5. Tabela de Símbolos

5.1 Visão Geral

5.2 Símbolos

5.3 Escopos

5.4 Tipos

5.5 Universo

Responsabilidades da Tabela de Símbolos

1. Armazenar todos os nomes declarados e seus atributos

- tipo
- valor (para constantes)
- endereço (para variáveis locais e argumentos de métodos)
- parâmetros (para métodos)
- ...

2. É usada para recuperar atributos de um nome

- Mapeamento: nome ⬇ (tipo, valor, endereço, ...)

Conteúdo da Tabela de Símbolos

- *Nodos Símbolo*: informações sobre os nomes declarados
- *Nodos Estutura*: informações sobre estruturas de tipos

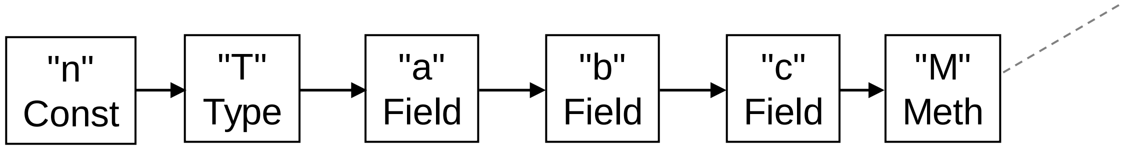
=> mais adequadamente implementadas como uma estrutura dinâmica
- listas lineares
- árvore binária
- tabela hash

Symbol Table as a Linear List

Given the following declarations

```
const int n = 10;
class T { ... }
int a, b, c;
void M () { ... }
```

we get the following linear list



for every declared name there is a Symbol node

+ simple
+ declaration order is retained (important if addresses are assigned only later)

- slow if there are many declarations

Basic interface

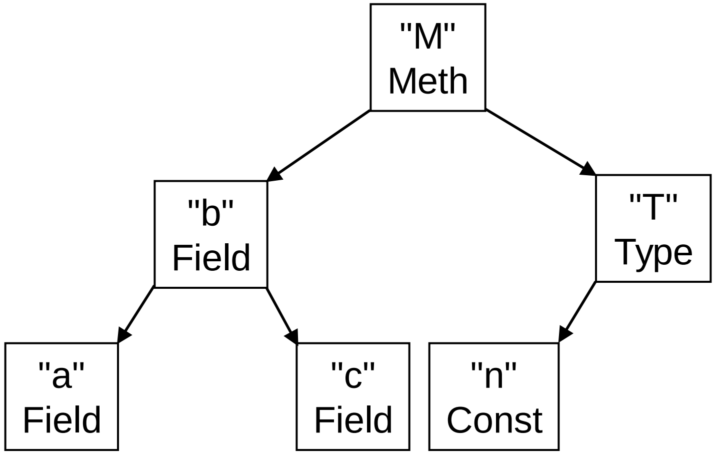
```
public class Tab {
    public static Symbol Insert (Symbol.Kinds kind, string name, ...);
    public static Symbol Find (string name);
}
```

Symbol Table as a Binary Tree

Declarations

```
const int n = 10;
class T { ... }
int a, b, c;
void M () { ... }
```

Resulting binary tree



+ fast

- can degenerate unless it is balanced
- larger memory consumption
- declaration order is lost

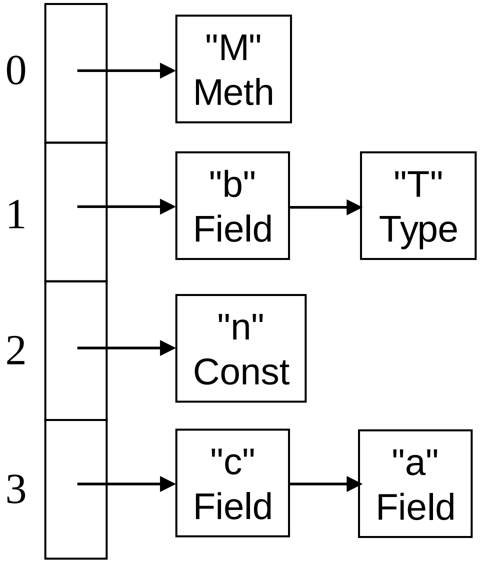
Only useful if there are many declarations

Symbol Table as a Hashtable

Declarations

```
const int n = 10;
class T { ... }
int a, b, c;
void M () { ... }
```

Resulting hashtable



+ fast

- more complicated than a linear list
- declaration order is lost

For our purposes a linear list is sufficient

- Every scope is a list of its own anyway
- A scope has hardly more than 10 names

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Symbol Nodes

Every declared name is stored in a Symbol node

Kinds of symbols in Z#

- constants
- global variables
- fields
- method arguments
- local variables
- types
- methods
- program

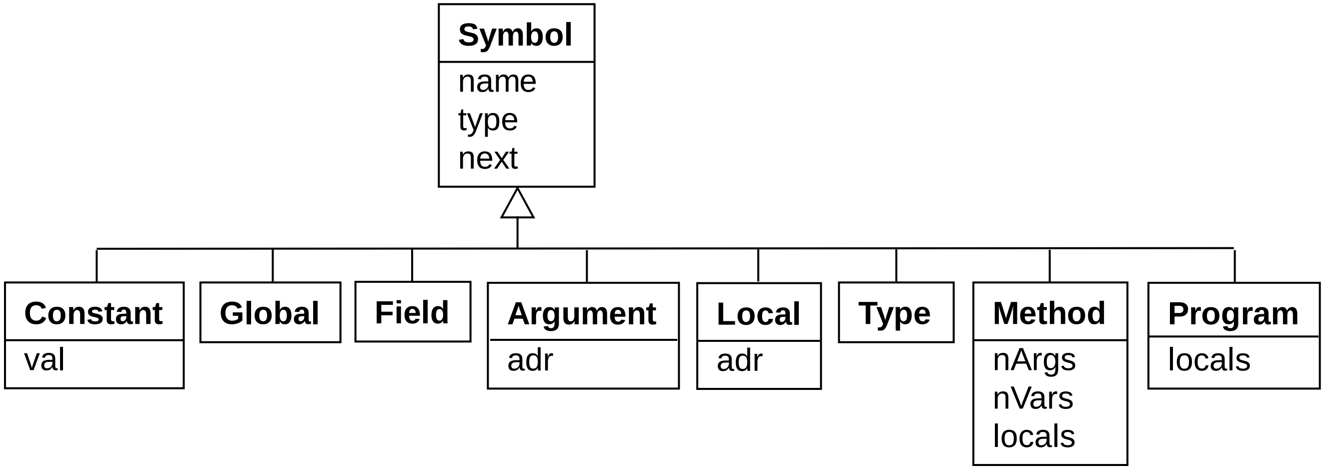
```
public enum Kinds {
    Const,
    Global,
    Field,
    Arg,
    Local,
    Type,
    Meth,
    Prog
}
```

What information is needed about objects?

