Symbol Tables

ASU Textbook Chapter 7.6, 6.5 and 6.3

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Definitions

- **Symbol table: A data structure used by a compiler to keep track of semantics of variables.**
  - **Data type.**
  - **When is used: scope.**
    - ▷ *The effective context where a name is valid.*
  - **Where it is stored: storage address.**
- **Possible implementations:**
  - **Unordered list: for a very small set of variables.**
  - **Ordered linear list: insertion is expensive, but implementation is relatively easy.**
  - **Binary search tree: $O(\log n)$ time per operation for n variables.**
  - **Hash table: most commonly used, and very efficient provided the memory space is adequately larger than the number of variables.**

Hash table

- **Hash function $h(n)$: returns a value from $0, \dots, m-1$, where n is the input name and m is the hash table size.**
  - **Uniformly and randomly.**
- **Many possible good designs.**
  - **Add up the integer values of characters in a name and then take the remainder of it divided by m.**
  - **Add up a linear combination of integer values of characters in a name, and then take the remainder of it divided by m.**
- **Resolving collisions:**
  - **Linear resolution: try $(h(n)+1) \bmod m$, where m is a large prime number, and then $(h(n)+2) \bmod m$, $\dots$, $(h(n)+i) \bmod m$.**
  - **Chaining: most popular.**
    - ▷ ***Keep a chain on the items with the same hash value.***
    - ▷ ***Open hashing.***
  - **Quadratic-rehashing:**
    - ▷ ***try $(h(n)+1^2) \bmod m$, and then***
    - ▷ ***try $(h(n)+2^2) \bmod m$, $\dots$,***
    - ▷ ***try $(h(n)+i^2) \bmod m$.***

Performance of hash table

- Performance issues on using different collision resolution schemes.
- Hash table size must be adequately larger than the maximum number of possible entries.
- Frequently used variables should be distinct.
  - Keywords or reserved words.
  - Short names, e.g., i, j and k.
  - Frequently used identifiers, e.g., $main$.
- Uniformly distributed.

Contents in symbol tables

- **Possible entries in a symbol table:**
  - **Name: a string.**
  - **Attribute:**
    - ▷ *Reserved word*
    - ▷ *Variable name*
    - ▷ *Type name*
    - ▷ *Procedure name*
    - ▷ *Constant name*
    - ▷ ...
  - **Data type.**
  - **Scope information: where and when it can be used.**
  - **Storage allocation, size, ...**
  - ...

How names are stored

- **Fixed-length name: allocate a fixed space for each name allocated.**
  - **Too little: names must be short.**
  - **Too much: waste a lot of spaces.**

NAME										ATTRIBUTES
s	o	r	t							
a										
r	e	a	d	a	r	r	a	y		
i	2									

- **Variable-length name:**
  - **A string of space is used to store all names.**
  - **For each name, store the length and starting index of each name.**

NAME		ATTRIBUTES
index	length	
0	5	
5	2	
7	10	
17	3	

0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19
s	o	r	t	$	a	$	r	e	a	d	a	r	r	a	y	$	i	2	$

