8 Parameter Passing

Pass by Value

```
 1 // ex0801.c  Pass by value
 2 #include <stdio.h>
 3 int x = 7;
 4 void f(int a)
 5 {
 6    a = a + 1;
 7 }
 8 =====================
 9 int main()
10 {
11    f(x);
12    printf("%d\n", x);
13    return 0;
14 }
```

When main calls `f` (line 11), it passes the value of `x`, which is 7. The parameter `a` in `f` receives this value. Thus, on entry into `f`, `x` and `a` are

Note that `x` and `a` correspond to separate locations in memory. Thus, when `f` increments `a` (line 6), the value in `x` is unaffected:

Here is the assembler code for this program:

Example of Pass by Value

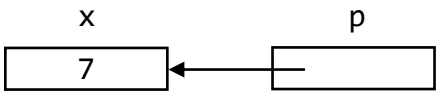
```
 1 ; ex0801.a  Pass by value
 2 startup:  bl main
 3           halt
 4 ;=============================================================
 5                             ; #include <stdio.h>
 6 x:        .word 7           ; int x = 7;
 7                             ; void f(int a)
 8 f:        push lr           ; {
 9           push fp
10           mov fp, sp
11
12           ldr r0, fp, 2     ;    a = a + 1;
13           add r0, r0, 1
14           str r0, fp, 2
15
16           mov sp, fp
17           pop fp
18           pop lr
19           ret
20                             ; }
21    ;=============================================================
22                             ; int main()
23 main:     push lr           ; {
24           push fp
25           mov fp, sp
26
27           ld r0, x          ;    f(x);
28           push r0
29           bl f
30           add sp, sp, 1
31
32           ld r0, x          ;    printf("%d\n", x);
33           dout r0
34           nl
35
36           mov r0, 0         ;    return 0;
37           mov sp, fp
38           pop fp
39           pop lr
40           ret
41                             ; }
42
```

Pass by Address

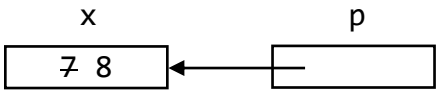
```
f(&x);
```

```
 1 // ex0802.c  Pass by address
 2 #include <stdio.h>
 3 int x = 7;
 4 void f(int *p)
 5 {
 6    *p = *p + 1;
 7 }
 8 //===================
 9 int main()
10 {
11    f(&x);              // pass by address
12    printf("%d\n", x);
13    return 0;
14 }
```

The parameter `p` in `f` receives this address. Thus, on entry into `f`, `p` points to `x`:



On line 6, `f` dereferences `p` twice: first to access the value in `x` and second to store a new value in `x`, after which `x` and `p` are



Because `f` changes the value of the argument `x`, we say that `f` has a *side effect*—that is, it has a non-local effect. In particular, it changes a variable not local to `f` (the global variable `x`). Here is the assembler code for the program:

Example of Pass by Address

```
 1 ; ex0802.a  Pass by address
 2 startup:  bl main
 3           halt
 4 ;=============================================================
 5                             ;  #include <stdio.h>
 6 x:        .word 7           ; int x = 7;
 7
 8                             ; void f(int *p)
 9 f:        push lr           ; {
10           push fp
11           mov fp, sp
12
13           ldr r0, fp, 2     ;    *p = *p + 1;
14           ldr r0, r0, 0
15           add r0, r0, 1
16           ldr r1, fp, 2
17           str r0, r1, 0
18
19           mov sp, fp        ; }
20           pop fp
21           pop lr
22           ret
23 ;=============================================================
24                             ; int main()
25 main:     push lr           ; {
26           push fp
27           mov fp, sp
28
29           lea r0, x         ;    f(&x);
30           push r0
31           bl f
32           add sp, sp, 1
33
34           ld r0, x          ;    printf("%d\n", x);
35           dout r0
36           nl
37
38           mov r0, 0         ;    return 0;
39           mov sp, fp
40           pop fp
41           pop lr
42           ret
43                             ; }
```

Several Important Observations on Pass by Address

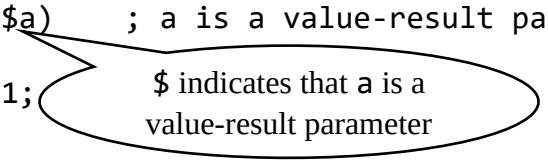
- The standard mechanism for returning a value to a calling function is for the called function to place the return value in `r0` prior to executing the `ret` instruction. However, because pass by address can have side effects, it can also be used to return values. We saw this in the program above. It returns 8 to `main` by storing 8 in `x`. It does this by the dereferencing `p`, the parameter corresponding to `x`. One advantage of the pass-by-address mechanism over the `r0` return mechanism is that the pass-by-address mechanism can return any number of values, one for each pass-by-address parameter. The `r0` mechanism, however, can return only one value.

