Symbol Tables

COMP 520: Compiler Design (4 credits)
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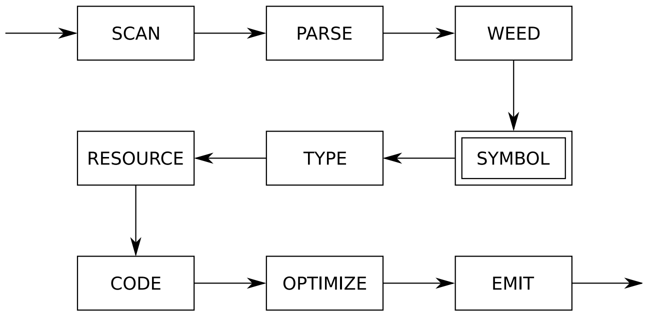
MWF 13:30-14:30, MD 279



***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.

In general, symbol tables allow us to:

- collect and analyze symbol declarations; and
- relate symbol uses with their respective declarations.

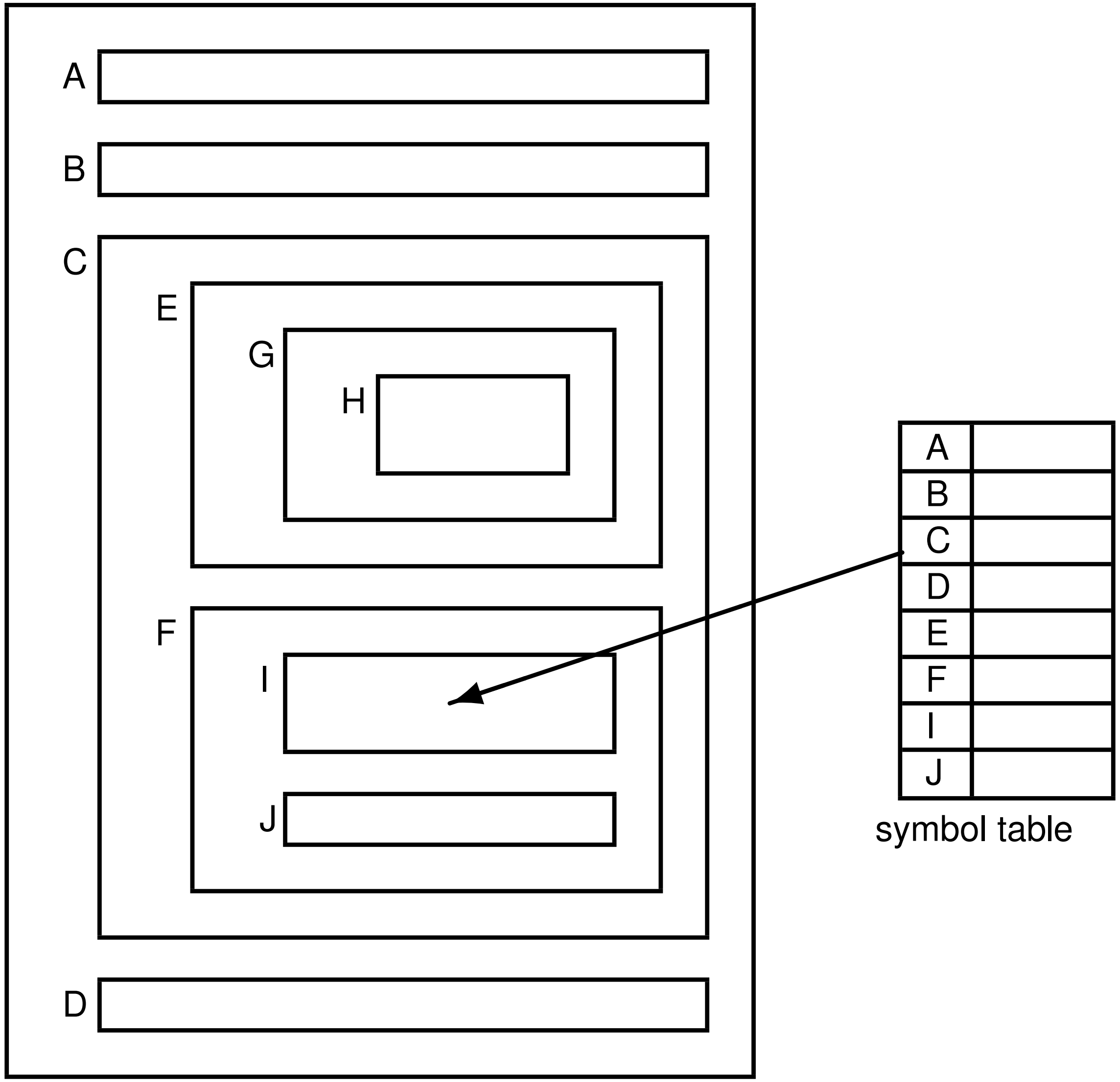
We can use these relationships to enforce certain properties impossible in the earlier phases:

