Symbol Table

ALSU Textbook Chapter 2.7 and 6.5

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Definition

- **Symbol table: A data structure used by a compiler to keep track of semantics of names.**
  - **Data type.**
  - **When is used: scope.**
    - *The effective context where a name is valid.*
  - **Where it is stored: storage address.**
- **Operations:**
  - **Find: whether a name has been used.**
  - **Insert: add a name.**
  - **Delete: remove a name when its scope is closed.**

Some possible implementations

- **Unordered list:**
  - ▷ *for a very small set of variables;*
  - ▷ *coding is easy, but performance is bad for large number of variables.*
- **Ordered linear list:**
  - ▷ *use binary search;*
  - ▷ *insertion and deletion are expensive;*
  - ▷ *coding is relatively easy.*
- **Binary search tree:**
  - ▷ $O(\log n)$ *time per operation (search, insert or delete) for* n *variables;*
  - ▷ *coding is relatively difficult.*
- **Hash table:**
  - ▷ *most commonly used;*
  - ▷ *very efficient provided the memory space is adequately larger than the number of variables;*
  - ▷ *performance maybe bad if unlucky or the table is saturated;*
  - ▷ *coding is not too difficult.*

Hash table

- **Hash function $h(n)$: returns a value from $0, \ldots, m-1$, 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 $(h(n)+2) \bmod m, \ldots,$ $(h(n)+i) \bmod m$.**
  - **Chaining: most popular.**
    - ▷ ***Keep a chain on the items with the same hash value.***
  - **Quadratic-rehashing:**
    - ▷ ***try*** $(h(n)+1^2) \bmod m$***, and then***
    - ▷ ***try*** $(h(n)+2^2) \bmod m$***, and then***
    - ▷ $\cdots$
    - ▷ ***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 a symbol table

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

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	STORAGE ADDR	...
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	STORAGE ADDR	...
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

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

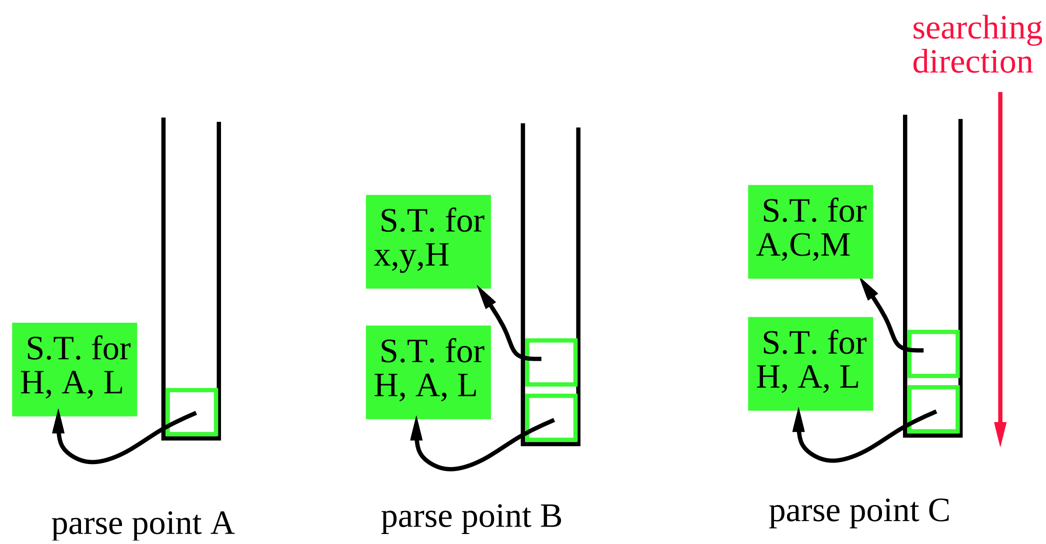
Sample code: block structure

```
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 */
      /* A used here is char */
      ...
      }
}
```