• for all symbols	name, type structure, symbol kind, pointer to the next symbol
• for constants	value
• for method arguments	address (= order of declaration)
• for local variables	address (= order of declaration)
• for methods	number of arguments and local variables, local symbols (args + local vars)
• for program	global symbols (= local to the program)
• for global vars, fields, types	---

Possible Object-oriented Architecture

Possible class hierarchy of objects



However, this is too complicated because it would require too many type casts

```
Symbol sym = Tab.Find("x");
if (sym is Argument) ((Argument) sym).adr = ...;
else if (sym is Method) ((Method) sym).nArgs = ...;
...
```

Therefore we choose a "flat implementation": all information is stored in a single class.
This is ok because

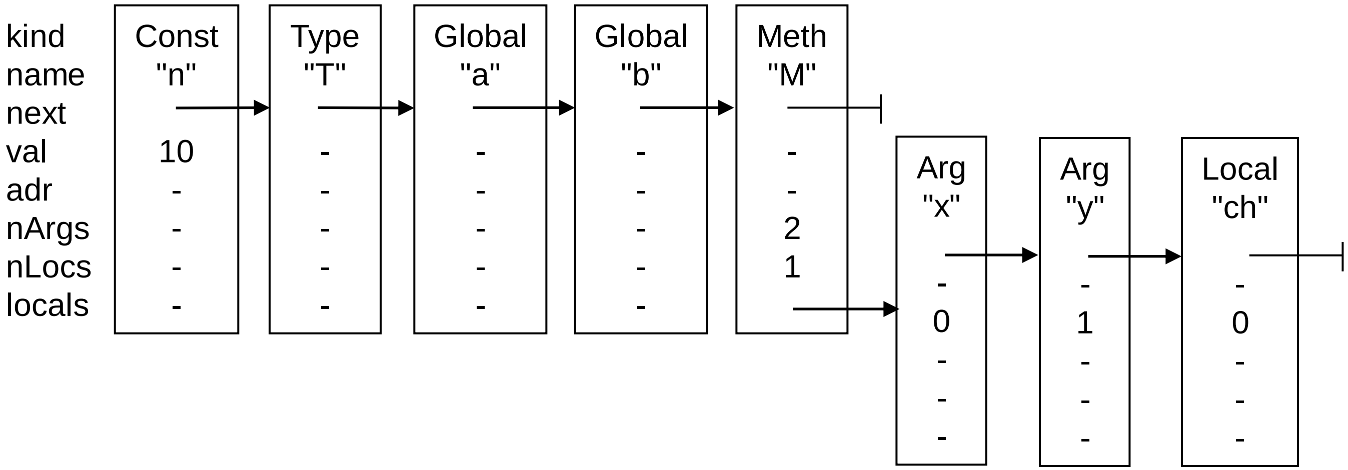
- extensibility is not required: we never need to add new object variants
- we do not need dynamically bound method calls

Class Symbol

```
class Symbol {
    public enum Kinds { Const, Global, Field, Arg, Local, Type, Meth, Prog }
    Kinds    kind;
    string   name;
    Struct   type;
    Symbol   next;
    int      val;          // Const: value
    int      adr;          // Arg, Local: address
    int      nArgs;        // Meth: number of arguments
    int      nLocs;        // Meth: number of local variables
    Symbol   locals;       // Meth: parameters & local variables; Prog: symbol table of program
}
```

Example

```
const int n = 10;
class T { ... }
int a, b;
void M (int x, int y)
    char ch;
{ ... }
```



kind	Const	Type	Global	Global	Meth	Arg	Arg	Local
name	"n"	"T"	"a"	"b"	"M"	"x"	"y"	"ch"
next	→	→	→	→	⊣	→	→	⊣
val	10	-	-	-	-	-	-	-
adr	-	-	-	-	-	0	1	0
nArgs	-	-	-	-	2	-	-	-
nLocs	-	-	-	-	1	-	-	-
locals	-	-	-	-	→	-	-	-

Entering Names into the Symbol Table

The following method is called whenever a name is declared

```
Symbol sym = Tab.Insert(kind, name, type);
```

- creates a new object node with *kind*, *name*, *type*
- checks if *name* is already declared (if so => error message)
- assigns successive addresses to variables and fields
- enters the declaration level for variables (0 = global, 1 = local)
- appends the new node to the end of the symbol table list
- returns the new node to the caller

