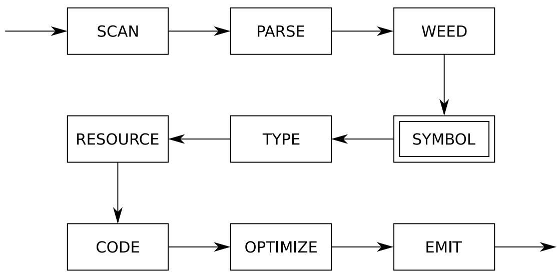
Symbol tables



Symbol tables are used to describe and analyse definitions and uses of identifiers.

Grammars are too weak; the language:

$$\{w\alpha w | w \in \Sigma^*\}$$

is not context-free.

A symbol table is a map from identifiers to meanings:

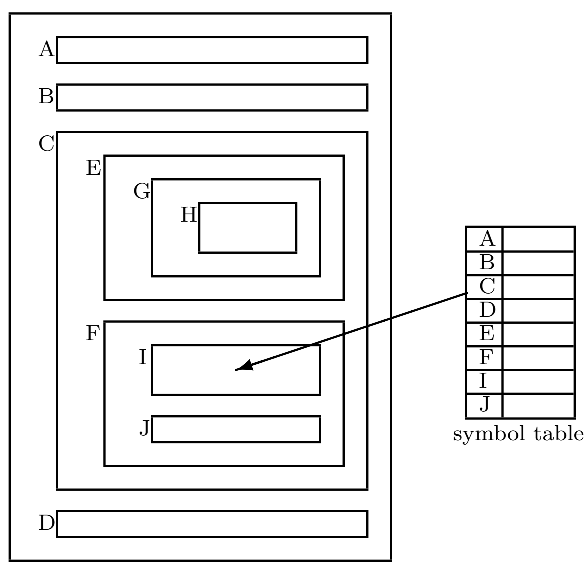
`i`	local	int
`done`	local	boolean
`insert`	method	...
`List`	class	...
`x`	formal	`List`
⋮	⋮	⋮

We must construct a symbol table for every program point.

Using symbol tables to analyse JOOS:

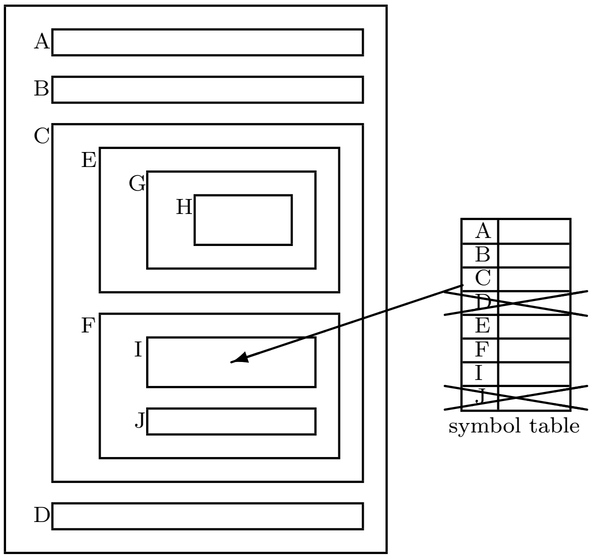
- which classes are defined;
- what is the inheritance hierarchy;
- is the hierarchy well-formed;
- which fields are defined;
- which methods are defined;
- what are the signatures of methods;
- are identifiers defined twice;
- are identifiers defined when used; and
- are identifiers used properly?

Static, nested scope rules:



The standard of modern languages.

