Class Information

INFORMATION and REMINDERS

• **Warning grades** are due today.
• First project due on Friday after the spring break.
• Homework 3 grades will be posted soon.
Lexical Scoping Example

**scope of a declaration**: Portion of program to which the declaration applies

```plaintext
Program
  x, y: integer  // declarations of x and y
begin
  Procedure B    // declaration of B
    y, z: real  // declaration of y and z
    begin
      ...
      y = x + z  // occurrences of y, x, and z
      if (...) call B  // occurrence of B
    end
  Procedure C    // declaration of C
    x: real    // declaration of x
    begin
      ...
      call B    // occurrence of B
    end
  ...
  call C         // occurrence of C
  call B         // occurrence of B
end
```
Lexical Scoping Example

Calling chain: MAIN ⇒ C ⇒ B ⇒ B
Scoping and the Run-time Stack

**Access links** and **control links** may be used to look for non-local variable references.

**Static Scope:**

Access link points to stack frame of the most recently activated lexically enclosing procedure

⇒ Non-local name binding is determined at *compile time*, and implemented at *run-time*

**Dynamic Scope:**

Control link points to stack frame of caller

⇒ Non-local name binding is determined and implemented at *run-time*
Lexical scoping (de Bruijn notation)

Symbol table matches declarations and occurrences.
⇒ Each variable name can be represented as a pair (nesting_level, local_index).

Program
(1,1), (1,2): integer // declarations of x and y
begin
Procedure B // declaration of B
(2,1), (2,2): real // declaration of y and z
begin
  ... // occurrences of y, x, and z
(*)
  (2,1) = (1,1) + (2,2)
  if (...) call B // occurrence of B
end
Procedure C // declaration of C
(2,1): real // declaration of x
begin
  ...
  call B // occurrence of B
end

... call C // occurrence of C
call B // occurrence of B
end
Access to non-local data

How does the code find non-local data at \textit{run-time}?

\textbf{Real globals}

- visible \textit{everywhere}
- translated into an address at compile time

\textbf{Lexical scoping}

- view variables as \((\textit{level}, \textit{offset})\) pairs
  \textit{(compile-time symbol table)}
- \textit{look-up} of \((\textit{level}, \textit{offset})\) pair uses chains of access links \textit{(at run-time)}
- optimization to reduce access cost: \textit{display}

\textbf{Dynamic scoping}

- variable names must be preserved
- \textit{look-up} of variable name uses chains of control links \textit{(at run-time)}
- optimization to reduce access cost: \textit{reference table}
Access to non-local data (lexical scoping)

What code (ILOC) do we need to generate for statement (*)?

\[(2,1) = (1,1) + (2,2)\]

What do we know?

1. The nesting level of the statement is level 2.
2. Register \(r_0\) contains the current FP (frame pointer).
3. \((2,1)\) and \((2,2)\) are local variables, so they are allocated in the activation record that current FP points to; \((1,1)\) is a non-local variable.

Compiler-generated code for the statements in a procedure must work for all possible, valid runtime stacks/environments
Access to non-local data (lexical scoping)

What code do we need to generate for statement (*)?

\[(2,1) = (1,1) + (2,2)\]

\[\begin{align*}
(1,1) & | \text{loadAI } r0, -4 \Rightarrow r1 // \text{get access link; } r1 \text{ now} \\
& | \text{contains ‘‘one-level-up’’ FP} \\
& | \text{in frame (bytes)} \\
& | \text{loadAI } r1, 4 \Rightarrow r2 // \text{get content of first local variable} \\
& | \text{in ‘‘one-level-up’’ frame (bytes)} \\
\end{align*}\]

\[\begin{align*}
(2,2) & | \text{loadAI } r0, 8 \Rightarrow r3 // \text{content of second local variable} \\
& | \text{in current frame (bytes)} \\
+ & | \text{Add } r2, r3 \Rightarrow r4 // (1,1) + (2,2) \\
\end{align*}\]

\[\begin{align*}
(2,1) & | \text{storeAI } r4 \Rightarrow r0, 4 // \text{store value into first local variable} \\
= & | \text{in current frame (bytes)} \\
\end{align*}\]
Access to non-local data (lexical scoping)

Two important problems arise

1. *How do we map a name into a (level,offset) pair?*

   We use a block structured symbol table
   (**compile-time**)
   
   • when we look up a name, we want to get the most recent declaration for the name
   • the declaration may be found in the current procedure or in any nested procedure

2. *Given a (level,offset) pair, what’s the address?*

   Two classic approaches
   (**run-time**)
   
   ⇒ access links
   
   ⇒ displays
Managing non-local data (lexical scoping)

To find the value specified by \((l, o)\):

- need current procedure level, \(k\)
- if \(k = l\), is a local value
- if \(k > l\), must find \(l\)’s activation record
  \(\Rightarrow\) follow \(k - l\) access links
- \(k < l\) cannot occur

Maintaining access links:
If procedure \(p\) is nested immediately within procedure \(q\), the access link for \(p\) points to the activation record of the most recent activation of \(q\).

- calling level \(k + 1\) procedure
  1. pass my FP as access link
  2. my backward chain will work for lower levels
- calling procedure at level \(l \leq k\)
  1. find my link to level \(l - 1\) and pass it
  2. its access link will work for lower levels
The display

To improve run-time access costs, use a display.