- To access a value parameter requires only one instruction (`ldr` or `str`) but to dereference a pass-by-address parameter requires a two-instruction sequence (`ldr-ldr` or `ldr-str`). Thus, there is a cost in both time and space associated with using pass by address.

- In general, it is better to pass an aggregate structure, such as an array, by address than by value. For example, suppose an argument in a function call is a 1000-slot array. If the array is passed by value, then the calling sequence would push a copy of the *entire array* onto the stack. If, however, the array is passed by address, then the calling sequence would push only the address of the array. Thus, for a large array, pass by value is grossly inefficient compared to pass by address.

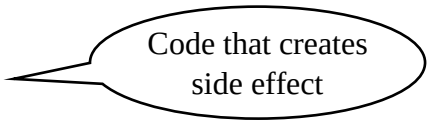
Pass by Value-Result

```
 1 // ex0803.c Pass by value-result (not supported by C)
 2 #include <stdio.h>
 3 int x = 7;
 4 void f(int $a)    ; a is a value-result parameter
 5 {
 6    a = a + 1;
 7 }
 8 //===================
 9 int main()
10 {
11    f(x);
12    printf("%d\n", x);
13    return 0;
14 }
```



Example of Pass by Value-Result

```
 1 ; ex0803.a  Pass by value-result (not supported by C)
 2
 3 startup:  mov sp, 0        ; initialize stack pointer
 4           mov fp, 0        ; initialize frame pointer
 5           bl main
 6           halt             ; back to operating system
 7 ;============================================================
 8                            ; #include <stdio.h>
 9 x:        .word 7          ; int x = 7;
10                            ; void f(int $a)
11 f:        push lr          ; {
12           push fp
13           mov fp, sp
14
15           ldr r0, fp, 2    ;    a = a + 1;
16           add r0, r0, 1
17           str r0, fp, 2
18
19           mov sp, fp
20           pop fp
21           pop lr
22           ret
23                            ; }
24 ;============================================================
25                            ; int main()
26 main:                      ; {
27           push lr
28           push fp
29           mov fp, sp
30
31           ld r0, x         ;    f(x);
32           push r0
33           bl f
34           pop r0
35           st r0, x
36
37           ld r0, x         ;    printf("%d\n", x);
38           dout r0
39           nl
40
41           mov r0, 0        ;    return 0;
42           mov sp, fp
43           pop fp
44           pop lr
45           ret
46                            ; }
```



Pass by Name

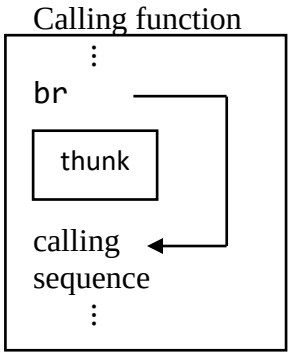
```
f(a+b);
```

```
 1 // ex0804.c  Pass by name (not supported by C)
 2 #include <stdio.h>
 3 int a = 1;
 4 void f(int #x)
 5 {
 6    printf("%d\n", x);   // displays 3
 7    a = a + 2;
 8    printf("%d\n", x);   // displays 5
 9 }
10 //===================
11 int main()
12 {
13    int b = 2;
14    f(a+b);
15    return 0;
16 }
```

# indicates that x is a name parameter

The call of `f` on line 14 conceptually passes the expression `a+b`—not its value—to `f`. This expression replaces every occurrence of the parameter `x` in `f`. Thus, lines 6 and 8 both become

