5. Symbol Table

5.1 Overview
5.2 Objects
5.3 Scopes
5.4 Types
5.5 Universe

Responsibilities of the Symbol Table

1. It maintains all declared names and their properties

- type
- value (for named constants)
- address (for variables, fields and methods)
- parameters (for methods)
- ...

2. It is used to retrieve the properties of a name

- Mapping: name $\Rightarrow$ (type, value, address, ...)

3. It manages the scopes of names

Contents of the symbol table

- *Object* nodes: Information about declared names
- *Structure* nodes: Information about type structures
- *Scope* nodes: for managing the visibility of names

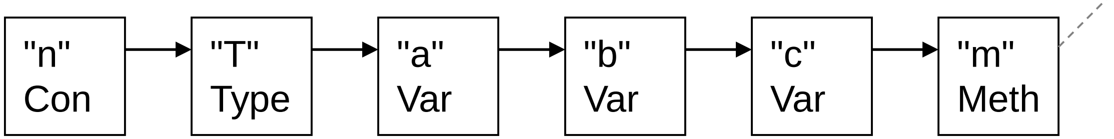
=> most suitably implemented as a dynamic data structure
(linear list, binary tree, hash table)

Symbol Table as a Linear List

Given the following declarations

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

we get the following linear list



for every declared name there is an Object 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 Obj insert (String name, ...);
    public static Obj find (String name);
}
```

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Object Nodes

Every declared name is stored in an object node

Kinds of names (objects) in MicroJava

- constants
- variables and fields
- types
- methods

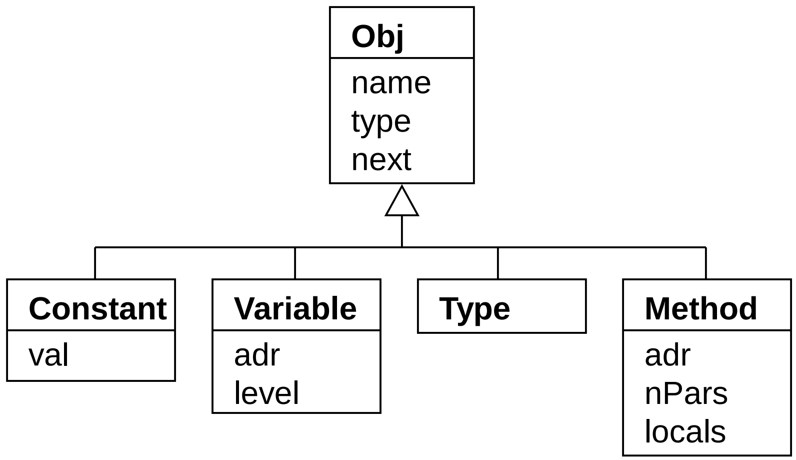
```
static final int
   Con   = 0,
   Var   = 1,
   Type  = 2,
   Meth  = 3;
```

What information is needed about objects?

• for all objects	name, type, object kind, pointer to the next object
• for constants	value
• for variables	address, declaration level
• for types	-
• for methods	address, number of parameters, parameters

Possible Object-oriented Architecture

Possible class hierarchy of objects



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

```
Obj obj = Tab.find("x");
if (obj instanceof Variable) {
    ((Variable)obj).adr = ...;
    ((Variable)obj).level = ...;
}
```

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

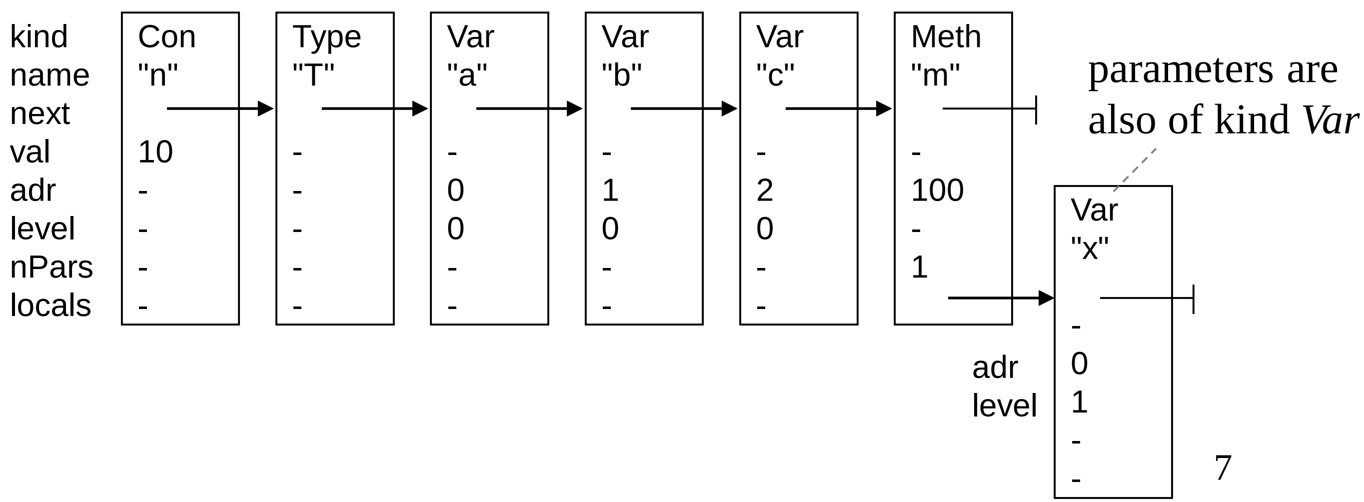
- extensibility is not required: we never need to add new object variants
- we do not need dynamically bound method calls

Class Obj

```
class Obj {
   static final int Con = 0, Var = 1, Type = 2, Meth = 3;
   int     kind;         // Con, Var, Type, Meth
   String  name;
   Struct  type;
   Obj     next;
   int     val;          // Con: value
   int     adr;          // Var, Meth: address
   int     level;        // Var: 0 = global, 1 = local
   int     nPars;        // Meth: number of parameters
   Obj     locals;       // Meth: parameters and local objects
}
```

Example