Example for calling *Insert()*

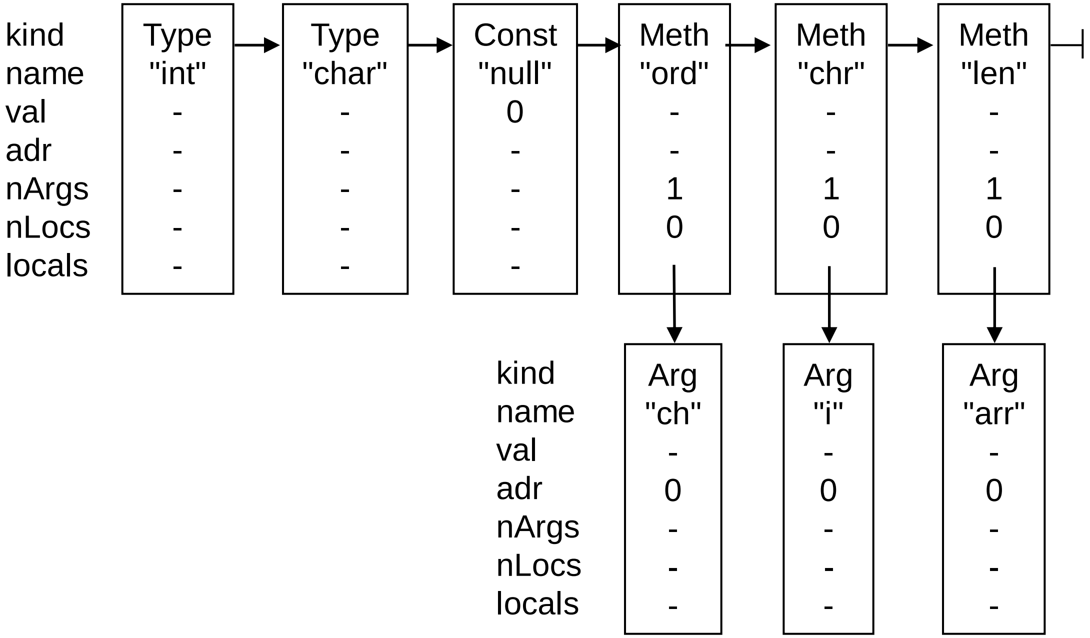
```
VarDecl<❉Symbol.Kinds kind>
=  Type<✸type>
   ident                    (. Tab.insert(Obj.Var, name, type); .)
   { ";" ident              (. Tab.insert(Obj.Var, name, type); .)
   }.
```

Predeclared Names

Which names are predeclared in Z#?

- Standard types: int, char
- Standard constants: null
- Standard methods: ord(ch), chr(i), len(arr)

Predeclared names are also stored in the symbol table ("Universe")



kind	Type	Type	Const	Meth	Meth	Meth
name	"int"	"char"	"null"	"ord"	"chr"	"len"
val	-	-	0	-	-	-
adr	-	-	-	-	-	-
nArgs	-	-	-	1	1	1
nLocs	-	-	-	0	0	0
locals	-	-	-			

kind	Arg	Arg	Arg
name	"ch"	"i"	"arr"
val	-	-	-
adr	0	0	0
nArgs	-	-	-
nLocs	-	-	-
locals	-	-	-

Special Names as Keywords

***int* and *char* could also be implemented as keywords.**

requires a special treatment in the grammar

```
Type<✸Struct type>
=  ident                (. Symbol sym = Tab.Find(token.str); type = sym.type; .)
|  "int"                (. type = Tab.intType; .)
|  "char"               (. type = Tab.charType; .)
.
```

It is simpler to have them predeclared in the symbol table.

```
Type<✸Struct type>
=  ident                (. Symbol sym = Tab.Find(token.str); type = sym.type; .)
```

+ uniform treatment of predeclared and user-declared names
- one can redeclare "int" as a user type

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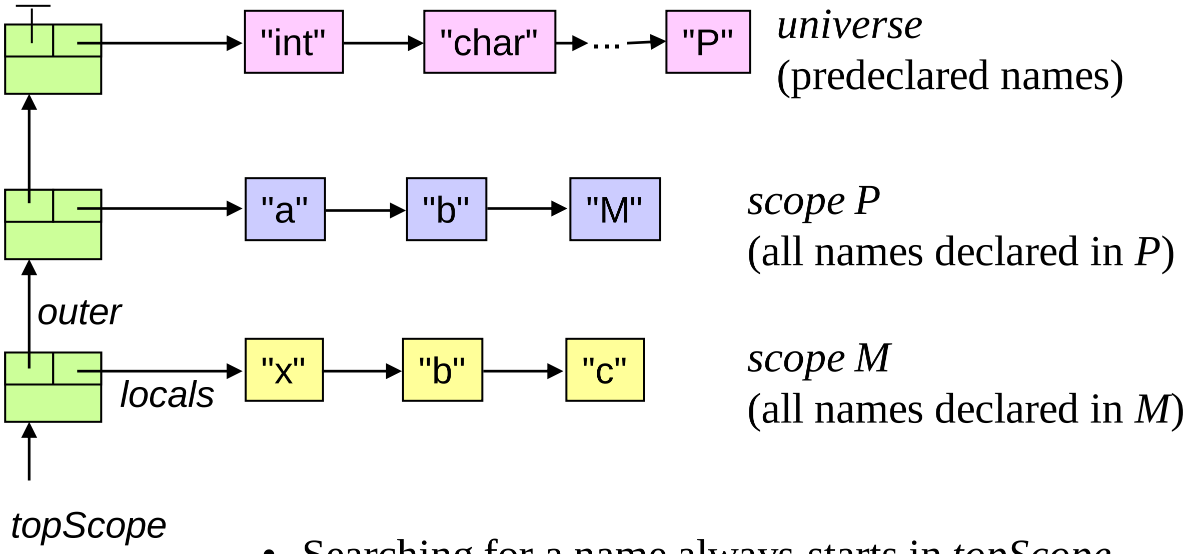
Scope = Range in which a Name is Valid

There are separate scopes (object lists) for

- the "universe" contains the predeclared names (and the program symbol)
- the program contains global names (= constants, global variables, classes, methods)
- every method contains local names (= argument and local variables)
- every class contains fields

Example

```
class P
    int a, b;
{
    void M (int x)
        int b, c;
    {
        ...
    }
    ...
}
```



- Searching for a name always starts in *topScope*
- If not found, the search continues in the next outer scope
- Example: search *b*, *a* and *int*

Scope Nodes

```
class Scope {
    Scope     outer;    // to the next outer scope
    Symbol  locals;   // to the symbols in this scope
    int         nArgs;   // number of arguments in this scope (for address allocation)
    int         nLocs;   // number of local variables in this scope (for address allocation)
}
```

Method for opening a scope

```
static void OpenScope () { // in class Tab
    Scope s = new Scope();
    s.nArgs = 0; s.nLocs = 0;
    s.outer = topScope;
    topScope = s;
}
```

- called at the beginning of a method or class
- links the new scope with the existing ones
- new scope becomes *topScope*
- *Tab.Insert()* always creates symbols in *topScope*

Method for closing a scope

```
static void CloseScope () { // in class Tab
    topScope = topScope.outer;
}
```

