Parameter Passing – Value Parameters

Value parameters are (usually) copied by the caller into the callee’s activation record. Changes to a formal won’t affect the actual.

Parameter Passing – Reference Parameters

Reference parameters are passed by passing the address (location, l-value) of the parameter. Changes to a formal affects the actual also.

Call-by-Value Parameters

1. The caller computes the arguments’ r-value.
2. The caller places the r-values in the callee’s activation record.

- The caller’s actuals are never affected by the call.
- Copies may have to be made of large structures.
Call-by-Reference Parameters

1. The caller computes the arguments' l-value.
2. Expression actuals (like \(a + b\)) are stored in a new location.
3. The caller places the l-values in the callee's activation record.

- The caller's actuals may be affected by the call.

```pascal
TYPE T = ARRAY 10000 OF CHAR;
PROC P (VAR a:INT; VAR b:T);
BEGIN a:=10; b[5]="4" END P;

VAR r :  INTEGER; X : T;
BEGIN P(5 + r, X) END 
```

Call-by-Name Parameters

(Un-)popularized by Algol 60.

- A name parameter is (re-)evaluated every time it is referenced, in the callers environment.

**Algorithm:**

1. The caller passes a thunk, a function which computes the argument's l-value and/or r-value, to the callee.
2. The caller also passes a static link to its environment.
3. Every time the callee references the name parameter, the thunk is called to evaluate it. The static link is passed to the thunk.

**Algorithm:**

4. If the parameter is used as an l-value, the thunk should return an l-value, otherwise an r-value.
5. If the parameter is used as an l-value, but the actual parameter has no l-value (it's a constant), the thunk should produce an error.

**Consequences:**

- Every time a callee references a name parameter, it may produce a different result.

```pascal
VAR i :  INTEGER; VAR a :  ARRAY 2 OF INTEGER;
PROCEDURE P (NAME x:INTEGER);
BEGIN
  i := i + 1; x := x + 1;
END;

BEGIN
  i := 1; a[1] := 1; a[2] := 2;
P(a[i]);
  WRITE a[1], a[2];
END
```

x := x + 1 becomes \(a[i] := a[i] + 1\).

- Since \(i\) is incremented before \(x\), we get \(a[2] := a[2] + 1\). → Print 1,3.
Call-by-Name – Implementation

PROCEDURE P (thunk : PROC());
BEGIN
    i := i + 1; thunk() := thunk() + 1;
END;

PROCEDURE thunk1 () : ADDRESS;
BEGIN RETURN ADDR(a[i]) END;

BEGIN
    i := 1; a[1] := 1; a[2] := 2;
    P(thunk1);
    WRITE a[1], a[2];
END

Call-by-Name – Jensen’s Device

PROC Sum (NAME Expr:REAL; NAME Idx:INTEGER; Max:INTEGER):INTEGER;
VAR Result : REAL := 0;
BEGIN
    FOR i := 1 TO Max DO;
        Idx := i; Result := Result + Expr;
    ENDFOR;
    RETURN Result;
END

VAR i : INTEGER;
BEGIN
    WRITE Sum(i, i, 5); (* \sum_{i=1}^{5} i *)
    WRITE Sum(i*i, i, 10); (* \sum_{i=1}^{10} i^2 *)
END

Large Value Parameters

Large value parameters have to be treated specially, so that a change to the formal won’t affect the actual.
Example:

TYPE T = ARRAY [1..1000] OF CHAR;
PROCEDURE P (x : T);
BEGIN
    x[5] := "f";
END P;
VAR L : T;
BEGIN
    P(L);
END.

Algorithm 1: Callee Copy

PROCEDURE P (VAR x : T);
VAR xT : T;
BEGIN
    copy(xT,x,1000); xT[5] := "f";
END P;
VAR L : T;
BEGIN
    P(L);
END

Algorithm 2: Caller Copy

PROCEDURE P (VAR x : T);
BEGIN
    x[5] := "f";
END P;
VAR L : T;
BEGIN
    copy(LT, L, 1000);
    P(LT);
END
Accessing Non-Local Variables

PROGRAM M;
PROC P(n);
  LOCAL L;
  PROC Q(); BEGIN PRINT L; END Q;
BEGIN
  L := n * 3;
  IF n >= 1 THEN P(n-1) ELSE Q() ENDIF;
END P;

Which L should Q print? There are three Ls on the stack to choose from!

Accessing Non-Local Variables...

PROCEDURE P (a: INTEGER);
  VAR L : INTEGER;
  PROCEDURE Q (x: INTEGER);
  BEGIN R(16) END Q;

  PROCEDURE R (y: INTEGER);
  VAR G : INTEGER;
  PROCEDURE V (z: INTEGER);
  BEGIN Q(10) END V;
  BEGIN V(12) END R;

  BEGIN Q (5) END P;

Accessing Non-Local Variables...

PROCEDURE P (a: INTEGER);
PROCEDURE Q (x: INTEGER);
PROCEDURE R (y: INTEGER);
PROCEDURE V (z: INTEGER);

We give each activation record an Access Link (aka Static Link).

Assume that Q is nested within P (as above). Then Q’s static link points to the activation record for the most recent activation of P.
Accessing Non-Local Variables...

Stack grows down! The access links point to each other!

The access links point to each other!

PROC P ();
VAR L: INTEGER;

PROC R ();
PROC V ();
BEGIN L:=... END V;

Access to non-local variable L:

- Assume that L is declared at nesting level \( n_L \), and that the reference to L is at nesting level \( n_R \) (as above).
- Follow \( n_R - n_L \) access links. We now point to the activation record for the most recent activation of P.