```
final int n = 10;
class T { ... }
int a, b, c;
void m(int x) { ... }
```

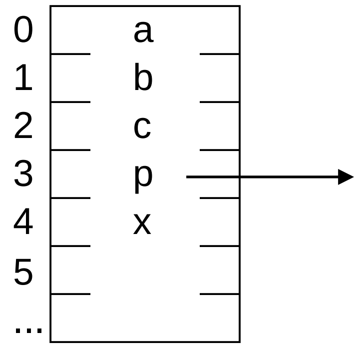


Global Variables

Global variables are stored in the *Global Data Area* of the MicroJava VM

```
program Prog
    int a, b;
    char c;
    Person p;
    int x;
{ ... }
```

Gobal Data Area

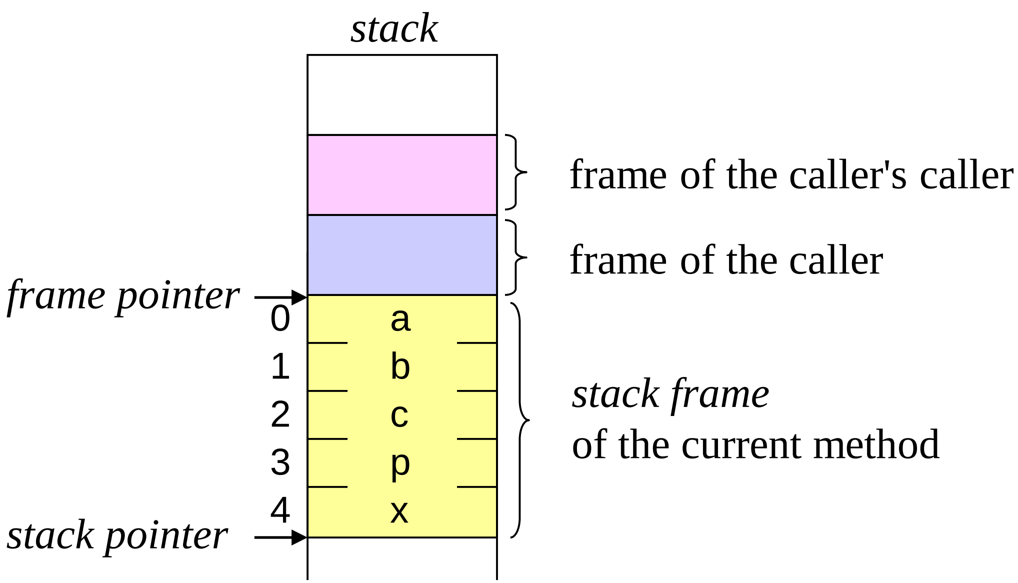


- Every variable occupies 1 word (4 bytes)
- Addresses are word numbers relative to the Global Data Area
- Addresses are allocated sequentially in the order of declaration

Local Variables

Local variables are stored in a "stack frame" on the method call stack

```
void foo()
    int a, b;
    char c;
    Person p;
    int x;
{ ... }
```



- Every variable occupies 1 word (4 bytes)
- Addresses are word numbers relative to the *frame pointer*
- Addresses are allocated sequentially in the order of their declaration

Entering Names into the Symbol Table

The following method is called whenever a name is declared

```
Obj obj = 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 consecutive 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
- returns the new node to the caller

Example for calling *insert()*

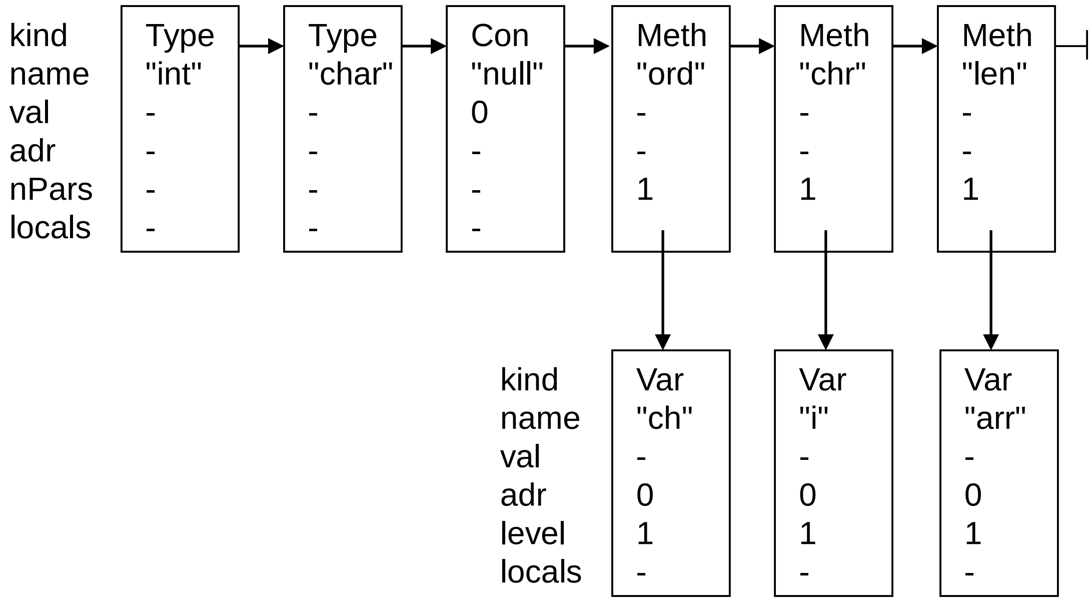
```
VarDecl
=  Type<↑type>
   ident<↑name>          (. Tab.insert(Obj.Var, name, type); .)
   { "," ident<↑name>    (. Tab.insert(Obj.Var, name, type); .)
   }
   ";" .
```

Predeclared Names

Which names are predeclared in MicroJava?