- called at the end of a method or class
- next outer scope becomes *topScope*

Entering Names in Scope

Names are always entered in *topScope*

```
class Tab {
    Scope topScope;   // Zeiger auf aktuellen Scope
    ...
    static Symbol Insert (Symbol.Kinds kind, string name, Struct type) {
        //--- create symbol node
        Symbol sym = new Symbol(name, kind, type);

        if (kind == Symbol.Kinds.Arg) sym.adr = topScope.nArgs++;
        else if (kind == Symbol.Kinds.Local) sym.adr = topScope.nLocs++;

        //--- insert symbol node
        Symbol cur = topScope.locals, last = null;
        while (cur != null) {
            if (cur.name == name) Error(name + " declared twice");
            last = cur; cur = cur.next;
        }
        if (last == null) topScope.locals = sym;
        else last.next = sym;
        return sym;
    }
    ...
}
```

Opening and Closing a Scope

```
MethodDecl                (. Struct type; .)
= Type<✸type>
  ident                   (. curMethod = Tab.insert(Symbol.Kinds.Meth, token.str, type);
                             Tab.OpenScope();
                           .)
  ...
  "{"
  ...
  "}"                     (. curMethod.nArgs = topScope.nArgs;
                             curMethod.nLocs = topScope.nLocs;
                             curMethod.locals = Tab.topScope.locals;
                             Tab.CloseScope();
                           .)
  .
```

global variable

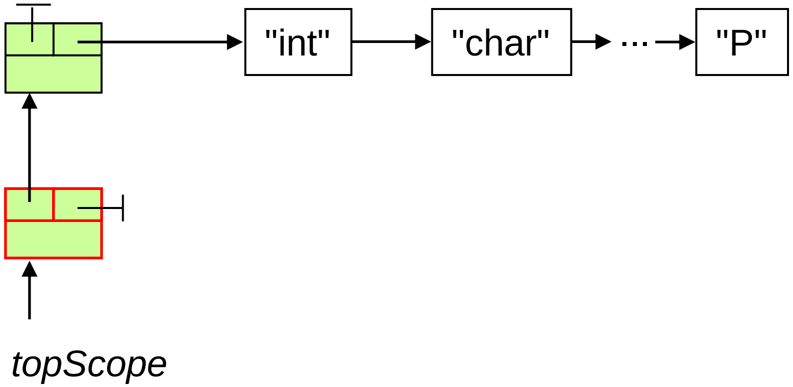
Note

- The method name is entered in the method's enclosing scope
- Before a scope is closed its local objects are assigned to *m.locals*
- Scopes are also opened and closed for classes

Example

class P

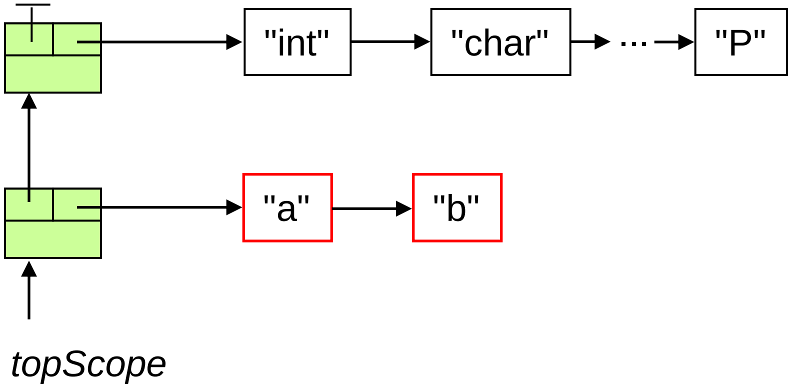
Tab.OpenScope();



Example

```
class P
    int a, b;
{
```

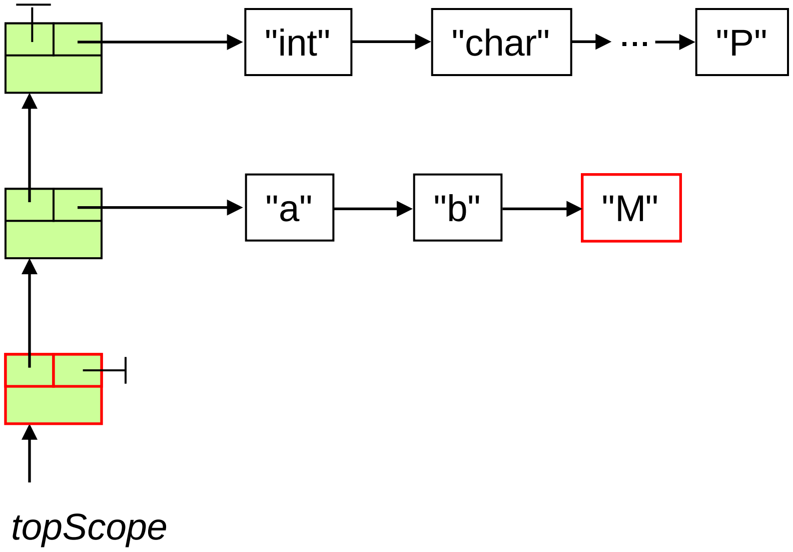
```
Tab.Insert(..., "a", ...);
Tab.Insert(..., "b", ...);
```



Example

```
class P
    int a, b;
{
    void M ()
```

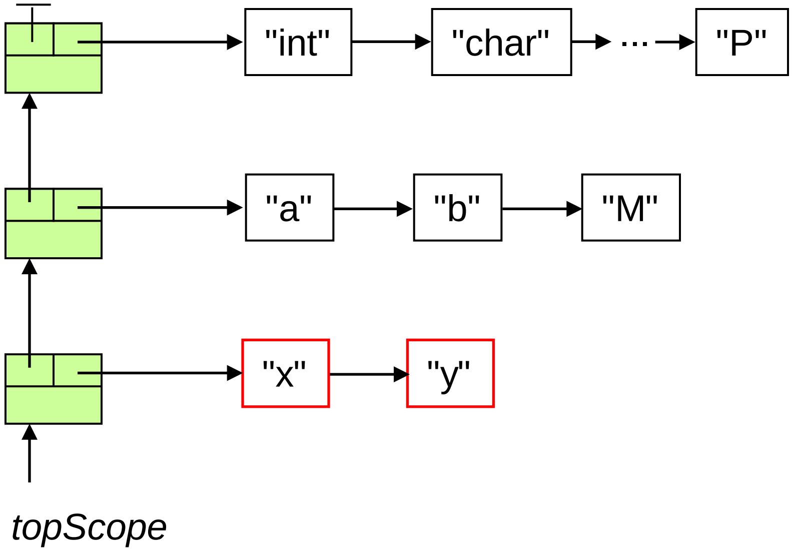
```
Tab.Insert(..., "M", ...);
Tab.OpenScope();
```