Multiple symbol tables in one 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 */
     ...
     }
}
```



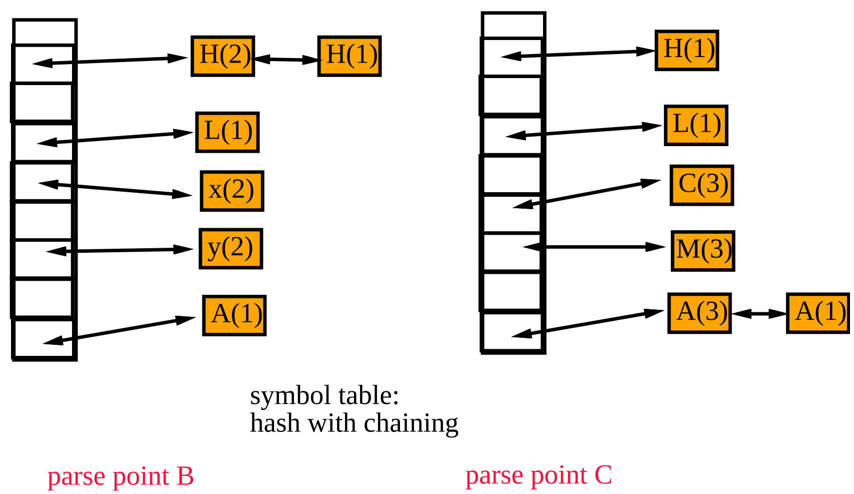
Pros and cons for multiple symbol tables

- **Advantage:**
  - **Easy to close a scope.**
- **Disadvantage: Difficulties encountered when a new scope is opened.**
  - **Need to allocate adequate amount of entries for each symbol table if it is a hash table.**
    - ▷ ***Waste lots of spaces.***
    - ▷ ***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 symbol table with chaining (1/2)

- **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.*

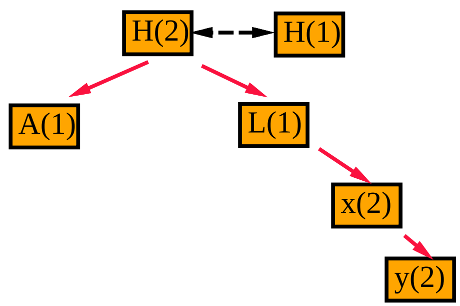
```
main()
{    /* open a new scope */
     int H,A,L;  /* parse point A */
     ...
     { /* open another new scope */
       float x,y,H; /* parse point B */
       ...
       /* x and y can only be used here */
       /* H used here is float */
       ...
     } /* close an old scope */
     ...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



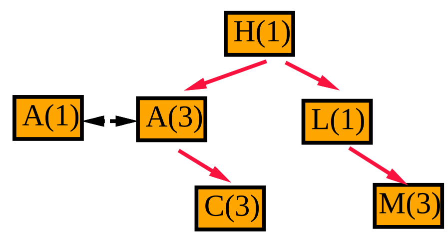
One symbol table with chaining (2/2)

- **A second coding choice:**
  - **Binary search tree with chaining.**
    - *Use a doubly linked list to chain all entries with the same name.*

```
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.**
  - **Little overhead in opening a scope.**
- **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 if needed.**

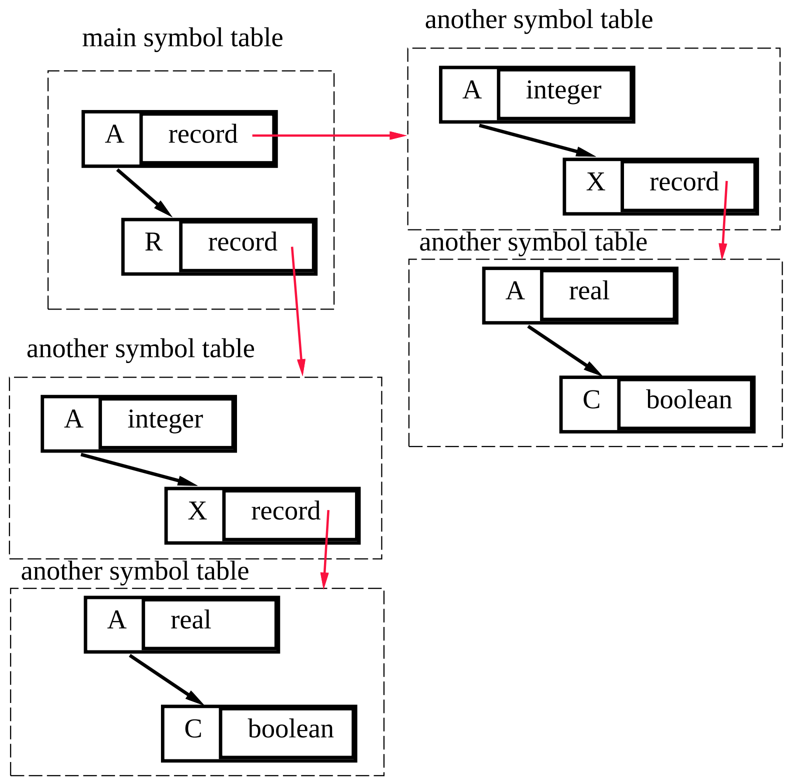
Records and fields

- 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.*

Locating field names

- **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, succeed only if it matches the name and 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 defined in this scope 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 that are declared.**
- **Possible implementations:**
  - **Multi-pass compiler.**
  - **Back-patching.**
    - ▷ ***Avoid resolving a symbol until all possible places where symbols can be declared 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.***
- **If names must be defined before their usages, then one-pass compiler with normal symbol table techniques suffices.**
- **Some possible usages for forward referencing:**
  - **GOTO labels.**
  - **Recursively defined pointer types.**
  - **Mutually or recursively called procedures.**

GOTO labels

- **Some language like C uses labels without declarations.**
  - **Implicit declaration.**
- **Example:**