Old-style one-pass technology:

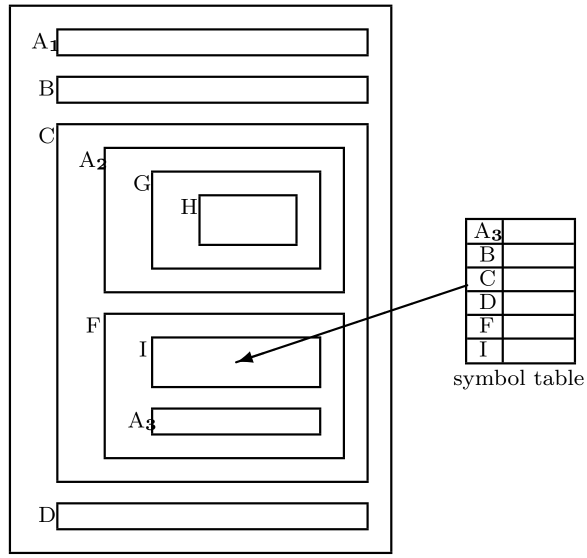


Still haunts some languages:

```
void weedPROGRAM(PROGRAM *p);
void weedCLASSFILE(CLASSFILE *c);
void weedCLASS(CLASS *c);
```

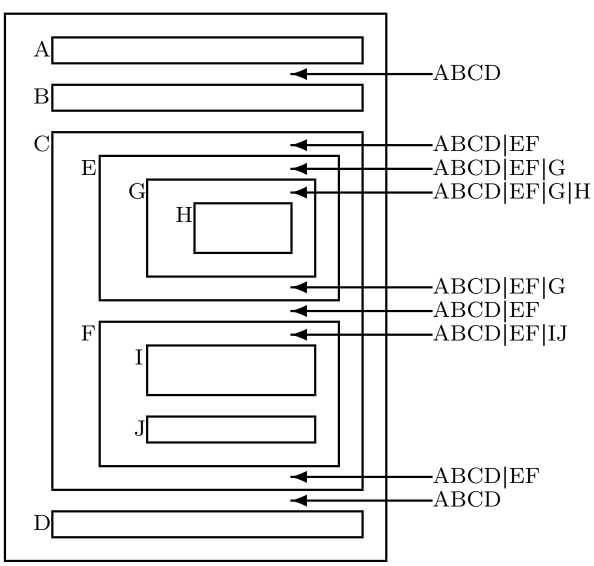
Forward declarations enable recursion.

Use the most closely nested definition:



Identifiers at same level must be unique.

The symbol table behaves like a stack:



The symbol table can be implemented as a simple stack:

- `pushSymbol(SymbolTable *t, char *name, ...)`
- `popSymbol(SymbolTable *t)`
- `getSymbol(SymbolTable *t, char *name)`

But how do we detect multiple definitions of an identifier at the same level?

Use *bookmarks* and a *cactus stack*:

- `scopeSymbolTable(SymbolTable *t)`
- `putSymbol(SymbolTable *t, char *name, ...)`
- `unscopeSymbolTable(SymbolTable *t)`
- `getSymbol(SymbolTable *t, char *name)`

Still just linear search, though.

Implement symbol tables as a cactus stack of *hash tables*:

- each hash table contains the identifiers in a level;
- push a new hash table when a level is entered;
- each identifier is entered in the top hash table;
- it is an error if it is already there;
- a use of an identifier is looked up in the hash tables from top to bottom;
- it is an error if it is not found;
- pop a hash table when a level is left.

What is a good hash function on identifiers?

Use the initial letter:

- `codePROGRAM`, `codeMETHOD`, `codeEXP`, ...

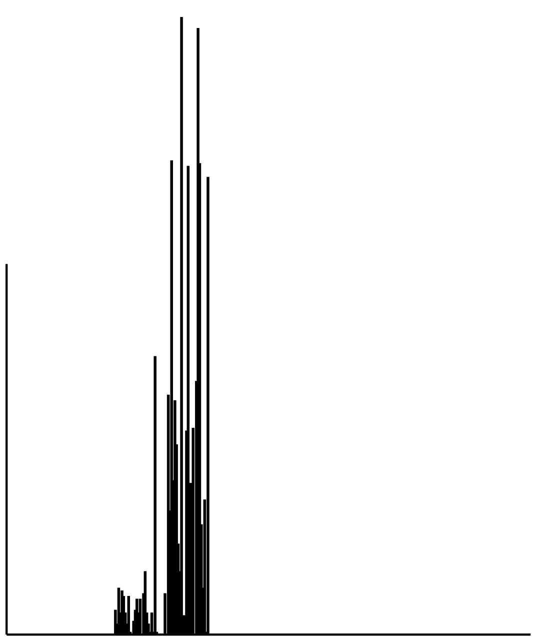
Use the sum of the letters:

- doesn't distinguish letter order

Use the shifted sum of the letters:

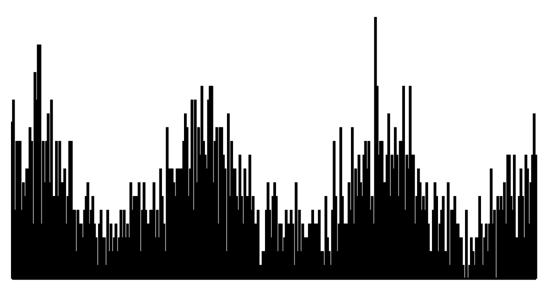
```
  "j" = 106 = 0000000001101010
shift         0000000011010100
+ "o" = 111 = 0000000001101111
=             0000000101000011
shift         0000001010000110
+ "o" = 111 = 0000000001101111
=             0000001011110101
shift         0000010111101010
+ "s" = 115 = 0000000001110011
=             0000011001011101
=             1629
```


Hash tables for the JOOS source code:

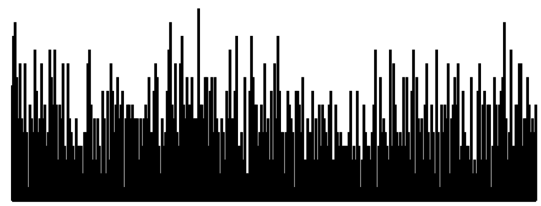


`hash = *str;`

Hash tables for the JOOS source code:



`while (*str) hash = hash + *str++;`



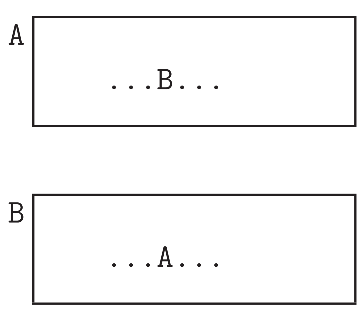
`while (*str) hash = (hash << 1) + *str++;`

```
$ cat symbol.h    # data structure definitions

#define HashSize 317

typedef struct SymbolTable {
    SYMBOL *table[HashSize];
    struct SymbolTable *next;
} SymbolTable;

$ cat symbol.c    # data structure operations

int Hash(char *str)
{ unsigned int hash = 0;
  while (*str) hash = (hash << 1) + *str++;
  return hash % HashSize;
}

SymbolTable *initSymbolTable()
{ SymbolTable *t;
  int i;
  t = NEW(SymbolTable);
  for (i=0; i < HashSize; i++) t->table[i] = NULL;
  t->next = NULL;
  return t;
}

SymbolTable *scopeSymbolTable(SymbolTable *s)
{ SymbolTable *t;
  t = initSymbolTable();
  t->next = s;
  return t;
}
```



```
SYMBOL *putSymbol(SymbolTable *t, char *name,
                                  SymbolKind kind)
{ int i = Hash(name);
  SYMBOL *s;
  for (s = t->table[i]; s; s = s->next) {
      if (strcmp(s->name,name)==0) return s;
  }
  s = NEW(SYMBOL);
  s->name = name;
  s->kind = kind;
  s->next = t->table[i];
  t->table[i] = s;
  return s;
}

SYMBOL *getSymbol(SymbolTable *t, char *name)
{ int i = Hash(name);
  SYMBOL *s;
  for (s = t->table[i]; s; s = s->next) {
      if (strcmp(s->name,name)==0) return s;
  }
  if (t->next==NULL) return NULL;
  return getSymbol(t->next,name);
}

int defSymbol(SymbolTable *t, char *name)
{ int i = Hash(name);
  SYMBOL *s;
  for (s = t->table[i]; s; s = s->next) {
      if (strcmp(s->name,name)==0) return 1;
  }
  return 0;
}
```


How to handle mutual recursion:



A single traversal of the abstract syntax tree is not enough.