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Setting up Access Links

- Every time we make a procedure call we have to set up the access link for the new procedure activation.
- There are two cases to consider:
  1. when the callee is nested within the caller, and
  2. when the caller is nested within the callee.

MIPS Example:

1. "lw $2, AL($fp) # AL is offset of access link."
2. "lw $2, ($2) # An access link points to"
   " # the previous access link."
3. "lw $3, 12($2) # Get the data in the AR."
Setting up Access Links...

Case (1): Callee Within Caller:

PROC P(); \(\leftarrow N_P = 1\)
PROC Q(); \(\leftarrow N_Q = 2\)
PROC V();

BEGIN Q(); END P;

\(P\) calls \(Q\). \(P\) is at level \(N_P\), \(Q\) is at level \(N_Q\). \(N_P = N_Q - 1\), since \(Q\) must be nested immediately within \(P\).

Make \(Q\)’s access link point to the access link in \(P\)’s activation record.

Parameter Passing

In Pascal, parameters are passed either by value or by reference (if the formal is preceded by the keyword var).

In C, all parameters are passed by value. Pass by reference can be simulated by explicitly passing the address of a variable: \texttt{swap(&x, &y)}.

In FORTRAN, all parameters are passed by reference. A programmer can simulate pass-by-value by explicitly making a local copy of an argument.

Unlike most languages, FORTRAN allows r-values to be passed by reference: \texttt{swap(3+4, 7*x)}. The compiler creates a temporary variable to hold the value.

Parameter Passing...

In Java, object references are transferred using pass-by-sharing. This means that the actual and formal will refer to the same object. The compiler simply passes the address of the object.

In Java, primitive types are passed by value.
Parameter Passing...

In Pascal and Modula-2 a programmer would use call-by-value to
- ensure that the callee cannot modify the actual argument.

In Pascal and Modula-2 a programmer would use call-by-reference to
- ensure that the callee can modify the actual argument, or to
- make sure that a large parameter (which semantically should be passed by value) is not copied. (This is done for efficiency reasons).

Parameter Passing in Ada

Ada has three modes:
1. **in**-parameters pass information from the caller to the callee. The callee cannot write to them.
2. **out**-parameters pass information to the callee from the caller. The callee can read and write them. They start out being uninitialized.
3. **in out**-parameters pass information from the caller to the callee and back.

Parameter Passing...

Modula-3 provides a **READONLY** parameter mode. A READONLY formal parameter cannot be changed by the callee. The formal
1. cannot be on the left-hand-side of an assignment statement, and
2. cannot be passed by reference to another routine.
- Small READONLY parameters are passed by value.
- Large READONLY parameters are passed by reference.

Parameter Passing in Ada...

For scalars and pointers, all modes should be implemented by copying values. Thus
1. **in**-parameters are **passed-by-value**.
2. **out**-parameters are **passed-by-result** (the formal is copied into the actual when the procedure returns).
3. **in out**-parameters are **passed-by-value/result** (On entry, the actual is copied into the formal. On return, the formal is copied back into the actual).
Parameter Passing in Ada...

For constructed types (records, arrays) an implementation is allowed to pass either values or addresses.

- If an `in out` parameter is passed by address an assignment to the formal changes the actual immediately.

- If an `in out` parameter is passed by value an assignment to the formal will not affect the actual until the procedure returns (and the formal is copied back into the actual).

Ada disallows programs that can tell which implementation a compiler uses.

type t is record a, b : integer; end record;

r : t;

procedure foo (s : in out t) is
begin
  r.a := r.a + 1;
  s.a := s.a + 1;
end foo;

r.a := 3;
foo(r);
if r.a = 4 then
  put("implementation uses pass-by-value")
else
  put("implementation uses pass-by-address")

Exam Problem 415.330/96 (A)

Show the status of the run-time stack when execution has reached point ◊ for the second time in the program on the next slide.

Fill in the name of each procedure invocation in the correct activation record. Also fill in the values of local variables and actual parameters, and show where the static links and control links are pointing.

Assume that all actual parameters are passed on the stack rather than in registers.

Exam Problem 415.330/96 (B)

PROGRAM M;
PROC P ( X:INT);
VAR W:INT;
VAR Z:INT;
PROC Q ( Y:INT);
VAR N:INT;
VAR Z:INT;
BEGIN
  L := W;
  P(3);
END P;
BEGIN
  N := W;
  Q(15);
END Q;
BEGIN
  W := X + 1;
END W;
BEGIN
  Z := W + 1;
END Z;
BEGIN
  R := Z + 1;
END R;
BEGIN
  Q(4);
  Q(5);
END Q;
BEGIN
  P(15);
END P;
BEGIN
  END P;
END P;
BEGIN
  END Q;
END Q;
BEGIN
  END W;
END W;
BEGIN
  END M;
END M.
Homework

Draw the stack when control reaches point ◇ for the third time. Include all actual parameters, local variables, return addresses, and static and dynamic links.

PROGRAM M;
PROCEDURE P(X:INTEGER);
VAR A : INTEGER;
PROCEDURE Q(Y : INTEGER);
VAR B : INTEGER;
BEGIN
B := Y + 1; A := B + 2;
◇
P(B);
END Q;
BEGIN
A := X + 1; Q(A);
END P;
BEGIN P(0); END M.

Summary

A parameter is often passed by the caller copying it (or its address, in case of VAR parameters) into the callees activation record. On the MIPS, the caller has an area in its own activation record in which it puts actual parameters before it jumps to the callee. For each procedure P the compiler figures out the maximum number of arguments P passes to any procedure it calls. The corresponding amount of memory has to be allocated in P’s activation record.

Readings and References

Read Scott, pp. 441–448, 450–464
Read the Dragon Book:
Parameter Passing 424–427