Handling block structures

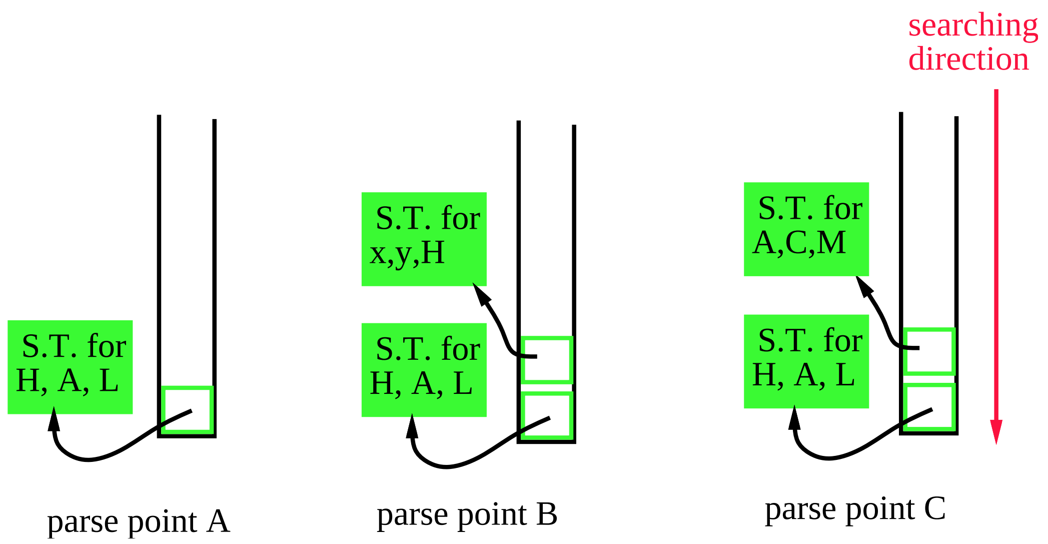
```
main() /* C code */
{    /* open a new scope */
     int H,A,L;  /* parse point A */
     ...
     { /* open another new scope */
       float x,y,H; /* parse point B */
       ...
       /* x and y can only be used here */
       /* H used here is float */
       ...
     } /* close an old scope */
     ...
     /* H used here is integer */
     ...
     { char A,C,M; /* parse point C */
     ...
     }
}
```

- **Nested blocks mean nested scopes.**
- **Two major ways for implementation:**
  - **Approach 1: multiple symbol tables in a STACK.**
  - **Approach 2: one symbol table with chaining.**

Multiple symbol tables in a stack

- **An individual symbol table for each scope.**
  - **Use a stack to maintain the current scope.**
  - **Search top of stack first.**
  - **If not found, search the next one in the stack.**
  - **Use the first one matched.**
  - **Note: a popped scope can be destroyed in a one-pass compiler, but it must be saved in a multi-pass compiler.**

```
main()
{    /* open a new scope */
     int H,A,L;  /* parse point A */
     ...
     { /* open another new scope */
       float x,y,H; /* parse point B */
       ...
       /* x and y can only be used here */
       /* H used here is float */
       ...
     } /* close an old scope */
     ...
     /* H used here is integer */
     ...
     { char A,C,M; /* parse point C */
     ...
     }
}
```



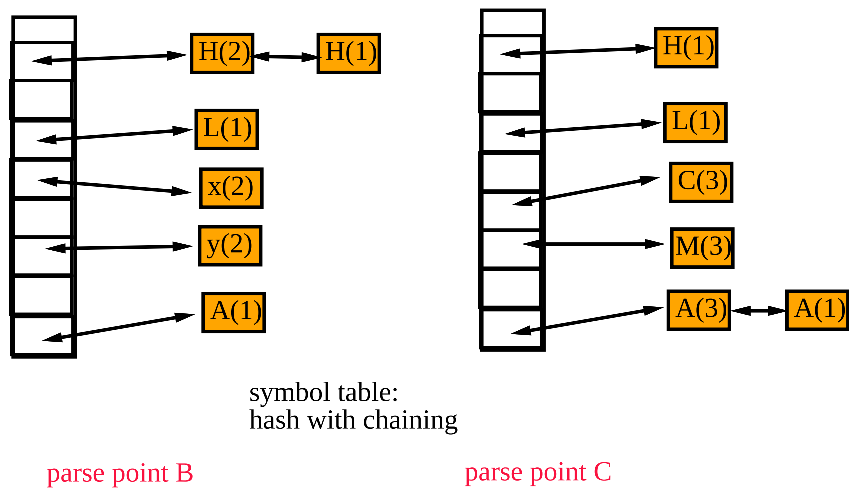
Pros and cons for multiple symbol tables