Make two traversals:

- collect definitions of identifiers; and
- analyse uses of identifiers.

For cases like recursive types, the definition is not completed before the second traversal.

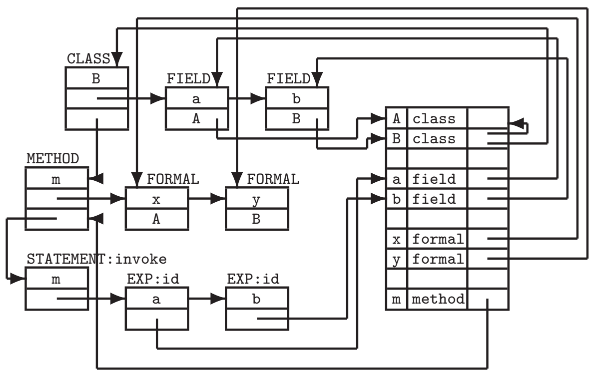
Symbol information in JOOS:

```
$ cat tree.h

[...]

typedef enum{classSym,fieldSym,methodSym,
             formalSym,localSym} SymbolKind;

typedef struct SYMBOL {
    char *name;
    SymbolKind kind;
    union {
      struct CLASS *classS;
      struct FIELD *fieldS;
      struct METHOD *methodS;
      struct FORMAL *formalS;
      struct LOCAL *localS;
    } val;
    struct SYMBOL *next;
} SYMBOL;

[...]
```

The information refers to abstract syntax tree nodes.

Symbol tables are weaved together with abstract syntax trees:

```
public class B extends A {
  protected A a;
  protected B b;

  public void m(A x, B y) {
    this.m(a,b);
  }
}
```



Complicated recursion in JOOS is resolved through multiple passes:

```
$ cat symbol.c

[...]

void symPROGRAM(PROGRAM *p)
{ classlib = initSymbolTable();
  symInterfacePROGRAM(p,classlib);
  symInterfaceTypesPROGRAM(p,classlib);
  symImplementationPROGRAM(p);
}

[...]
```

Each pass goes into further detail:

- `symInterfacePROGRAM`:
  define classes and their interfaces;
- `symInterfaceTypesPROGRAM`:
  build hierarchy and analyse interface types; and
- `symImplementationPROGRAM`:
  define locals and analyse method bodies.

Defining a JOOS class:

```
void symInterfaceCLASS(CLASS *c, SymbolTable *sym)
{ SYMBOL *s;
  if (defSymbol(sym,c->name)) {
     reportStrError("class name %s already defined",
                    c->name,c->lineno);
  } else {
     s = putSymbol(sym,c->name,classSym);
     s->val.classS = c;
     c->localsym = initSymbolTable();
     symInterfaceFIELD(c->fields,c->localsym);
     symInterfaceCONSTRUCTOR(c->constructors,
                             c->name,c->localsym);
     symInterfaceMETHOD(c->methods,c->localsym);
  }
}
```


Defining a JOOS method:

```
void symInterfaceMETHOD(METHOD *m, SymbolTable *sym)
{ SYMBOL *s;
  if (m!=NULL) {
     symInterfaceMETHOD(m->next,sym);
     if (defSymbol(sym,m->name)) {
        reportStrError("method name %s already defined",
                       m->name,m->lineno);
     } else {
        s = putSymbol(sym,m->name,methodSym);
        s->val.methodS = m;
     }
  }
}
```

and its signature:

```
void symInterfaceTypesMETHOD(METHOD *m, SymbolTable *sym)
{ if (m!=NULL) {
     symInterfaceTypesMETHOD(m->next,sym);
     symTYPE(m->returntype,sym);
     symInterfaceTypesFORMAL(m->formals,sym);
  }
}
```

Analysing a JOOS class implementation:

```
void symImplementationCLASS(CLASS *c)
{ SymbolTable *sym;
  sym = scopeSymbolTable(classlib);
  symImplementationFIELD(c->fields,sym);
  symImplementationCONSTRUCTOR(c->constructors,c,sym);
  symImplementationMETHOD(c->methods,c,sym);
}
```

