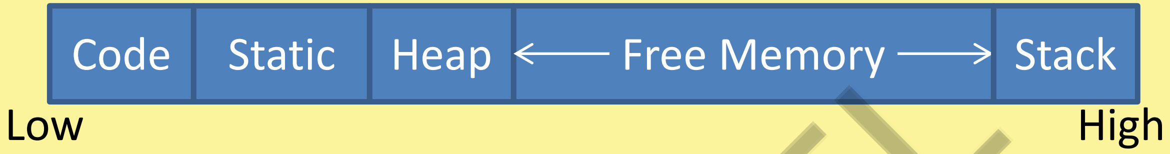
- What is Runtime Environment
- Activation Record
- Environment without Local Procedures
- Environment with Local Procedures
- Display
- Conclusion

What is Runtime Environment

- Refers to the program snap-shot during execution
- Three main segments of a program
  - Code
  - Static and global variables
  - Local variables and arguments
- Memory needed for each of these entities
  - Generated code: Text for procedures and programs. Size known at compile time. Space can be allotted statically before execution
  - Data objects:
    - Global variables/constants – space known at compile time
    - Local variables – space known at compile time
    - Dynamically created variables – space (heap) in response to memory allocation requests
  - Stack: To keep track of procedure activations

Logical Address Space of Program



- Code occupies the lowest portion
- Global variables are allocated in the static portion
- Remaining portion of the address space, stack and heap are allocated from the opposite ends to have maximum flexibility

Activation Record

- Storage space needed for variables associated with each activation of a procedure – *activation record* or *frame*
- Typical activation record contains
  - Parameters passed to the procedure
  - Bookkeeping information, including return values
  - Space for local variables
  - Space for compiler generated local variables to hold sub-expression values