- **Advantage:**
  - **Easy to close a scope.**
- **Disadvantage:**
  - **Waste lots of spaces.**
  - **Need to allocate adequate amount of entries for each symbol table if it is a hash table.**
    - ▷ ***A block within a procedure does not usually have many local variables.***
    - ▷ ***There may have many global variables and many local variables when a procedure is entered.***

One hash table with chaining

- **A single global table marked with the scope information.**
  - ▷ *Each scope is given a unique* *scope number.*
  - ▷ *Incorporate the scope number into the symbol table.*
- **Two possible codings (among others):**
  - **Hash table with chaining.**
    - ▷ *Chaining at the front when names hashed into the same location.*
    - ▷ *When a scope is closed, all entries of that scope are removed.*

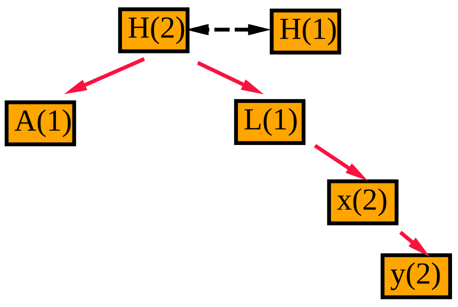
```
main()
{    /* open a new scope */
     int H,A,L;  /* parse point A */
     ...
     { /* open another new scope */
       float x,y,H; /* parse point B */
       ...
       /* x and y can only be used here */
       /* H used here is float */
       ...
     } /* close an old scope */
     ...
     /* H used here is integer */
     ...
     { char A,C,M; /* parse point C */
     ...
     }
}
```



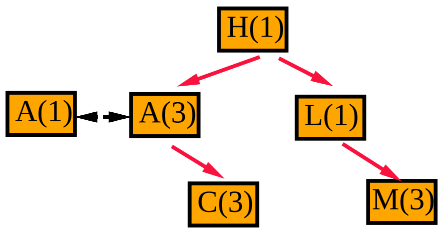
One binary search tree with chaining

- **A second coding choice:**
  - **Binary search tree:**

```
main()
{    /* open a new scope */
     int H,A,L;  /* parse point A */
     ...
     { /* open another new scope */
       float x,y,H; /* parse point B */
       ...
       /* x and y can only be used here */
       /* H used here is float */
       ...
     } /* close an old scope */
     ...
     /* H used here is integer */
     ...
     { char A,C,M; /* parse point C */
     ...
     }
}
```



parse point B



parse point C

Pros and cons for a unique symbol table

- **Advantage:**
  - Does not waste spaces.
- **Disadvantage: It is difficult to close a scope.**
  - Need to maintain a list of entries in the same scope.
  - Using this list to close a scope and to reactive it for the second pass.