```
[C]
L0:
    ...
    goto L0;
    ...
    goto L1;
    ...
L1:
    ...
```

Recursively defined pointer types

- **Determine the element type if possible;**
- **Chaining together all references to unknown type names until the end of the type declaration;**
- **All type names can then be looked up and resolved.**
  - **Names that are unable to resolved are undeclared type names.**
- **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.**
  - **Some languages require prototype definitions.**
- **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 (labeled 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, and might also be needed during debugging.**

Usage of symbol table with YACC

- **Define symbol table routines:**
  - **lookup**($name$,$scope$): **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;***
  - **enter**($name$,$scope$)
    - ▷ ***Return the newly created entry.***
- **For interpreters:**
  - **Use the attributes associated with the symbols to hold temporary values.**
  - **Use a structure with maybe some unions to record all attributes.**

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

YACC coding: declaration I

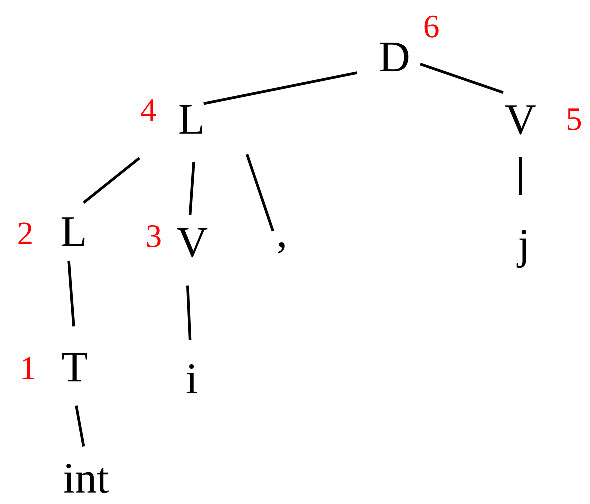
- **Declaration:**
  - $D \rightarrow L\ V$
    - ▷ ***{use lookup to check whether \$2.name has been declared;***
    - ▷ ***use enter to insert \$2.name with the type \$1.type;***
    - ▷ ***allocate*** $sizeof(\$1.type)$ ***bytes;***
    - ▷ ***record the storage address in the symbol table entry;***
    - ▷ ***\$\$.type = \$1.type;}***
  - $L \rightarrow L\ V\ ,$
    - ▷ ***{use lookup to check whether \$2.name has been declared;***
    - ▷ ***use enter to insert \$2.name with the type \$1.type;***
    - ▷ ***allocate*** $sizeof(\$1.type)$ ***bytes;***
    - ▷ ***record the storage address in the symbol table entry;***
    - ▷ ***\$\$.type = \$1.type;}***

    $\mid T$
    - ▷ ***{\$\$.type = \$1.type;}***
  - $V \rightarrow id$
    - ▷ ***{save*** $yytext$ ***into \$\$.name;}***
  - $T \rightarrow int$
    - ▷ ***{\$\$.type = int;}***

Grammar I

- **Grammar I: using only simple synthesized attributes**
  - ▷ $D \rightarrow L\ V$
  - ▷ $L \rightarrow L\ V, \mid T$
  - ▷ $V \rightarrow id$
  - ▷ $T \rightarrow int$