- variables must be declared before use;
- identifiers may not be redeclared (in all circumstances);
- assignment compatibility;
- ...

Using symbol tables to analyse JOOS:

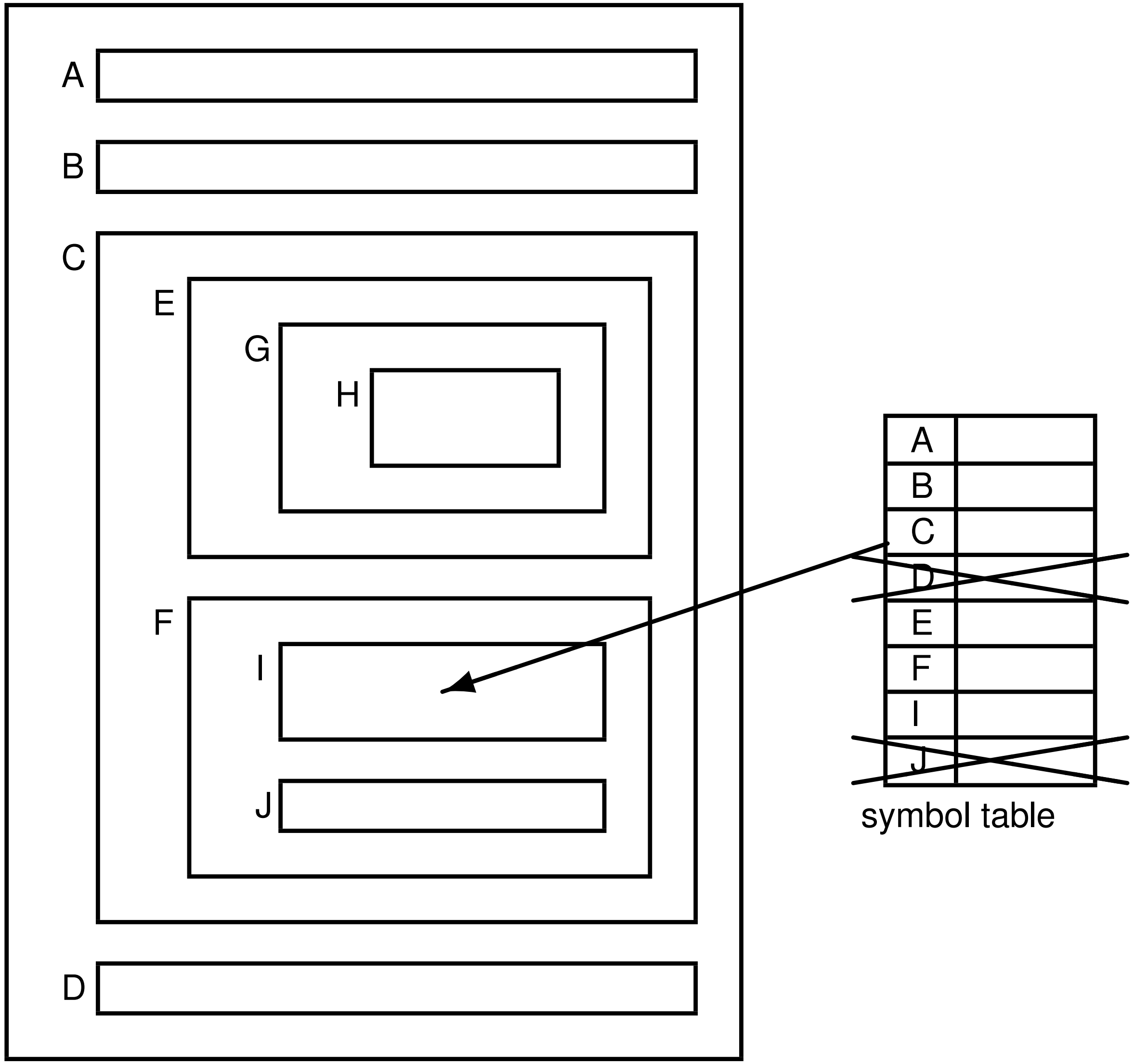
- which classes are defined;
- what is the inheritance hierarchy;
- is the hierarchy well-formed;
- which fields are defined;
- which methods are defined;
- what are the signatures of methods;
- are identifiers defined twice;
- are identifiers defined when used; and
- are identifiers used properly?