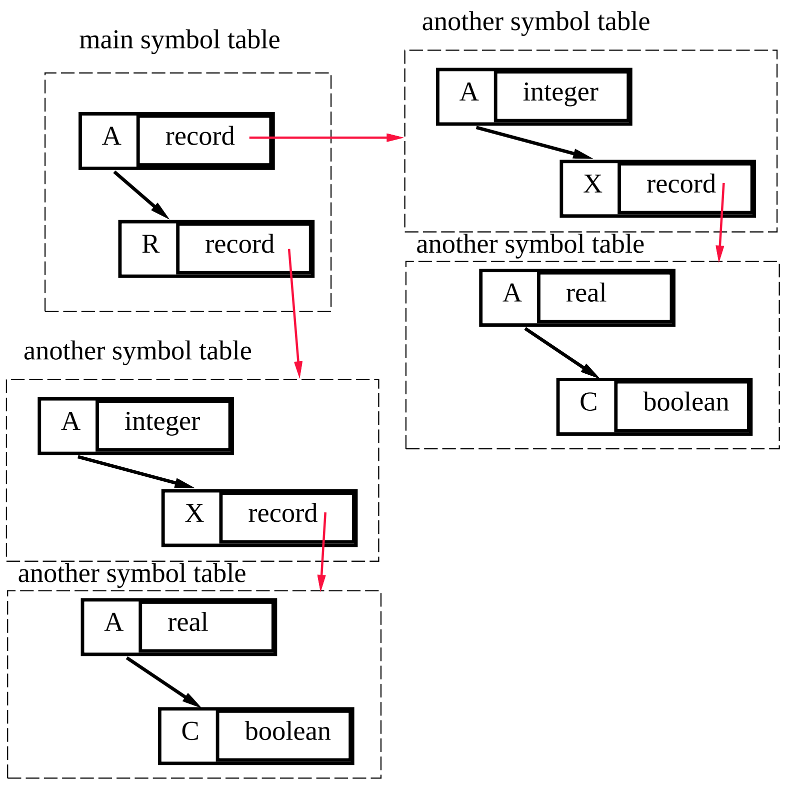
Records and fields

- **The "with" construct in PASCAL can be considered an additional scope rule.**
  - **Field names are visible in the scope that surrounds the record declaration.**
  - **Field names need only to be unique within the record.**
- **Another example is the "using namespace" directive in C++.**
- **Example (PASCAL code):**

```
A, R: record
        A: integer
        X: record
             A: real;
             C: boolean;
           end
       end
...
R.A := 3;      /* means R.A := 3; */
with R do
  A := 4;      /* means R.A := 4; */
```

Implementation of field names

- Two choices for handling field names:
  - Allocate a symbol table for each record type used.



  - Associate a record number within the field names.
    - ▷ *Assign record number #0 to names that are not in records.*
    - ▷ *A bit time consuming in searching the symbol table.*
    - ▷ *Similar to the scope numbering technique.*

Specifying scope info. for records

- **Example:**

```
with R do
begin
    A := 3;
    with X do
      A := 3.3
end
```

- **If each record (each scope) has its own symbol table,**
  - **then push the symbol table for the record onto the STACK.**
- **If the record number technique is used,**
  - **then keep a stack containing the current record number**
  - **during searching, success only if it matches the current record number.**
  - **If fail, then use next record number in the stack as the current record number and continue to search.**
  - **If everything fails, search the normal main symbol table.**

Overloading (1/3)

- **A symbol may, depending on context, have more than one semantics.**
- **Examples.**
  - **operators:**
    - ▷ $I := I + 3;$
    - ▷ $X := Y + 1.2;$
  - **function call return value and recursive function call:**
    - ▷ $f := f + 1;$

Overloading (2/3)

- **Implementation:**
  - **Link together all possible definitions of an overloading name.**
  - **Call this an overloading chain.**
  - **Whenever a name that can be overloaded is defined**
    - ▷ ***if the name is already in the current scope, then add the new definition in the overloading chain;***
    - ▷ ***if it is not already there, then enter the name in the current scope, and link the new entry to any existing definitions;***
    - ▷ ***search the chain for an appropriate one, depending on the context.***
  - **Whenever a scope is closed, delete the overloading definitions from the head of the chain.**

Overloading (3/3)

- **Example: PASCAL function name and return variable.**
  - **Within the function body, the two definitions are chained.**
    - ▷ *i.e., function call and return variable.*
  - **When the function body is closed, the return variable definition disappears.**

```
[PASCAL]
function f: integer;
begin
    if global > 1 then f := f +1;
    return
end
```

Forward reference

- **Definition:**
  - **A name that is used before its definition is given.**
  - **To allow mutually referenced and linked data types, names can sometimes be used before it is declared.**
- **Possible usages:**
  - **GOTO labels.**
  - **Recursively defined pointer types.**
  - **Mutually or recursively called procedures.**

GOTO labels

- If labels must be defined before its usage, then one-pass compiler suffices.
- Otherwise, we need either multi-pass compiler or one with "back-patching".
  - Avoid resolving a symbol until all its possible definitions have been seen.
  - In C, ADA and languages commonly used today, the scope of a declaration extends only from the point of declaration to the end of the containing scope.