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

Predeclared names are also stored in the symbol table



Alternative: Special Names as Keywords

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

requires a special treatment in the grammar

```
Type<↑type>
=  ident<↑name>    (. Obj x = Tab.find(name); type = x.type; .)
|   "int"          (. type = Tab.intType; .)
|   "char"         (. type = Tab.charType; .)
.
```

It is simpler to have them predeclared in the symbol table

```
Type<↑type>
=  ident<↑name>    (. Obj x = Tab.find(name); type = x.type; .).
```

uniform treatment of predeclared and user-declared names

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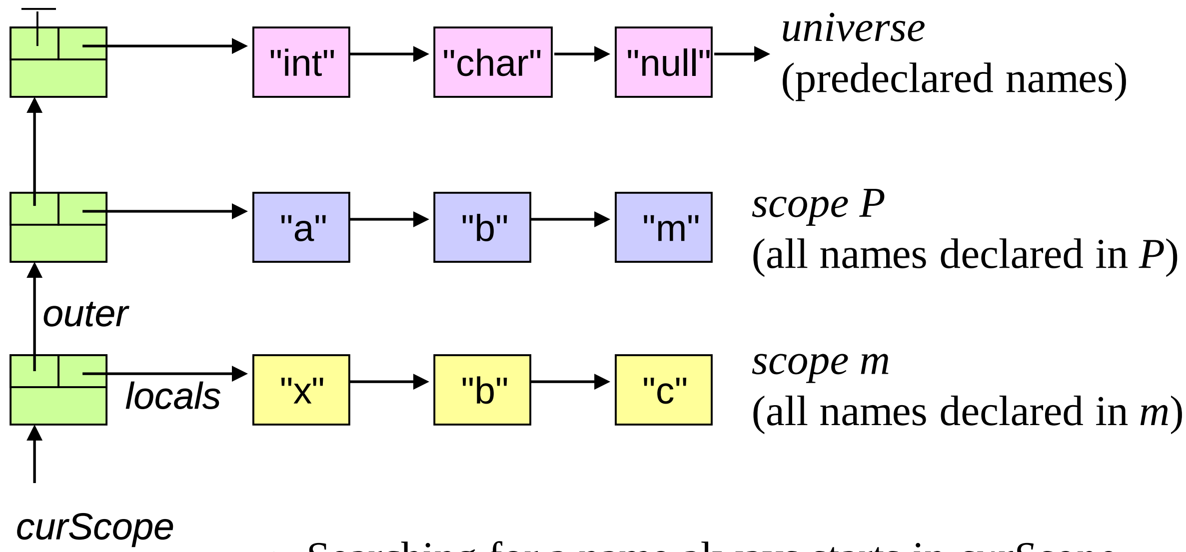
Scope = Range in which a Name is Valid

There are separate scopes (object lists) for

- the program — contains global names
- every method — contains local names
- every class — contains fields
- the "universe" — contains the predeclared names

Example

```
program P
    int a, b;
{
    void m (int x)
        int b, c;
    {
        ...
    }
    ...
}
```



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

Scope Nodes

```
class Scope {
    Scope  outer;     // to the next outer scope
    Obj    locals;    // to the objects in this scope
    int    nVars;     // number of variables in this scope (for address allocation)
}
```

Method for opening a scope

```
static void openScope() { // in class Tab
    Scope s = new Scope();
    s.outer = curScope;
    curScope = s;
    curLevel++;
}
```

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

Method for closing a scope

```
static void closeScope() { // in class Tab
    curScope = curScope.outer;
    curLevel--;
}
```

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

Opening and Closing a Scope

```
MethodDecl                (. Struct type; String name; .)
= Type<↑type>
  ident<↑name>            (.  curMethod = Tab.insert(Obj.Meth, name, type);
                              Tab.openScope(); .)
  "(" ... ")"
  ...
  "{"                     (. curMethod.locals = Tab.curScope.locals; .)
  ...
  "}"                     (.  Tab.closeScope(); .)
  .
```

Note

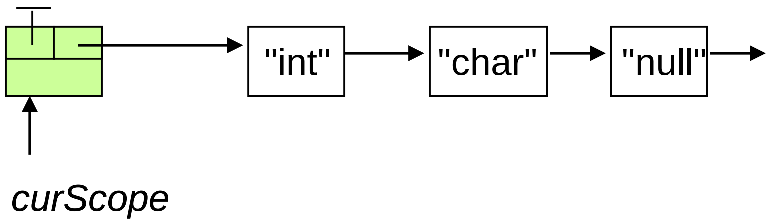
- The method name is entered in the method's enclosing scope
- *curMethod* is a global variable of type *Obj*
- After processing the declarations the local objects of the scope are assigned to *curMethod.locals*
- Scopes are also opened and closed for classes

Entering Names into a Scope

Names are always entered in *curScope*

```
class Tab {
    static Scope curScope;   // current scope
    static int curLevel;          // current declaration level (0 = global, 1 = local)
    ...
    static Obj insert (int kind, String name, Struct type) {
        //--- create object node
        Obj obj = new Obj(kind, name, type);
        if (kind == Obj.Var) {
            obj.adr = curScope.nVars; curScope.nVars++;
            obj.level = curLevel;
        }
        //--- append object node
        Obj p = curScope.locals, last = null;
        while (p != null) {
            if (p.name.equals(name)) error(name + " declared twice");
            last = p; p = p.next;
        }
        if (last == null) curScope.locals = obj; else last.next = obj;
        return obj;
    }
    ...
}
```