- table of access links for lower levels
- lookup is index from known offset
- takes slight amount of time at call
- a single display or one per frame

Access with the display

assume a value described by \((l, o)\)

- find slot as \(DP[l]\) in display pointer array
- add offset to pointer from slot

“setting up the activation frame” now includes display manipulation.
Display management

Single global display: simple method

on entry to a procedure at level \( l \)

save the level \( l \) display value

push FP into level \( l \) display slot

on return

restore the level \( l \) display value
Review: Procedures

• Modularize program structure
  – Argument: information passed from caller to callee (actual parameter)
  – Parameter: local variable whose value (usually) is received from caller (formal parameter)

• Procedure declaration
  – procedure name, formal parameters, procedure body with local declarations and statement lists, optional result type
  example: void translate(point *p, int dx)
Parameters

Scott: Chapter 8.3

Parameter Association

- **Positional association**: Arguments associated with formals one-by-one; example: C, Pascal, Scheme, Java.

- **Keyword association**: formal/actual pairs; mix of positional and keyword possible; example: Ada
  
  procedure plot(x, y: in real; penup: in boolean)
  
  ... plot (0.0, 0.0, penup ⇒ true)
  
  ... plot (penup ⇒ true, x ⇒ 0.0, y ⇒ 0.0)

Parameter Passing Modes

- **pass-by-value**: C, Pascal, Ada (**in** parameter), Scheme, Algol 68

- **pass-by-result**: Ada (**out** parameter)

- **pass-by-value-result**: Ada (**in out** parameter)

- **pass-by-reference**: Fortran, Pascal (**var** parameter)

- **pass-by-name** (not really used any more): Algol60
Review: Stack Frames

- Run-time stack contains frames for main program and each active procedure.

- Each stack frame includes:
  1. Pointer to stack frame of caller (control link)
  2. Return address (within calling procedure)
  3. Mechanism to find non-local variables (access link)
  4. Storage for parameters
  5. Storage for local variables
  6. Storage for final values
Pass-by-?????

begin
  c: array[1..10] of integer;
  m, n: integer;
  procedure r(k, j: integer)
  begin
    k := k+1;
    j := j+2;
  end r;
...
  m := 5;
  n := 3
  r(m,n);
  write m,n;
end

Output?:
Pass-by-value

begin
  c: array[1..10] of integer;
  m, n: integer;
  procedure r(k, j: integer)
  begin
    k := k+1;
    j := j+2;
  end r;
...
  m := 5;
  n := 3
  r(m,n);
  write m, n;
end

Output:
5 3

Advantage: Argument protected from changes in callee
Disadvantage: Copying of values takes execution time and space, especially for aggregate values (e.g.:arrays, structs).
Pass-by-reference

begin
  c: array[1..10] of integer;
  m, n: integer;
  procedure r(k, j: integer)
  begin
    k := k+1;
    j := j+2;
  end r;
  ...
  m := 5;
  n := 3
  r(m,n);
  write m,n;
end

Output:
6 5

**Advantage**: more efficient than copying

**Disadvantage**: leads to **aliasing**: there are two or more names for the same storage location; hard to track side effects
Pass-by-result

begin
  c: array[1..10] of integer;
  m, n: integer;
  procedure r(k, j: integer)
  begin
    k := k+1;       ==> ERROR: CANNOT USE PARAMETERS
    j := j+2;       WHICH ARE UNINITIALIZED
  end r;
...
  m := 5;
  n := 3
  r(m,n);
  write m,n;
end

Output: program doesn’t compile or has runtime error
Pass-by-result

begin
  c: array[1..10] of integer;
  m, n: integer;
  procedure r(k, j: integer)
  begin
    k := 1;          ==> HERE IS ANOTHER PROGRAM
    j := 2;          THAT WORKS
  end r;
  ...
  m := 5;
  n := 3
  r(m,m);          ==> NOTE: CHANGED THE CALL
  write m,n;
end

Output: 1 or 2?

Problem: order of copy-back makes a difference; implementation dependent.
Pass-by-value-result

begin
  c: array[1..10] of integer;
  m, n: integer;
  procedure r(k, j: integer)
  begin
    k := k+1;
    j := j+2;
  end r;
...
  m := 5;
  n := 3
  r(m,n);
  write m,n;
end

Output:
6 5

Problem: order of copy-back can make a difference; implementation dependent.
Pass-by-value-result

begin
  c: array[1..10] of integer;
  m, n: integer;
  procedure r(k, j: integer)
  begin
    k := k+1;
    j := j+2;
  end r;
...
/* set c[m] = m */
  m := 2;
  r(m,c[m]);==> WHAT ELEMENT OF ‘‘c’’ IS ASSIGNED TO?
write c[1], c[2], ... c[10];
end

Output:
1 4 3 4 5 ... 10 on entry
1 2 4 4 5 ... 10 on exit

Problem: When is the address computed for the copy-back operation? At procedure call (procedure entry), just before procedure exit, somewhere inbetween? (Example: ADA on entry)
Next Lectures Roadmap

• More on parameter passing.
• Introduction to functional languages; read Scott Chapter 10
• Lambda calculus