Recursively defined pointer types

- Determine the element type if possible;
- Chaining together all references to a pointer to type T until the end of the type declaration;
- All type names can then be looked up and resolved.
- Example:

```
[PASCAL]
type link = ^ cell;
cell = record
         info: integer;
         next: link;
      end;
```

Mutually or recursively called procedures

- **Need to know the specification of a procedure before its definition.**
- **Example:**

```
procedure A()
{
          ...
          call B();
          ...
}
...
procedure B()
{
            ...
            call A();
            ...
}
```

Type equivalent and others

- **How to determine whether two types are equivalent?**
  - **Structural equivalence.**
    - ▷ *Express a type definition via a directed graph where nodes are the elements and edges are the containing information.*
    - ▷ *Two types are equivalent if and only if their structures (graphs) are the same.*
    - ▷ *A difficult job for compilers.*

```
entry = record                          [entry]
          info : real;                     +-----> [info] <real>
          coordinates : record             +-----> [coordinates]
                   x : integer;                    +----> [x] <integer>
                   y : integer;                    +----> [y] <integer>
                   end
        end
```

  - **Name equivalence.**
    - ▷ *Two types are equivalent if and only if their names are the same.*
    - ▷ *An easy job for compilers, but the coding takes more time.*
- **Symbol table is needed during compilation, might also be needed during debugging.**

Usage of symbol table in YACC

- **Define symbol table routines:**
  - **Find_in_symbol_table**($name$,$scope$): **check whether a name within a particular scope is currently in the symbol table or not.**
    - ▷ *return not found or*
    - ▷ *an entry in the symbol table*
  - **Insert_into_symbol_table**($name$,$scope$)
    - ▷ *Return the newly created entry.*
  - **Delete_from_symbol_table**($name$,$scope$)
- **For interpreters:**
  - **Use the attributes associated with the symbols to hold temporary values.**
  - **Use a structure to record all attributes.**

```
struct YYTYPE {
        char type;       /* data type of a variable */
        int value;
        int addr;
        char * namelist; /* list of names */
}
```

Hints on YACC coding (1/2)

- **Declaration:**
  - $D \rightarrow TL$
    - ▷ **{ insert each name in $2.namelist into symbol table, i.e., use Find_in_symbol_table to check for possible duplicated names;**
    - ▷ **use Insert_into_symbol_table to insert each name in the list with the type $1.type;**
    - ▷ **allocate** $sizeof(\$1.type)$ **bytes**
    - ▷ **record the storage address in the symbol table entry}**
  - $T \rightarrow int$
    - ▷ **{$$.type = int}**
  - $L \rightarrow L, id$
    - ▷ **{insert the new name yytext into $1.namelist;**
    - ▷ **return $$.namelist as $1.namelist}**

    $\mid id$
    - ▷ **{the variable name is in yytext;**
    - ▷ **create a list of one name, i.e., yytext, $$.namelist}**

Hints on YACC coding (2/2)

- **Usage of variables:**
  - $Assign\_S \rightarrow L\_var := Expression;$
    - ▷ ***{$1.addr is the address of the variable to be stored;***
    - ▷ ***$3.value is the value of the expression;***
    - ▷ ***generate code for storing $3.value into $1.addr}***
  - $L\_var \rightarrow id$
    - ▷ ***{ use Find_in_symbol_table to check whether yytext is already declared;***
    - ▷ ***$$.addr = storage address}***
  - $Expression \rightarrow Expression + Expression$
    - ▷ ***{$$.value = $1.value + $3.value}***

      $| \ Expression - Expression$

    - ▷ ***{$$.value = $1.value - $3.value}***

      $\ldots$

      $| \ id$

    - ▷ ***{ use Find_in_symbol_table to check whether yytext is already declared;***
    - ▷ ***$$.value = the value of the variable yytext}***