Example

```
class P
    int a, b;
{
    void M ()
        int x, y;
```

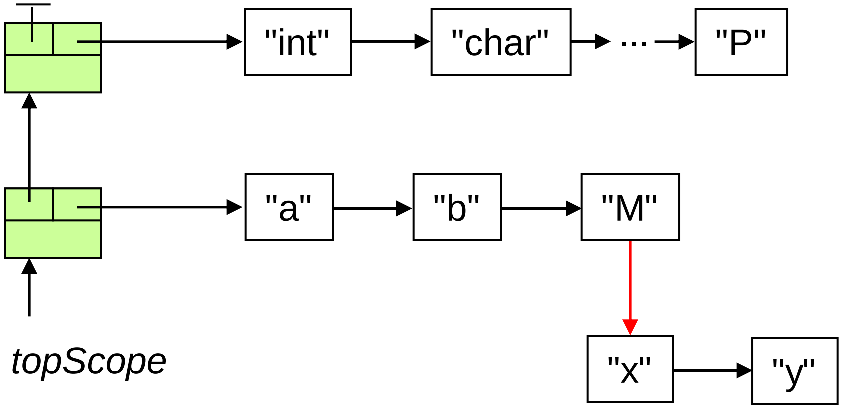
```
Tab.Insert(..., "x", ...);
Tab.Insert(..., "y", ...);
```



Example

```
class P
    int a, b;
{
    void M ()
        int x, y;
    {
        ...
    }
```

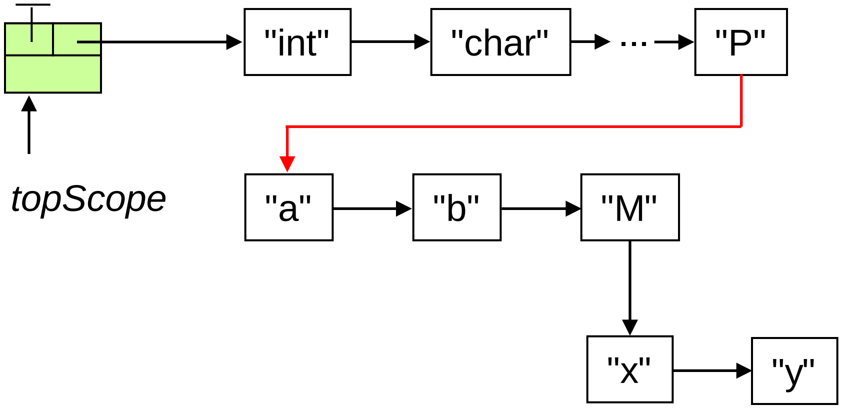
```
meth.locals =
    Tab.topScope.locals;
Tab.CloseScope();
```



Example

```
class P
    int a, b;
{
    void M ()
        int x, y;
    {
        ...
    }
    ...
}
```

```
prog.locals =
    Tab.topScope.locals;
Tab.CloseScope();
```



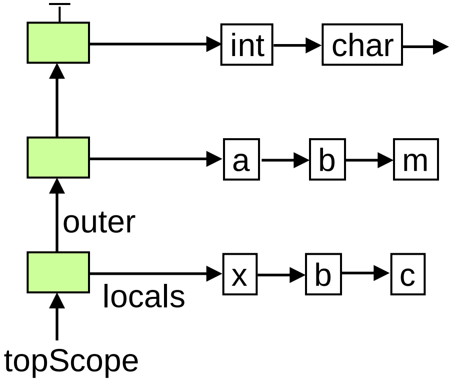
Searching Names in the Symbol Table

The following method is called whenever a name is used

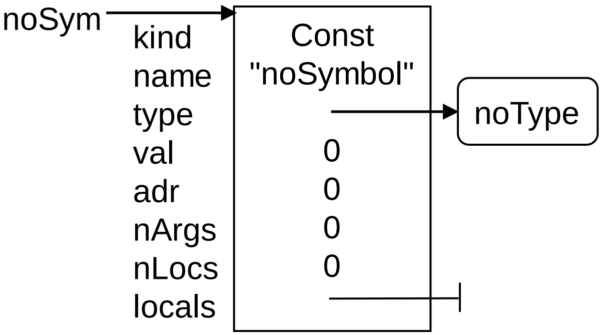
```
Symbol sym = Tab.Find(name);
```

- Lookup starts in *topScope*
- If not found, the lookup is continued in the next outer scope

```
static Symbol Find (string name) {
    for (Scope s = topScope; s != null; s = s.outer)
        for (Symbol sym = s.locals; sym != null; sym = sym.next)
            if (sym.name == name) return sym;
    Parser.Error(name + " is undeclared");
    return noSym;
}
```



If a name is not found the method returns *noSym*



- predeclared dummy symbol
- better than *null*, because it avoids aftereffects (exceptions)

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Types

Every object has a type with the following properties

- size (in Z# determined by metadata)
- structure (fields for classes, element type for arrays, ...)

Kinds of types in Z#?

