COMP151: Object-Oriented Programming

Procedures and Functions:
Scope and Parameter Passing,
Activation Records

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Elements of a Procedure

double BM_Log (double x)
{
    if (x <= 0)
    {
        cout << "Error\n";
        return -1;
    }
    else
    {
        return log(x);
    }
}

A call of the procedure will be something like:

BM_Log(2.5);  /* 2.5 is the actual parameter */
**Procedure**

- **function** (function procedure):
  - returns a result to the caller
  - extends the built-in operators (+, −, ×, /). e.g. \( \text{sin}(x) \)

- **procedure** (proper procedure):
  - does not return a result
  - extends the built-in actions/statements. e.g. \( \text{free}(x) \)

- But they are both called “functions” in C.
- And, unfortunately, functions are called “procedures” in Scheme.

Procedures/functions are called using **prefix** notation.
i.e. `<procedure-name>` ( `<formal-parameter-list>` )
(c.f. Built-in binary operations are in **infix** notation.)

- The parentheses “(” and “)”) are **redundant**.
- The use of a procedure = a **call** of the procedure.
- The execution of a procedure body = an **activation** of the procedure.
Procedure: Benefits

- **Modular Design**: program $\rightarrow$ set of subprograms
  - better organization $\Rightarrow$ easier to read/maintain
  - easier to develop (“divide-and-conquer”)

- **Procedure Abstraction**: during the design phase, it abstracts away from *how* it works, and let’s think in terms of *what* it does.

- **Implementation Hiding**: allows programmers to modify the underlying algorithm *without* affecting the high-level design.

- **Libraries**: allow procedures of well-designed interface to be shared (reusable codes)
int factorial(int x) 
{
    if (x < 0)
        exit(-1);
    else if (x <= 1)
        return 1;
    else
        return x*factorial(x-1);
}

A recursive procedure can have multiple activations in progress at the same time.
e.g \( F(4) \Rightarrow 4 \times F(3) \Rightarrow 4 \times (3 \times F(2)) \Rightarrow 4 \times (3 \times (2 \times F(1))) \)
Recursion: Example 1

```java
boolean Even(int x) {
    if (x == 0)
        return TRUE;
    else
        return Odd(x-1);
}

boolean Odd(int x) {
    if (x == 0)
        return FALSE;
    else
        return Even(x-1);
}
```

In this example, two recursive procedures run in “parallel”, calling each other.
Activation Tree: Example 2

```c
int main()
{
    A(); B();
}
```

```c
void B()
{
    C(); D();
}
```

```c
void D()
{
    E();
}
```

- if $P()$ calls $Q()$, then $Q$ is a **child** of $P$.
- if $P()$ calls $Q()$ and then $R()$, then $Q$ appears to the **left** of $R$. 

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Part I

Activation Records
Activation Records: Memory Layout

result

actual parameter #2
actual parameter #1

control link
(to its caller’s AR)

(optional) access link

saved machine status

local variables

temporary storage

callee saves

caller saves

callee saves

caller saves
When a procedure is activated, temporary memory called 
activation record (AR) is allocated to run the procedure.

AR of procedure $P()$ usually contains memory for:
- returned result (if $P()$ is a proper function)
- actual parameters
- control link (dynamic link) — points to the AR of $P$’s caller.
  e.g. if $F()$ calls $P()$, then the control link in $P$’s AR points to $F$’s AR.
Activation Records ..

- **access link** (static link) — points to the **most recent** AR of the **innermost** enclosing procedure in which \( P() \) is defined.
  - used to implement the **lexical scope rule**.
  - Pascal has access links.
  - C does **not** need access links as C does **not** allow nested procedures. Thus, all variables are either local or global.
  - C++, however, **does** have nested scopes.
  - Scheme also uses lexical scope, so needs access links.
  - Lisp uses the **dynamic scope rule**, so doesn’t need access links.

- **saved machine status**: e.g.
  - **registers values** just before \( P() \)'s activation
  - **return program counter** so as to resume caller’s execution when \( P() \) is done

- **local variables**

- **temporary storage**
The figure shows the memory layout of a C program during its execution.

Activations can be managed in the

- **stack**: traditional method for imperative language
- **heap**: if the *activation* of a procedure or function may be returned as a result, stored in a variable and used in an outer scope then its activation record must be stored in a heap so that its variables still exist when it is used.
  
  (e.g. functional programming languages)
A language that uses a stack to manage activation records is said to obey a stack discipline — last-in/first-out.

Thus, AR is also called a stack frame.