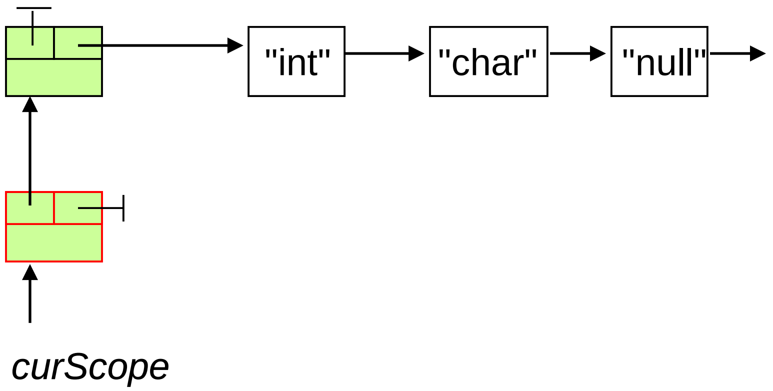
Example



Example

program P

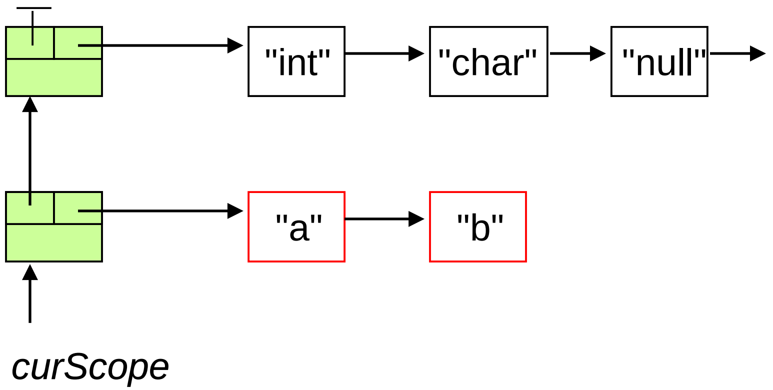
Tab.openScope();



Example

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

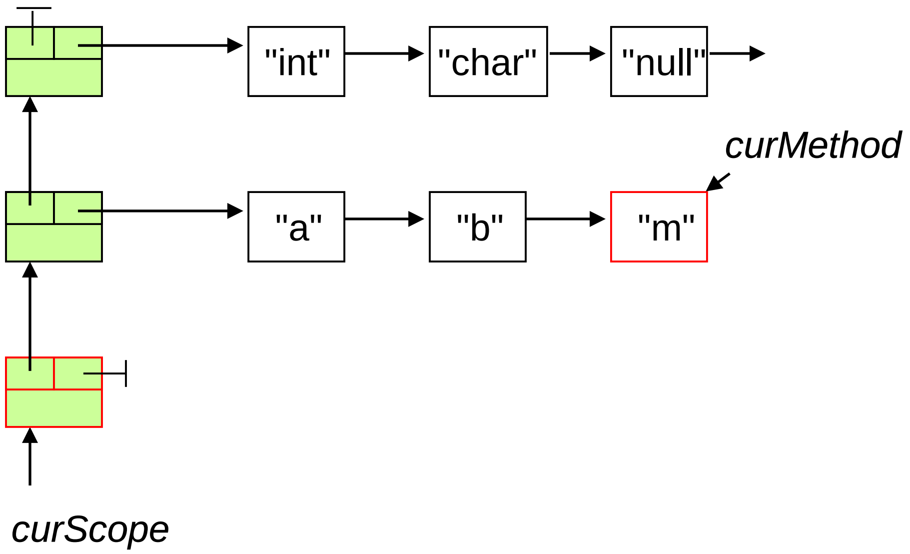
```
Tab.insert(..., "a", ...);
Tab.insert(..., "b", ...);
```



Example

```
program P
    int a, b;
{
    void m()
```

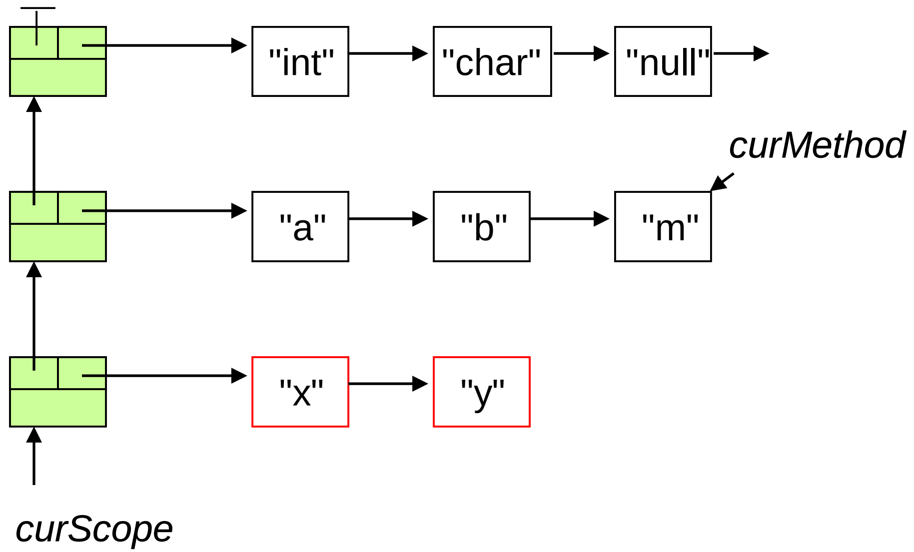
Tab.insert(..., "m", ...);
Tab.openScope();



Example

```
program P
   int a, b;
{
   void m()
      int x, y;
```

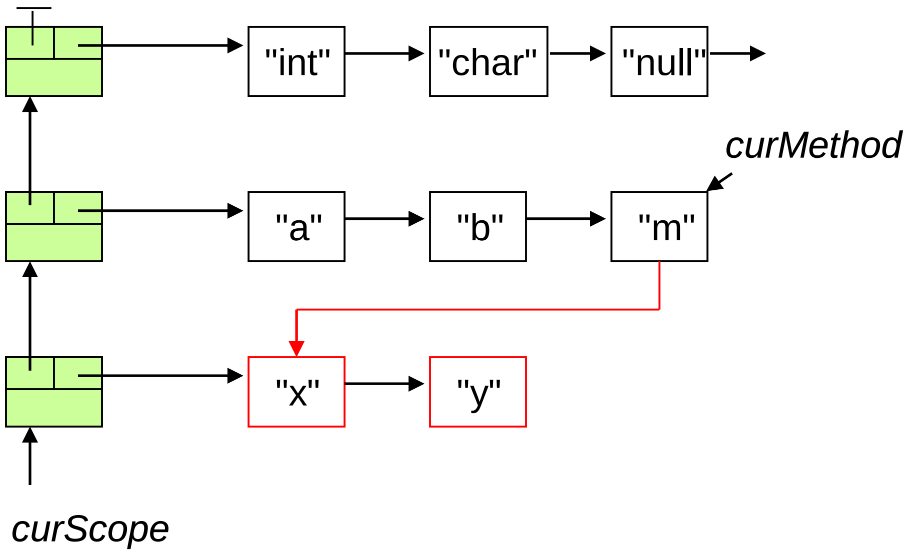
Tab.insert(..., "x", ...);
Tab.insert(..., "y", ...);