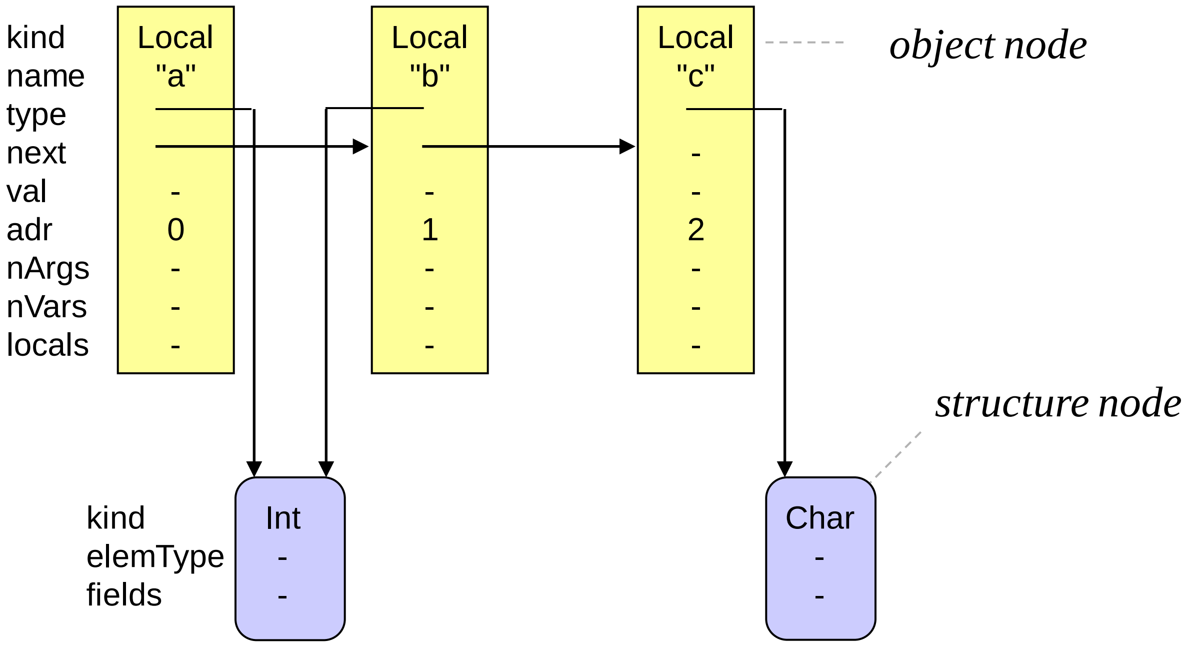
- primitive types (int, char)
- arrays
- classes

Types are represented by structure nodes

```
class Struct {
   public enum Kinds { None, Int, Char, Arr, Class }
   Kinds   kind;
   Struct  elemType;  // Arr: element type
   Symbol               fields;          // Class: list of fields
}
```

Structure Nodes for Primitive Types

```
int a, b;
char c;
```



kind	Local	Local	Local
name	"a"	"b"	"c"
type			
next			-
val	-	-	-
adr	0	1	2
nArgs	-	-	-
nVars	-	-	-
locals	-	-	-

object node

kind	Int	Char
elemType	-	-
fields	-	-

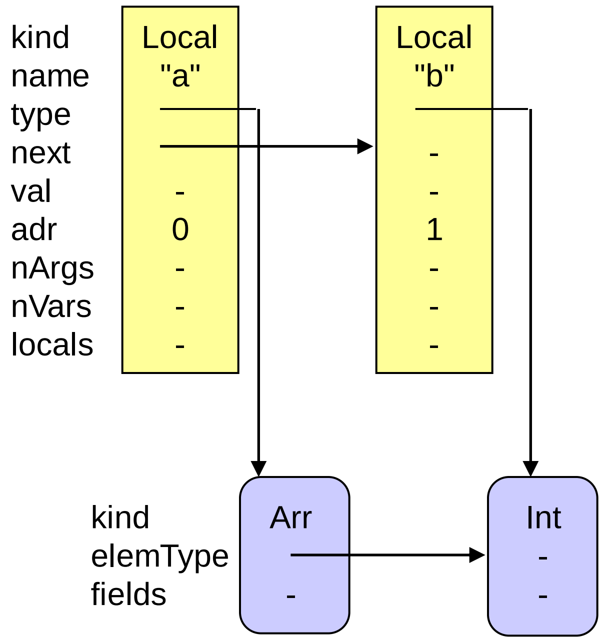
structure node

There is just one structure node for *int* in the whole symbol table. All symbols of type *int* reference this one.

The same is true for structure nodes of type *char*.