- Advantage: efficient
- Disadvantage: doesn’t allow function activations to be stored or passed around dynamically
When a procedure \( Q() \) is called in the body of procedure \( P() \), \( P \) and \( Q \) share responsibility in filling \( Q \)'s AR:

- \( P \) evaluates the \textbf{actual parameters} and put their values in \( Q \)'s AR.

- \( P \) stores information in \( Q \)'s AR so that when \( Q \) is done, \( P \) may continue execution from where it is left.

- \( P \) set \( Q \)'s \textbf{control link} to point to its AR.

- \( Q \) allocates space for its \textbf{locals}, and some \textbf{temporary storage}.

- The body of the procedure is executed.

- Control returns to the caller \( P \), and \( Q \)'s AR, which is no longer needed, is popped out of the stack. The \textbf{frame pointer} is also reset from the control link.
Tail-recursive procedure: when the last executable statement in its body is the recursive call.

- Recursion simplifies programming, but naive implementation pays a price of worse efficiency since procedure call involves a lot of overhead.
- This problem can be eliminated by replacing any tail-recursive call with a loop.
- Scheme actually requires elimination of tail-recursion in its language specification.
int bsearch(int* a, int x, int lo, int hi)
{
    if (lo > hi) return NOT_FOUND;
    int k = (lo + hi) / 2;
    if (x == a[k]) {
        return k;
    } else if (x < a[k]) {
        return bsearch(a, x, lo, k-1);
    } else if (x > a[k]) {
        return bsearch(a, x, k+1, hi);
    }
}
int bsearch(int* a, int x, int lo, int hi) 
{
    while (1) {
        if (lo > hi) return NOT_FOUND;
        int k = (lo + hi) / 2;
        if (x == a[k]) {
            return k;
        } else if (x < a[k]) {
            // a = a;
            // x = x;
            // lo = lo;
            hi = k-1;
        } else if (x > a[k]) {
            // a = a;
            // x = x;
            lo = k+1;
            // hi = hi;
        }
    }
}
(define M (lambda (j k)

  (define P (lambda (x y z)

    (define Q (lambda ()

      (define R (lambda ()

        (P j k z))) ; end R

        (* (R) y))) ; end Q

        (+ (Q) x))) ; end P

        (P j k 2))) ; end M
Part II

Parameter Passing
Parameter-Passing: Running Example

```c
int a[] = {1, 2, 3, 4};
void Swap(int ... x, int ... y) {
    int temp = x;
    x = y;
    y = temp;
    a[1] = 0;    // nonlocal a[]
}

int main() {
    int j = 1; Swap(j, a[j]);
}
```

- Result depends on the relation between the actuals and formals.
What does it mean by:

\[ x = x + 1; \]

- variable \( x \) is assigned the sum of 1 and the value of \( x \)
- \( \text{location}(x) \leftarrow \text{value}(x) + 1 \)
- \( \text{l-value}(x) \leftarrow \text{r-value}(x) + 1 \)
- the meaning of the variable “\( x \)” is overloaded
A **macro** preprocessor in C/C++ supports language extensions:

```c
#define BUFFER_SIZE 1024
#define BIGGER(a,b) ((a)>(b) ? (a) : (b))
```

C++’s **inline functions** are better macros allowing type-checking:

```c
inline int Bigger(int a, int b)
{
  return (a > b) ? a : b;
}
```

However, it is just a **recommendation** to the compiler to expand the procedure before compilation; the compiler might not do so!

- Macro expansion is more efficient: no overhead in procedure calls.
- Macro expansion cannot handle recursion
  ⇒ should be used only on simple codes
Scope rules of a language determine which declaration of a name “x” applies to an occurrence of “x” in a program.

- **static/lexical scope rules**: the binding of name occurrences to declarations is done statically, at **compile time**.

- **dynamic scope rules**: the binding of name occurrences to declarations is done dynamically, at **run time**.

Most languages use lexical scope rule.

Dynamic scope are used for **macros** and **inline functions**.
int main()
{
    int j;          // apply to S1,S5,S6
    int k;          // apply to S1,S2,S3,S4,S6
    S1;

    for (...
    {
        int j;        // apply to S2,S4
        S2;

            while (...)
            {
                int j;      // apply to S3
                S3;
            }
        S4;
    }

    while (...
    {
        int k;        // apply to S5
        S5;
    }
    S6;
}
Renaming Principle of Local Variables:
Consistent renaming of local names in the source text does not change the meaning of a program.

- Under lexical scope rule, we can always rename local variables until each name has only one declaration in the entire program.