Static, nested scope rules:

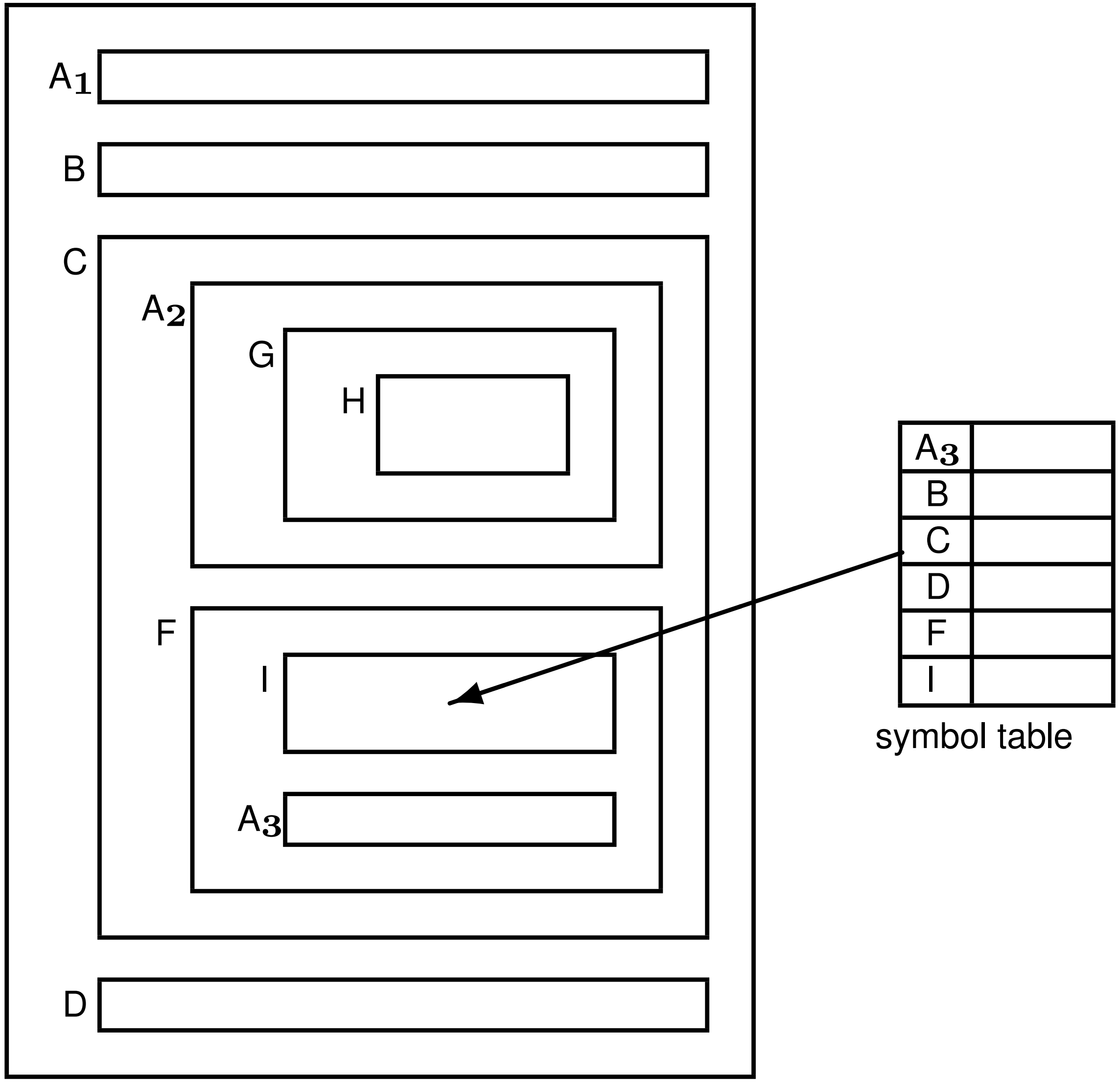


The standard of modern languages.