Structure Nodes for Arrays

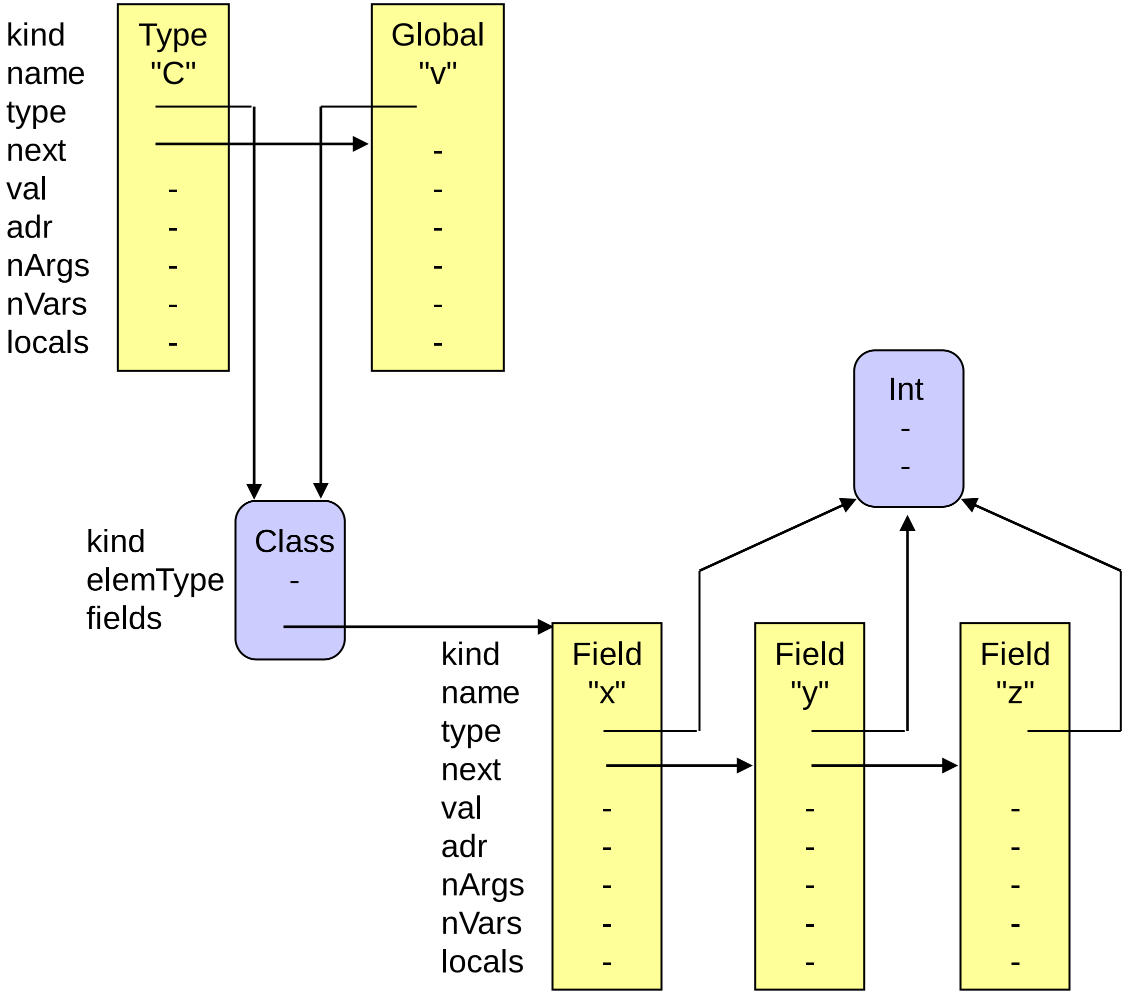
```
int[] a;
int b;
```



The length of an array is statically unknown.
It is stored in the array at run time.

Structure Nodes for Classes

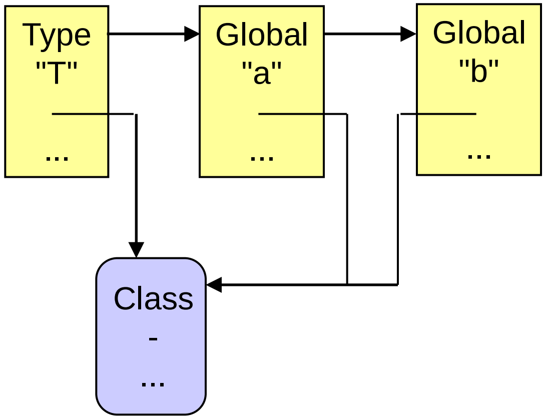
```
class C {
    int x;
    int y;
    int z;
}
C v;
```



Type Compatibility: Name Equivalence

Two types are equal if they are represented by the same type node
(i.e. if they are denoted by the same type name)

```
class T { ... }
T a;
T b;
```



The types of *a* and *b* are the same

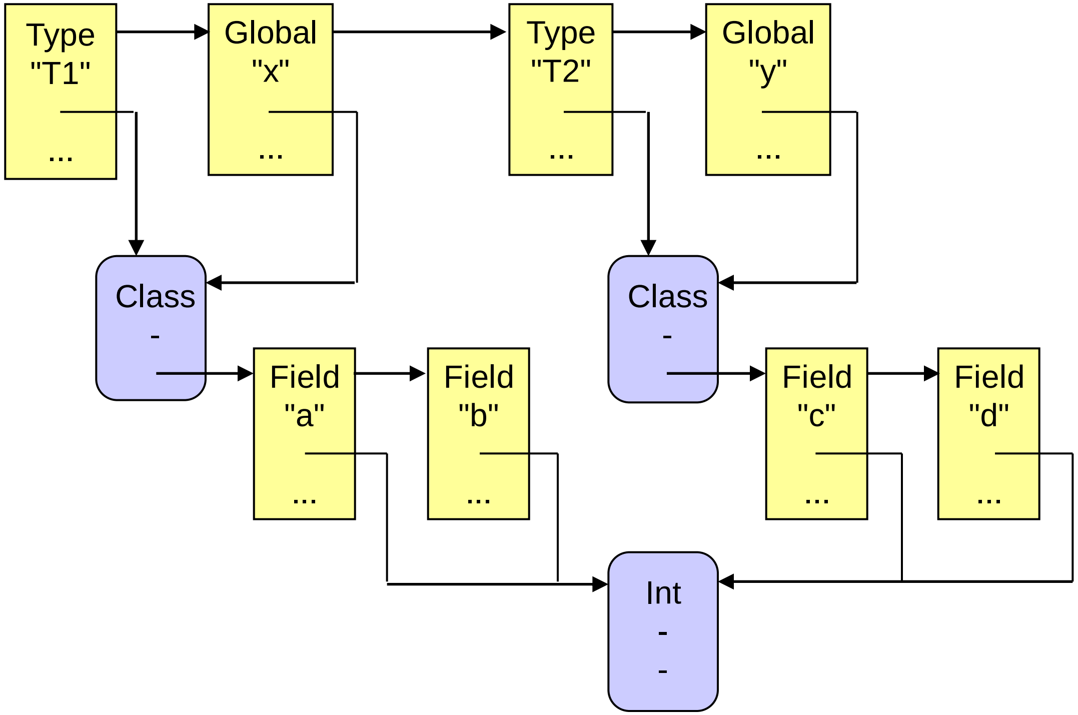
Name equivalence is used in Java, C/C++/C#, Pascal, ..., Z#

Exception
In Java (and Z#) two array types are the same if they have the same element types!

Type Compatibility: Structural Equivalence

Two types are the same if they have the same structure
(i.e. the same fields of the same types, the same element type, ...)

```
class T1 { int a, b; }
class T2 { int c, d; }
T1 x;
T2 y;
```



The types of *x* and *y* are equal (but not in Z#!)

Structural equivalence is used in Modula-3 but not in Z# and most other languages!