Analysing a JOOS method implementation:

```
void symImplementationMETHOD(METHOD *m,
                             CLASS *this,
                             SymbolTable *sym)
{ SymbolTable *msym;
  if (m!=NULL) {
     symImplementationMETHOD(m->next,this,sym);
     msym = scopeSymbolTable(sym);
     symImplementationFORMAL(m->formals,msym);
     symImplementationSTATEMENT(m->statements,this,msym,
                                m->modifier==staticMod);
  }
}
```


Analysing JOOS statements:

```
void symImplementationSTATEMENT(STATEMENT *s, CLASS *this,
                                SymbolTable *sym, int stat)
{ SymbolTable *ssym;
  if (s!=NULL) {
     switch (s->kind) {

       [...]

       case localK:
            symImplementationLOCAL(s->val.localS,sym);
            break;

       [...]

       case blockK:
            ssym = scopeSymbolTable(sym);
            symImplementationSTATEMENT(s->val.blockS.body,
                                       this,ssym,stat);
            break;

       [...]
     }
  }
}
```


Analysing JOOS local declarations:

```
void symImplementationLOCAL(LOCAL *l, SymbolTable *sym)
{ SYMBOL *s;
  if (l!=NULL) {
     symImplementationLOCAL(l->next,sym);
     symTYPE(l->type,sym);
     if (defSymbol(sym,l->name)) {
        reportStrError("local %s already declared",
                       l->name,l->lineno);
     } else {
        s = putSymbol(sym,l->name,localSym);
        s->val.localS = l;
     }
  }
}
```


Identifier lookup in the JOOS class hierarchy:

```
SYMBOL *lookupHierarchy(char *name, CLASS *start)
{ SYMBOL *s;
  if (start==NULL) return NULL;
  s = getSymbol(start->localsym,name);
  if (s!=NULL) return s;
  if (start->parent==NULL) return NULL;
  return lookupHierarchy(name,start->parent);
}

CLASS *lookupHierarchyClass(char *name, CLASS *start)
{ SYMBOL *s;
  if (start==NULL) return NULL;
  s = getSymbol(start->localsym,name);
  if (s!=NULL) return start;
  if (start->parent==NULL) return NULL;
  return lookupHierarchyClass(name,start->parent);
}
```

For which class do we return NULL on line 5 of each function?

Analysing expressions:

```
void symImplementationEXP(EXP *e, CLASS *this,
                          SymbolTable *sym, int stat)
{ switch (e->kind) {
    case idK:
         e->val.idE.idsym = symVar(e->val.idE.name,sym,
                                   this,e->lineno,stat);
         break;
    case assignK:
         e->val.assignE.leftsym =
            symVar(e->val.assignE.left,sym,
                   this,e->lineno,stat);
         symImplementationEXP(e->val.assignE.right,
                              this,sym,stat);
         break;

    [...]
  }
}
```


Analysing an identifier:

```
SYMBOL *symVar(char *name, SymbolTable *sym,
               CLASS *this, int lineno, int stat)
{ SYMBOL *s;
  s = getSymbol(sym,name);
  if (s==NULL) {
     s = lookupHierarchy(name,this);
     if (s==NULL) {
        reportStrError("identifier %s not declared",
                       name,lineno);
     } else {
        if (s->kind!=fieldSym)
           reportStrError(
                 "%s is not a variable as expected",
                 name,lineno); }
  } else {
     if ((s->kind!=fieldSym) && (s->kind!=formalSym) &&
         (s->kind!=localSym))
        reportStrError("%s is not a variable as expected",
                       name,lineno);
  }
  if (s!=NULL && s->kind==fieldSym && stat)
     reportStrError("illegal static reference to %s",
     name,lineno);
  return s;
}
```


The testing strategy for the symbol tables involves an extension of the pretty printer.

A textual representation of the symbol table is printed once for every scope area.

- In Java, use `toString()`.

These tables are then compared to a corresponding manual construction for a sufficient collection of programs.

Furthermore, every error message should be provoked by some test program.