Example

```
program P
   int a, b;
{
   void m()
      int x, y;
   {
```

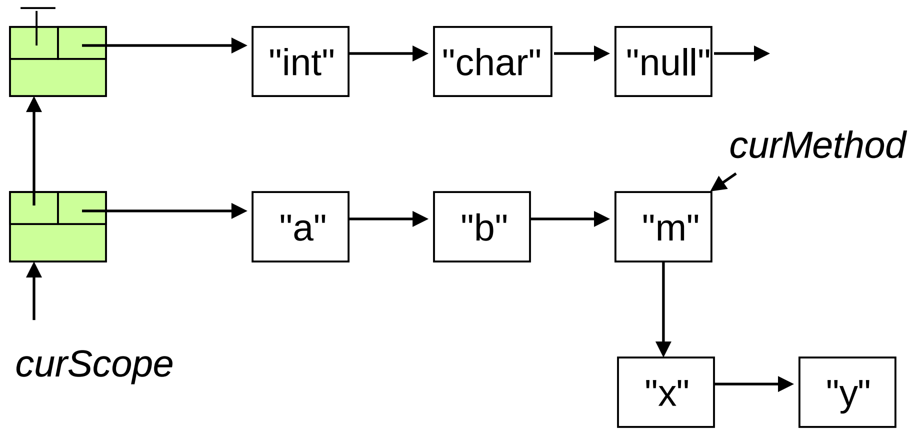
curMethod.locals =
Tab.curScope.locals



Example

```
program P
    int a, b;
{
    void m()
        int x, y;
    {
        ...
    }
```

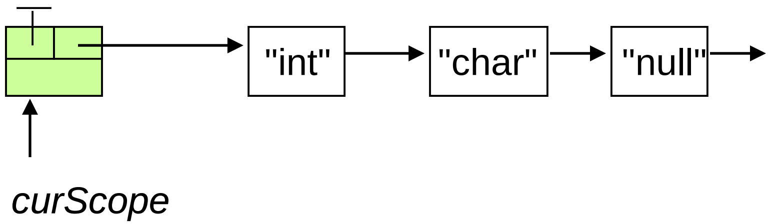
Tab.closeScope();



Example

```
program P
   int a, b;
{
   void m()
      int x, y;
   {
      ...
   }
   ...
}
```

Tab.closeScope();



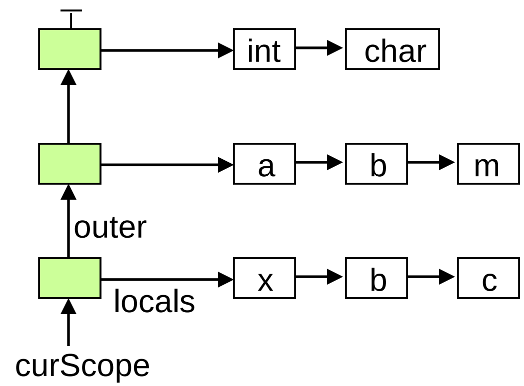
Searching Names in the Symbol Table

The following method is called whenever a name is used

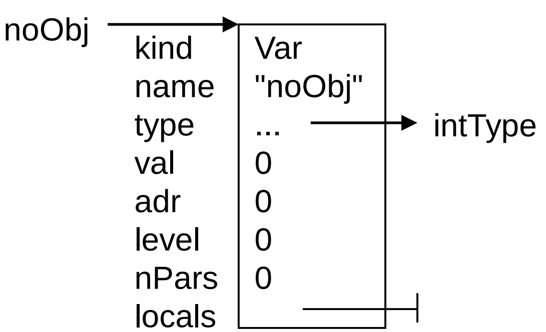
```
Obj obj = Tab.find(name);
```

- The lookup starts in *curScope*
- If not found, the lookup is continued in the next outer scope

```
static Obj find (String name) {
   for (Scope s = curScope; s != null; s = s.outer)
      for (Obj p = s.locals; p != null; p = p.next)
         if (p.name.equals(name)) return p;
   error(name + " is undeclared");
   return noObj;
}
```



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



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

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Types

Every object has a type with the following properties

- size (in MicroJava always 4 bytes)
- structure (fields for classes, element type for arrays, ...)

Kinds of types in MicroJava?

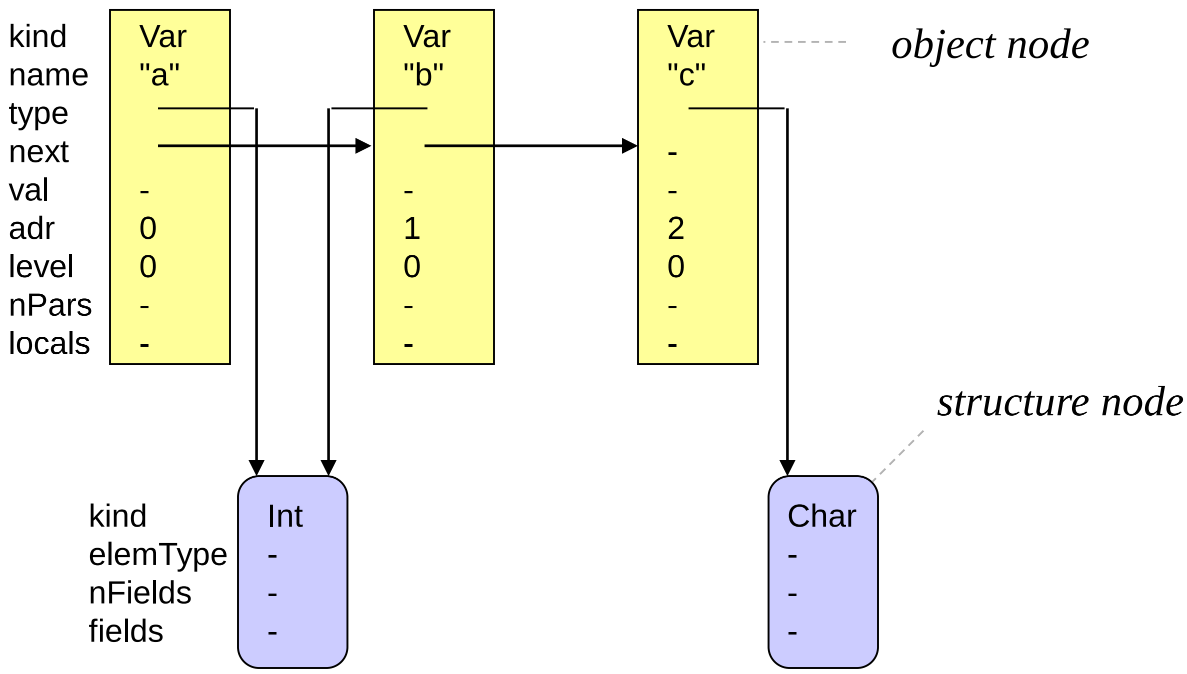
- primitive types (int, char)
- arrays
- classes