Methods for Checking Type Compatibility

```
class Struct {
    ...
    // checks, if two types are compatible (e.g. in comparisons)
    public bool CompatibleWith (Struct other) {
        return this.Equals(other) ||
               this == Tab.nullType && other.IsRefType() ||
               other == Tab.nullType && this.isRefType();
    }

    // checks, if this can be assigned to dest
    public bool AssignableTo (Struct dest) {
        return this.Equals(dest) ||
               this == Tab.nullType && dest.IsRefType() ||
               kind == Kinds.Arr && dest.kind == Kinds.Arr && dest.elemType == Tab.noType;
    }
```

necessary for standard function len(arr)

```
    // checks, if two types are equal (structural equivalence for array, name equivalence otherwise)
    public bool Equals (Struct other) {
        if (kind == Kinds.Arr)
            return other.kind == Kinds.Arr && elemType.Equals(other.elemType);
        return other == this;
    }

    public bool IsRefType() { return kind == Kinds.Class || kind = Kinds.Arr; }
}
```

Solving LL(1) Conflicts with the Symbol Table

Method syntax in Z#

```
void Foo ()
    int a;
{
    a = 0; ...
}
```

Actually we are used to write it like this

```
void Foo () {
    int a;
    a = 0; ...
}
```

But this would result in an LL(1) conflict

First(*VarDecl*) ∩ First(*Statement*) = {*ident*}

```
Block        =  "{" { VarDecl | Statement } "}".
VarDecl      =  Type ident { "," ident }.
Type         =  ident [ "[" "]" ].
Statement    =  Designator "=" Expr ";"
             |  ... .
Designator   =  ident { "." ident | "[" Expr "]" }.
```

Solving the Conflict With Semantic Information

```
static void Block () {
    Check(Token.LBRACE);
    for (;;) {
        if (NextTokenIsType()) VarDecl();
        else if (la ∈ First(Statement))
Statement();
        else if (la ∈ {rbrace, eof}) break;
        else {
            Error("..."); ... recover ...
        }
    }
    Check(Token.RBRACE);
}
```

```
static bool NextTokenIsType() {
    if (la != ident) return false;
    Symbol sym = Tab.Find(laToken.str);
    return sym.kind == Symbol.Kinds.Type;
}
```

Block = "{" { VarDecl | Statement } "}".

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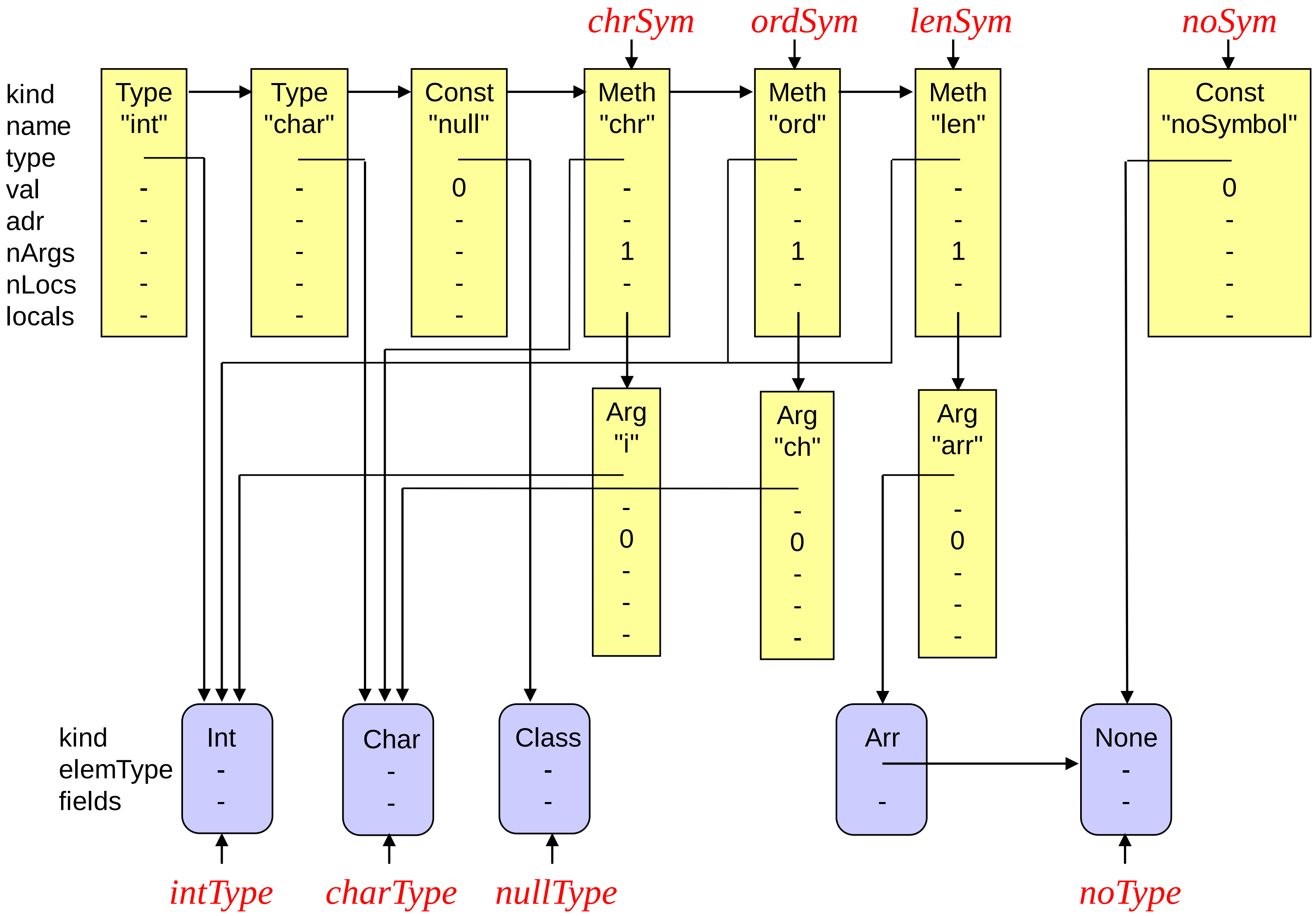
Structure of the "universe"



Interface of the Symbol Table

```
class Tab {
    static Scope     topScope;    // current top scope

    static Struct    intType;     // predefined types
    static Struct    charType;
    static Struct    nullType;
    static Struct    noType;

    static Symbol    chrSym;      // predefined symbols
    static Symbol    ordSym;
    static Symbol    lenSym;
    static Symbol    noSym;

    static Symbol    Insert (Symbol.Kinds kind, string name, Struct type) {...}
    static Symbol    Find (string name) {...}
    static void      OpenScope () {...}
    static void      CloseScope () {...}

    static void      Init () {...}    // builds the universe and initializes Tab
}
```