Old-style one-pass technology:

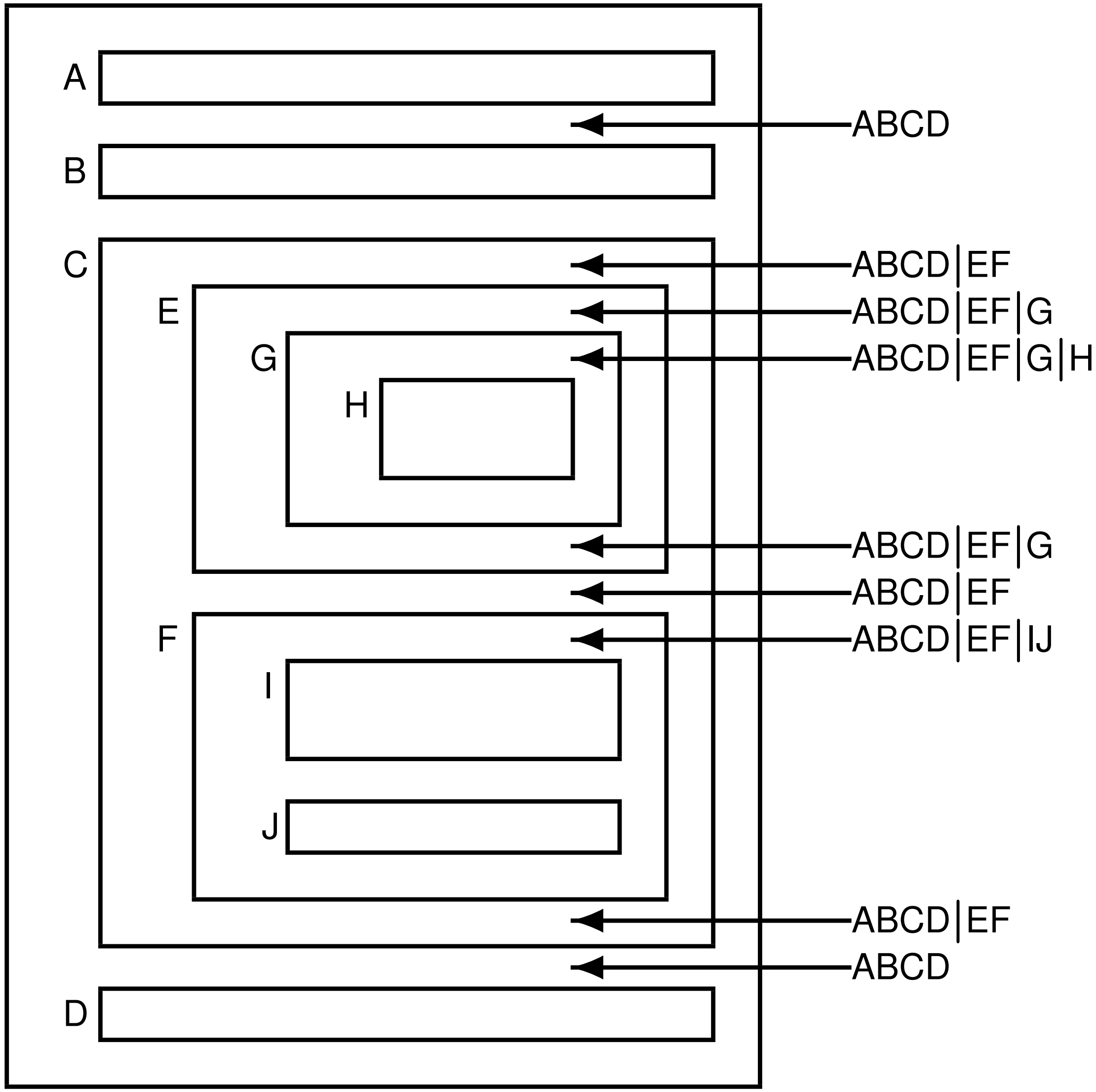


Use the most closely nested definition:



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-most 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 (but, don't deallocate, because AST nodes will have links to elements).

