Static Chain Maintenance

- The static chain must be modified for each subroutine call and return
- The return part is trivial
  - When a subroutine terminates, its activation record is simply removed
- The call part is more complex
  - When a subroutine is called, its activation record needs to be built
  - Two methods to construct static links

Static Link Construction 1

- When a subroutine is called, search the dynamic chain until the first one of the parent scope is found
- However, this search can be avoided by treating subroutine declarations and calls as variable definitions and references

Static Link Construction 2

- At compile time,
  - When the compiler encounters a subroutine call A() in subroutine C, it determines the subroutine B which declares A
  - It then computes the nesting_depth between C and B
  - The information is stored and can be accessed by subroutine call during execution
  - When A is called, the static link to B is determined by moving down the static chain of C() nesting_depth hops

Issues with Static Chains

- A nonlocal reference is slow if the nesting depth is large
  - In practice, references to distant nonlocal variables are rare
- Time-critical code is difficult
  - Costs of nonlocal references are difficult to determine
  - Code modifications can change nesting depth, and therefore the cost

Display

- An alternative to static chains to solve the problems
- Static links are stored in an auxiliary data structure called a **display**
- The content of the display is a list of addresses of accessible activation record instances
- However, it has not been found to be superior to the static-chain method

Blocks

- **Blocks** are user-specified local scopes for variables
- An example in C

```
{  int temp;
   temp = list[upper];
   list[upper] = list[lower];
   list[lower] = temp;
}
```

- The life time of the variable temp begins when control enters the block, and ends when control exits it

Advantage

- The local variables inside blocks cannot interfere with any other variable with the same name but declared elsewhere in the program

Implementing Blocks

- Two methods to implement block local variables
  - Treat blocks as parameter-less subroutines
  - Treat block variables as plain local variables

Method 1

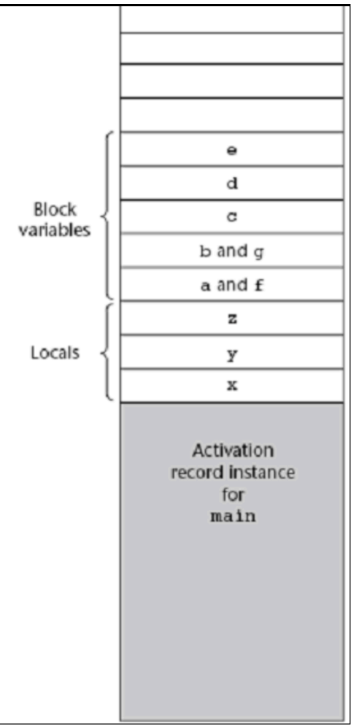
- Treat blocks as parameter-less subroutines that are always called from the same location
  - Every block has an activation record
  - An instance is created every time the block is executed
  - However, blocks can be implemented in a simpler and more efficient way

Method 2

- Insight
  - The maximum amount of storage required for block variables can be statically determined, because blocks are entered and exited in strictly textual order
- The block variables are allocated after local variables in the activation record
- Offset for all block variables can be statically computed, so block variables can be addressed exactly as if they were local variables

An Example

```
void main() {
  int x, y, z;
  while (…) {
    int a, b, c;
    while (…) {
      int d, e;
    }
    }
  while (…) {
    int f, g;
  }
}
```



Implementing Dynamic Scoping

- Two possible ways to implement local and nonlocal variables in a dynamic-scoped language
  - Deep access
  - Shallow access
- These are different from deep and shallow binding (different semantics)
- The semantics of dynamic scoping are unaltered by the access method

Deep Access

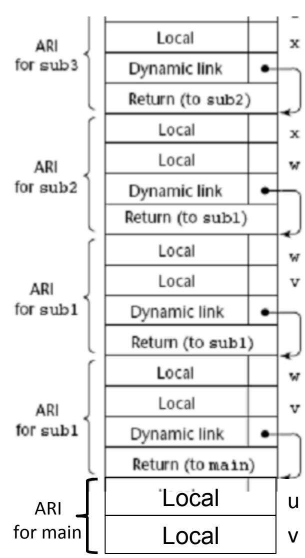
- Nonlocal references are found by searching the activation record instances on the dynamic chain
  - Length of the chain cannot be statically determined
  - Every activation record instance must have variable names

An Example

```
void sub3() {
  int x, z;
  x = u + v;
  …
}
void sub2() {
  int w, x;
  …
}
void sub1() {
  int v, w;
  …
}
void main() {
  int v, u;
  …
}
```

Where:
main calls sub1
sub1 calls sub1
sub1 calls sub2
sub2 calls sub3

How are the definitions of u and v found?

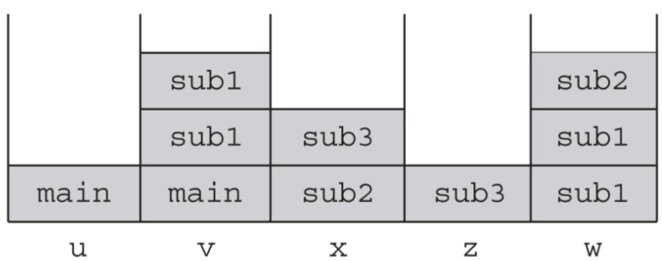


Shallow Access

- Key insight
  - With dynamic scoping, there is at most one visible version of a variable of any specific name at a given time
- Have a separate stack for each variable name in a program
  - When a variable is created, it is given a cell at the top of the stack for its name
  - Every reference to the name is to the variable on top of the stack
  - When the subroutine terminates, all variables it declares are popped from stacks

Revisit the Example

```
void sub3() {
  int x, z;
  x = u + v;
  …
}
void sub2() {
  int w, x;
  …
}
void sub1() {
  int v, w;
  …
}
void main() {
  int v, u;
  …
}
```



(The names in the stack cells indicate the program units of the variable declaration.)

Another way to implement shallow access

- Use a central table that has a location for each different variable name in a program
- Along with each entry, a bit called **active** is maintained that indicates whether it has a current binding or variable association
- Any access to any variable can then be to an offset into the central table
- The offset can be static, so the access can be fast

Central Table Maintenance

- When a subroutine is called, all of its local variables are logically placed in the central table
  - If the position of the new variable is already active, the original value must be saved somewhere
  - When a variable begins its lifetime, the corresponding active bit must be set

How to save values somewhere?

- Have a "hidden" stack on which all saved objects are stored
  - Since subroutines are called and then return, the lifetimes of local variables are nested, so this works
- All saved variables are stored in the activation record of the subroutine that created the replacement variable
  - The overhead is smaller because no extra stack is used