- **Input:** $\boxed{\textbf{int i,j}}$
  - ▷ ***right most derivation***
  - ▷ $D \Longrightarrow L\ V \Longrightarrow L\ j \Longrightarrow L\ V\ ,\ j \Longrightarrow L\ i\ ,\ j \Longrightarrow T\ i\ ,\ j \Longrightarrow int\ i\ ,\ j$

1. ***Known the type is integer***
2. ***Pass the type to the parent node***
3. ***Save the name "i"***
4. ***Symbol table processing for "i"***
5. ***Save the name "j"***
6. ***Symbol table processing for "j"***



YACC coding: declaration II

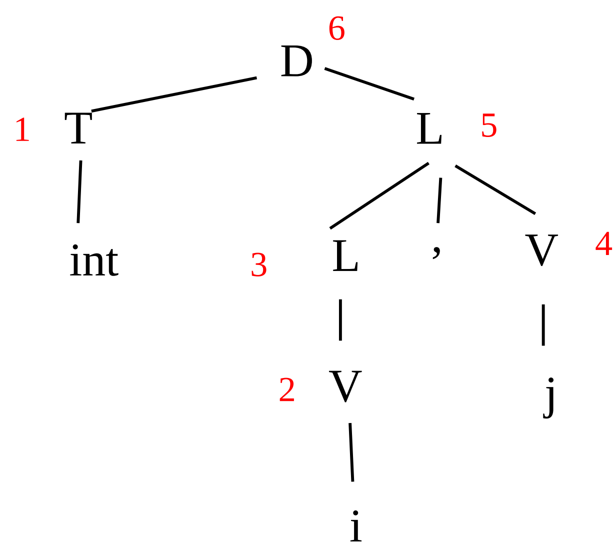
- **Declaration:**
  - $D \rightarrow T\ L$
    - ▷ ***{use lookup to check each name in the list $2.namelist for possible duplicated names;***
    - ▷ ***if it is not duplicated, then use enter to insert each name in the list $2.namelist with the type $1.type;***
    - ▷ ***allocate*** $sizeof(\$1.type)$ ***bytes;***
    - ▷ ***record the storage address in the symbol table entry;}***
  - $T \rightarrow int$
    - ▷ ***{$$.type = int;}***
  - $L \rightarrow L\ ,\ V$
    - ▷ ***{append the new name $3.name into the list $1.namelist;***
    - ▷ ***return $$.namelist as $1.namelist;}***

    $\mid V$
    - ▷ ***{the variable name is in $1.name;***
    - ▷ ***create a list of one name, i.e., $1.name, $$.namelist;}***
  - $V \rightarrow id$
    - ▷ ***{save*** $yytext$ ***into $$.name;}***

Grammar II

- **Grammar II: using a list of names**
  - $D \rightarrow T\ L$
  - $L \rightarrow L\ ,\ V \mid V$
  - $V \rightarrow id$
  - $T \rightarrow int$
- **Input:** $\boxed{\textbf{int i,j}}$
  - ***right most derivation***
  - $D \Longrightarrow T\ L \Longrightarrow T\ L\ ,V \Longrightarrow T\ L\ ,\ j \Longrightarrow T\ V\ ,\ j \Longrightarrow T\ i\ ,\ j \Longrightarrow int\ i\ ,\ j$

1. ***Known the type is integer***
2. ***Save the name "i"***
3. ***Create a name list***
4. ***Save the name "j"***
5. ***Append the new name***
6. ***Symbol table operations***



YACC coding: expressions and assignments

- **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 lookup 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 lookup to check whether*** $yytext$ ***is***
    - ▷ ***already declared;***
    - ▷ ***if no, error*** $\cdots$
    - ▷ ***if not, $$.value = the value of the variable*** $yytext$***}***