Types are represented by structure nodes

```
class Struct {
    static final int          // type kinds
        None = 0, Int = 1, Char = 2, Arr = 3, Class = 4;
    int       kind;           // None, Int, Char, Arr, Class
    Struct    elemType;       // Arr: element type
    int       nFields;        // Class: number of fields
    Obj       fields;         // Class: list of fields
}
```

Structure Nodes for Primitive Types

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

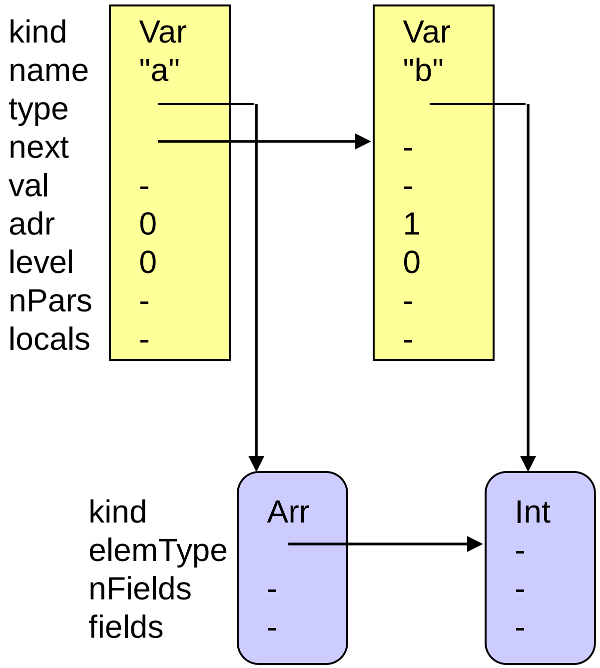


There is just a single structure node for *int* in the whole symbol table.
It is referenced by all objects of type *int*.