- Most-closely-nested rule: an occurrence of a name is in the scope of the innermost enclosing declaration of the name.
program dynamic_scope(input, output);
  var x : real;
procedure show;
  begin write(x) end;
procedure tricky;
  var x : real;
  begin x = 1.2; show end;
begin x := 5.6; show; tricky; end.

What is the output if lexical scope rule is used?
What is the output if dynamic scope rule is used?

Dynamic scope rule may be implemented by macros.
Call-by-Reference (CBR): Running Example

// Using C++ syntax
// Declare as: void Swap(int& x, int& y)
// Call as: Swap(j, a[j]);

x and j refer to the same object; // int& x = j;
y and a[j] refer to the same object; // int& y = a[j];
temp <- x; x <- y; y <- temp;
a[1] <- 0;

j =
a = { , , , }

x is called an alias of j, and y an alias of a[j]
int square(int x) { return x*x; } 
int main()
{
    int y = 8; y = square(y+y);
}

Under **CBV**,

\[ u \leftarrow y+y \quad \text{// done before calling square()} \]
\[ x \leftarrow r\text{-value}(u) \quad \text{// int } x = u; \]
\[ \text{result } \leftarrow x\times x \]
\[ \text{return result} \]
// Using C syntax
// Declare as: void Swap(int x, int y)
// Call as: Swap(j, a[j]);

x <- j;       // int x = j;
y <- a[j];    // int y = a[j];
temp <- x; x <- y; y <- temp;
a[1] <- 0;

• j =
• a = { , , , , }

Actually NO swapping has happened.
int a[] = {1, 2, 3, 4};
void Swap(int* x, int* y)
{
    int temp = *x;
    *x = *y;
    *y = temp;
    a[1] = 0;       // nonlocal a[]
}

int main()
{
    int j = 1; Swap(&j, &a[j]);
}
// Using C syntax
// Declare as: void Swap(int* x, int* y)
// Call as: Swap(&j, &a[j]);

x <- l-value(j);       // int* x = &j;
y <- l-value(a[j]);    // int* y = &a[j];
temp <- r-value(object that x points to);
l-value(object that x points to)
    <- r-value(object that y points to);
l-value(object that y points to) <- temp;
a[1] <- 0;

j =
a = { , , , }
// C, C++ don’t use this; but assuming C++ syntax
// Call as: Swap(j, a[j]);

x <- r-value(j);  // Copy in the values
y <- r-value(a[j]);

temp <- x; x <- y; y <- temp;  // Execute procedure
a[1] <- 0;

l-value(j) <- x;  // Copy out the results
l-value(a[j]) <- y;

j =

a = { , , , }
CBVR = CBR if the called procedure does not use any nonlocal variables.

CBVR may differ from CBR if the called procedure has more than one way of accessing a location in the caller.

```pascal
var i : integer;
var j : integer;
procedure foo(x, y); begin i := y end
begin
  i := 2; j := 3; foo(i,j);
end
```

if CBR:  i = , j =

if CBVR: i = , j =
Call-by-Name (CBN): Running Example

// C, C++ don’t use this; but assuming C++ syntax
// Call as: Swap(j, a[j]);

// textually substitute j for x, a[j] for y
int temp = j;
j = a[j];
a[j] = temp;
a[1] = 0;

j =
a = { , , , , }

CBN is NOT the same as macro expansion
program TRY;
    int n; n = 10;
procedure P(x);
    begin int i; i = i + n; x = x + n; end;
begin
    int i, n; int A[10];
    i = 3; n = 5;
    P(A[i]);
end;

**CBN** does more than just textual substitution.
if we simply substitute $A[i]$ for $x$ in $P(x)$

$$i = i + n; \ A[i] = A[i] + n;$$

$\Rightarrow$ conflict between the actuals ($A[i]$) and locals ($i$)  
$\Rightarrow$ renaming locals in the procedure body of $P(x)$

$\Rightarrow$ int $j; j = j + n; \ A[i] = A[i] + n;$

if we simply do macro expansion in the main program

$$i = 3; \ n = 5;$$
$$j = j + n; \ A[i] = A[i] + n;$$

$\Rightarrow$ conflict between $n$ of main program and $n$ of $P(x)$

$\Rightarrow$ renaming locals in the caller of $P(x)$

$\Rightarrow$ int $i, m; i = 3; \ m = 5; \ j = j + n; \ A[i] = A[i] + n;$
## Summary on Parameter Passing

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<th>Language</th>
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<td>C, C++</td>
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</tr>
<tr>
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<tr>
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