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

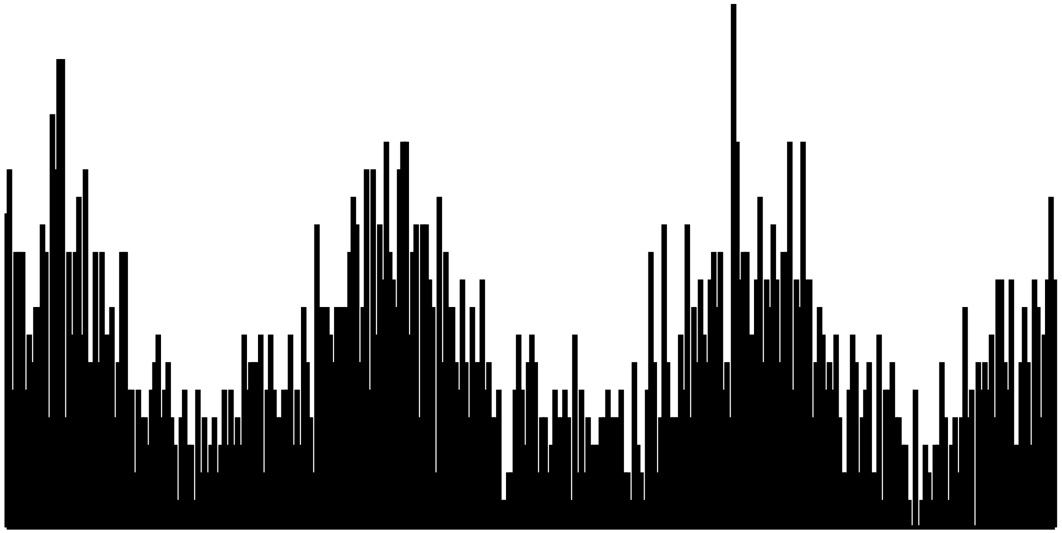
Use the shifted sum of the letters:

```
  "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 - option 1:

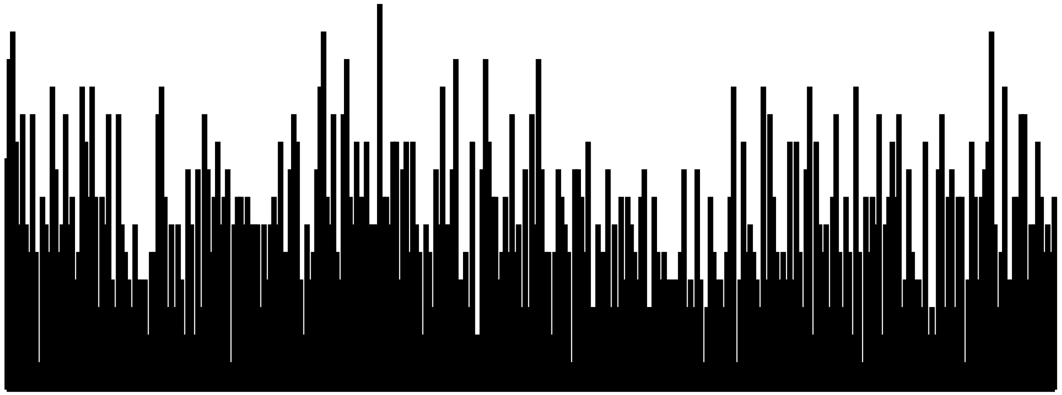
```
hash = *str;
```

Hash tables for the JOOS source code - option 2:



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

Hash tables for the JOOS source code - option 3:



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

Implementing a symbol table:

```
$ 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;
}
```

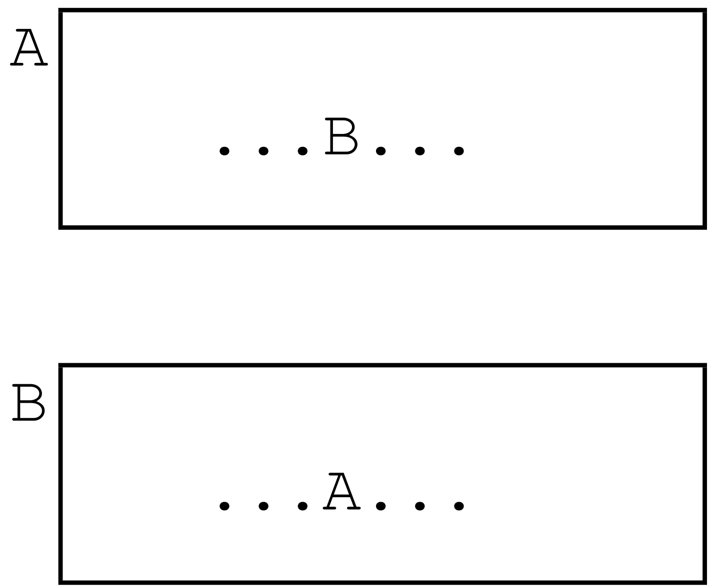
More of `symbol.c`

```
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 = malloc(sizeof(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:

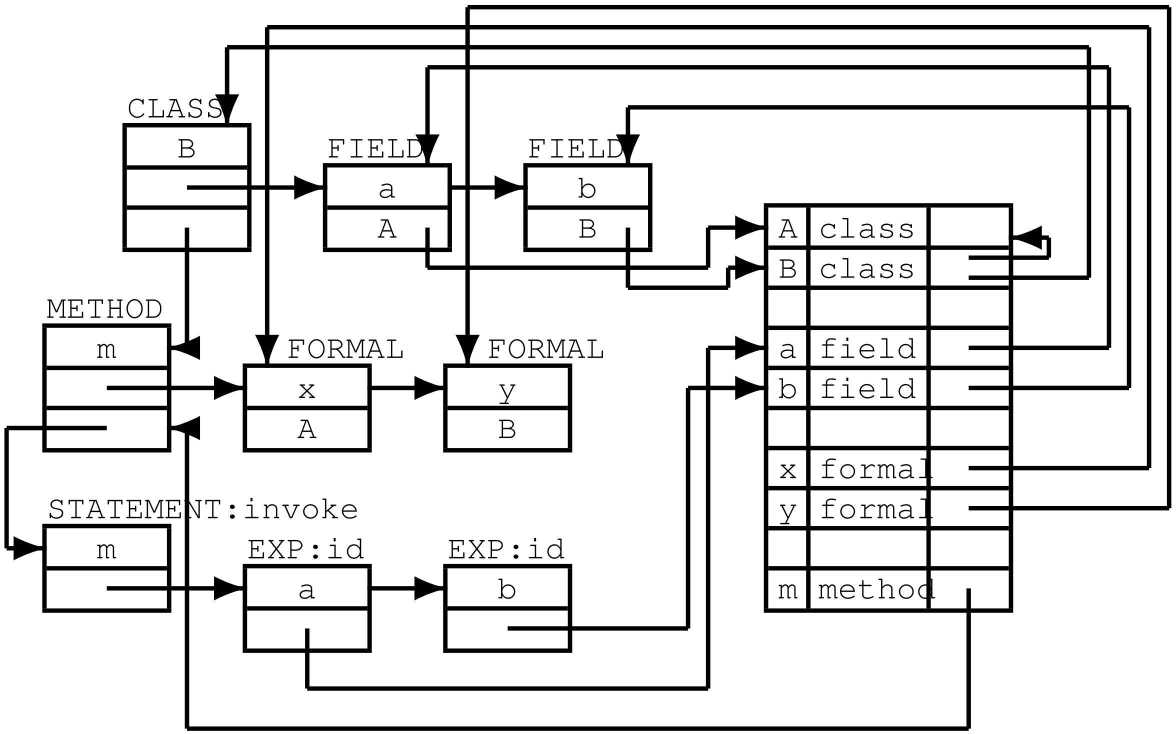
```
$ cat tree.h
```

```
[...]

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);
    }
}
```



Announcements (Monday, January 30th)

- Assignment 2 specifications posted on course website
- Assignment 2 due **Friday, February 10th 11:59 PM** on myCourses
- Assignment 1 grades posted

Assignment 1 wrapup

- Average 88.7%
- Come see us if you have any questions
- **Please** follow instructions!

Assignment 2:

- Questions?
- `read` strings

Dragon Name Vote:

1. Lexie
2. BiteCode
3. Snuggles
4. Tina
5. Compiley McCompileface

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 = 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);
}
```

What is the difference between these two functions?

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.