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

Structure Nodes for Arrays

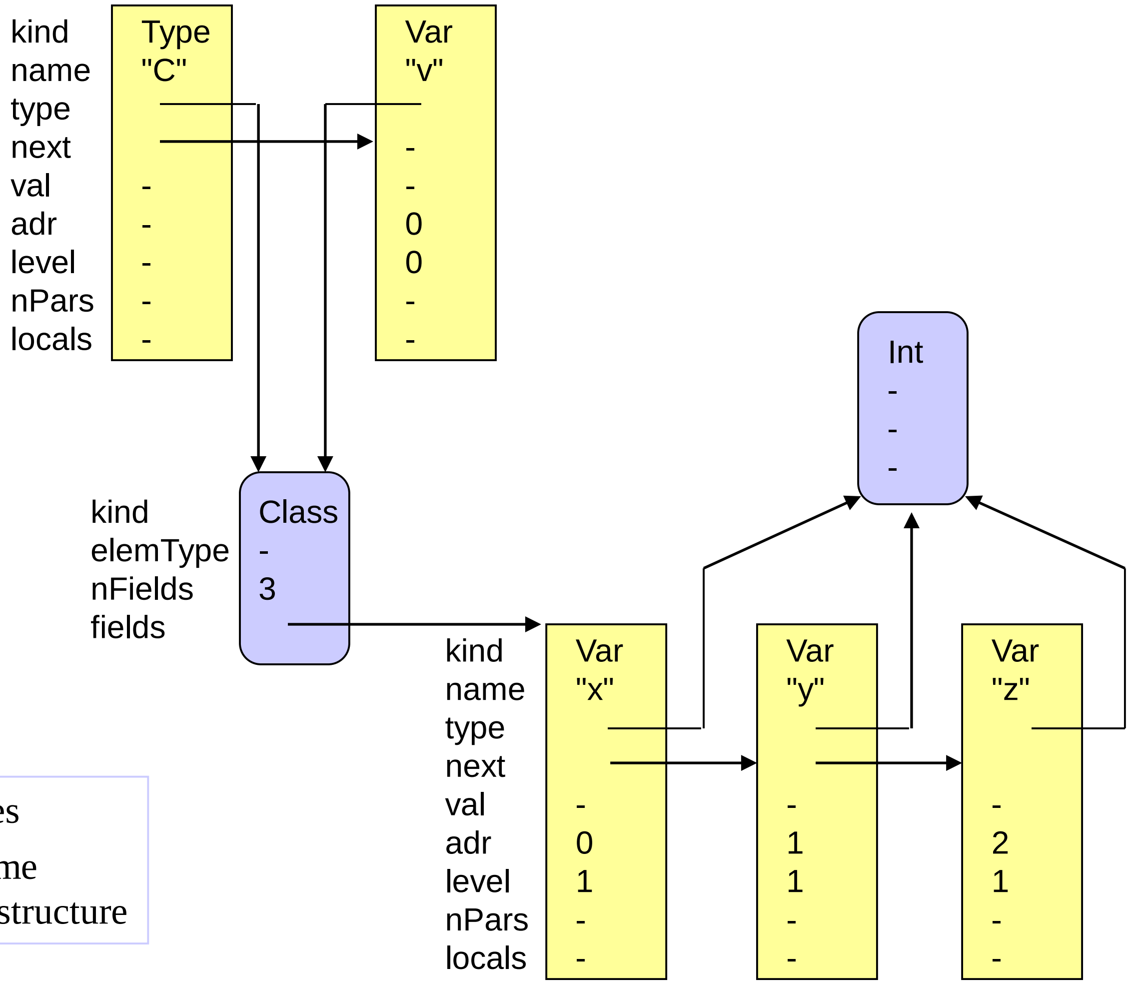
```
int[] a;
int b;
```



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;
```



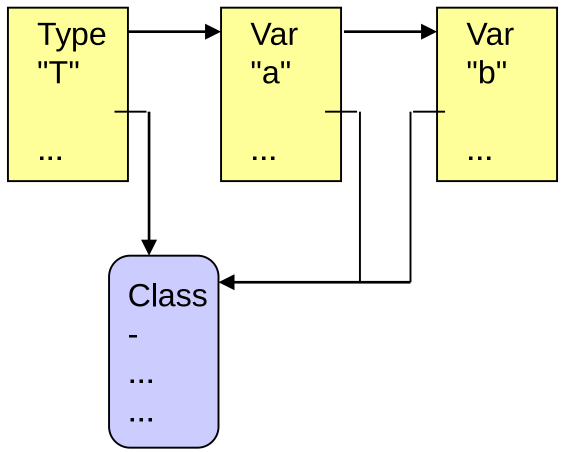
Types have 2 nodes

- object node: name
- structure node: structure

Type Compatibility: Name Equivalence

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

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



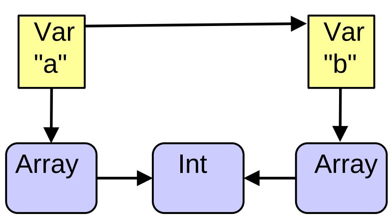
The types of *a* and *b* are the same (can be checked by `if (a.type == b.type) ...`)

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

Exception

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

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

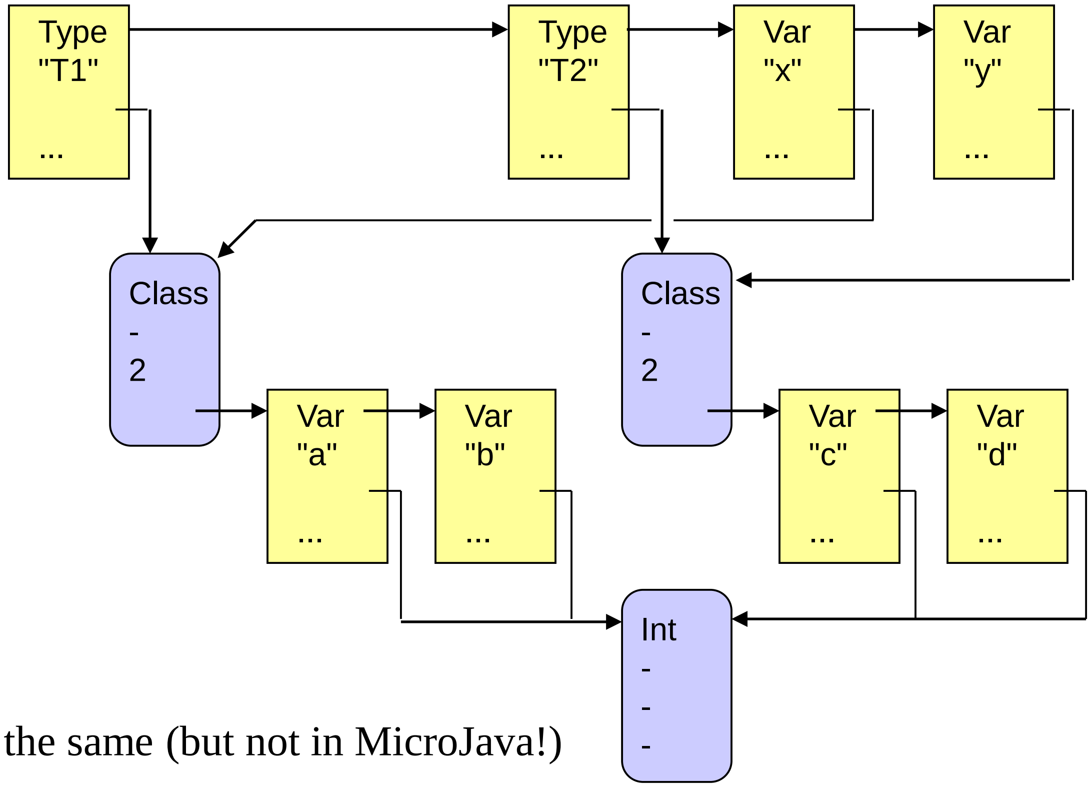


same types although
different type nodes

Type Compatibility: Structural Equivalence

Two types are the same if they have the <u>same structure</u>
(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 the same (but not in MicroJava!)

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

Methods for Checking Type Compatibility

```
class Struct {
    ...
    public boolean isRefType() {
        return this.kind == Class || this.kind == Arr;
    }

    // checks if two types are the same (structural equivalence for arrays, name equivalence otherwise)
    public boolean equals (Struct other) {
        if (this.kind == Arr)
            return other.kind == Arr && other.elemType == this.elemType;
        else
            return other == this;
    }

    // checks if "this" is assignable to "dest"
    public boolean assignableTo (Struct dest) {
        return this.equals(dest)
            ||  this == Tab.nullType && dest.isRefType()
            ||  this.kind == Arr && dest.kind == Arr && dest.elemType = Tab.noType;
    }
```

(dest.elemType = Tab.noType: necessary because of builtin function len(arr))

```
    // checks if two types are compatible (e.g. in compare operations)
    public boolean compatibleWith (Struct other) {
        return this.equals(other)
            ||  this == Tab.nullType && other.isRefType()
            ||  other == Tab.nullType && this.isRefType();
    }
}
```

Solving LL(1) Conflicts with the Symbol Table

Method syntax in MicroJava

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

Actually we would like to write it like this

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

But this would result in an LL(1) conflict

$$\text{First}(\mathit{VarDecl}) \cap \text{First}(\mathit{Statement}) = \{\mathit{ident}\}$$

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

Solving the Conflict With Semantic Information

```
private static void Block() {
   check(lbrace);
   while (sym ∉ {rbrace, eof}) {
      if (NextTokenIsType()) VarDecl();
      else Statement();
   }
   check(rbrace);
}
```

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

```
private static boolean NextTokenIsType() {
   if (sym != ident) return false;
   Obj obj = Tab.find(la.val);
   return obj.kind == Obj.Type;
}
```

checks if the next token is a type name

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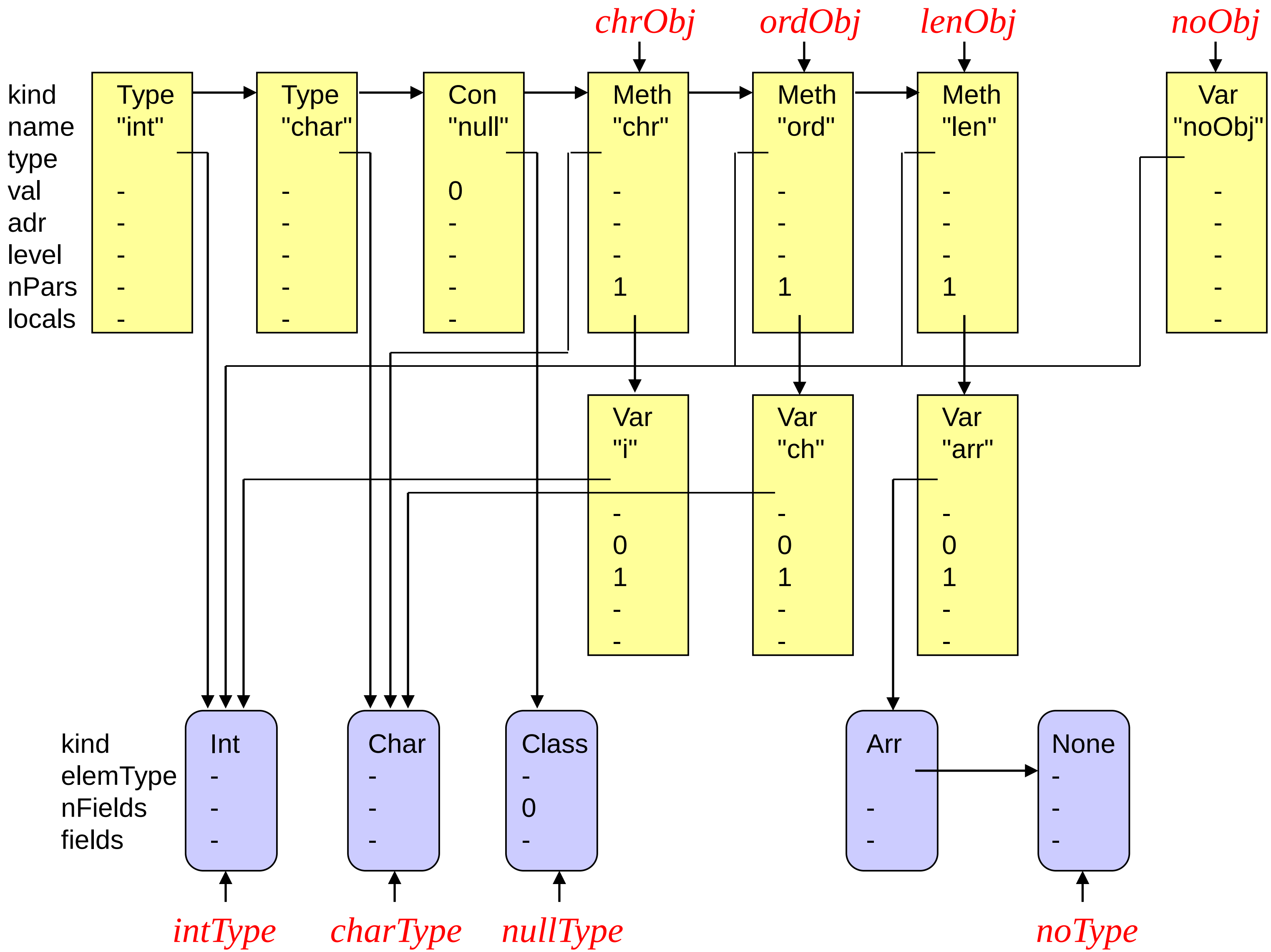
Structure of the "universe"



Interface of the Symbol Table

```
class Tab {
    static Scope  curScope;    // current top scope
    static int    curLevel;    // nesting level of current scope

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

    static Obj    chrObj;      // predefined objects
    static Obj    ordObj;
    static Obj    lenObj;
    static Obj    noObj;

    static Obj    insert (int kind, String name, Struct type) {...}
    static Obj    find (String name) {...}
    static void   openScope() {...}
    static void   closeScope() {...}
}
```

What you should do in the lab

- Create a new package *MJ.SymTab*
- Download *Tab.java* into it and complete *Tab.java*
- Call *Tab.openScope()* and *Tab.closeScope()* for the program, for methods and for classes
- Return a *Struct* node in *Type* (note that it can be an array type)

Enter names into the symbol table at every declaration

- constant declaration (set also the constant value)
- variable declaration (works also for fields)
- class declaration
- method declaration
- parameter declaration

Look up a name in the symbol table wherever it occurs in a program

- in *Designator*
- in *Type*
- in object creation (*new ident*)

Other

- call *Tab.dumpScope()* before you close the program scope