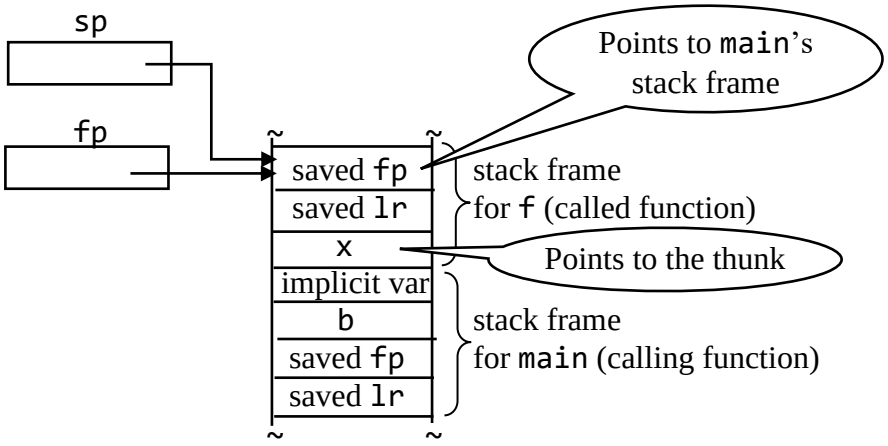
```
printf("%d\n", a+b);
```



What should the calling sequence pass to the called function? The called function has to call the thunk. So the calling sequence *has to pass the address of the thunk.* Here is the thunk and the calling sequence for the function call on line 14 in the program in `ex0804.c`:

```
 1            br @L0                  branch over the thunk to the calling sequence
 2
 3 @L1:       ld r0, a
 4            ldr r1, fp, -1          thunk that evaluates a+b and returns its value
 5            add r0, r0, r1
 6            str r0, fp, -2          store value of a+b in implicit variable
 7            add r0, fp, -2          get address of implicit variable
 8            ret
 9
10 @L0:       sub sp, sp, 1
11            lea r0, @L1
12            push r0                 calling sequence
13            bl f
14            add sp, sp, 2
```

Pass address of thunk



1. Load `r0` with the address of the thunk, which is in the name parameter `x`. `x` is at the offset 2 in `f`'s stack frame (see the stack diagram above).
   .

   ```
   ldr r0, fp, 2
   ```

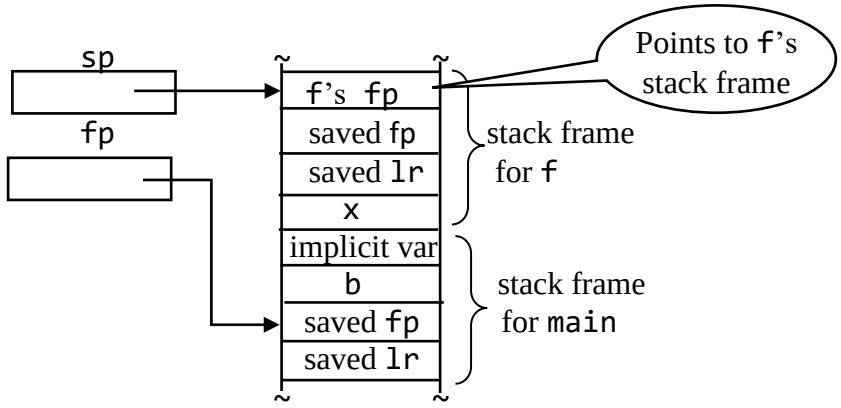
2. Save `fp` by pushing its contents onto the stack.

   ```
   push fp
   ```

3. Reset `fp` to point to `main`'s stack frame. `fp` is pointing to `main`'s `fp` (see the stack diagram above). Thus, to reset `fp`, load `fp` from the stack location that `fp` points to.

   ```
   ldr fp, fp, 0
   ```

The stack now looks like this:



4. Call the thunk via the address in `r0` from step 1 above.

```
blr r0
```

5. On return from the thunk, reset `fp` to point to `f`'s stack frame.

```
pop fp
```

6. Dereference the address returned by the thunk to get the value of the argument.

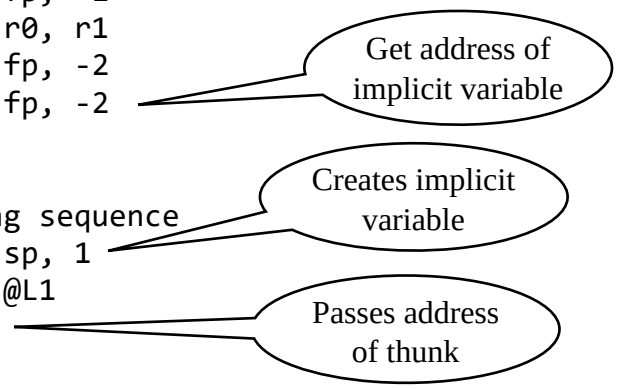
```
ldr r0, r0, 0
```

7. Use the value of the argument as indicated by the C code that references the name parameter. For this example, display the value of the argument.

```
dout r0
nl
```

```
1 ; ex0804.a  Pass by name (not supported by C)
2 startup:  bl main
3           halt              ; back to operating system
4 ;============================================================
5                             ; #include <stdio.h>
6 a:        .word 1           ; int a = 1;
7
8 f:        push lr           ; void f(int #x)
9           push fp           ; {
10          mov fp, sp
11
12          ; get thunk addr ;    printf("%d\n", x);
13          ldr r0, fp, 2
14          ; save f's fp
15          push fp
16          ; restore fp with caller's fp
17          ldr fp, fp, 0
18          ; call thunk
19          blr r0
20          ; restore fp with called function's fp
21          pop fp
22          ; dereference address returned by thunk
23          ldr r0, r0, 0
24          ; display value returned
25          dout r0
26          nl
27
28          ld r0, a          ;    a = a + 2;
29          add r0, r0, 2
30          st r0, a
31
32          ; get thunk addr ;    printf("%d\n", x);
33          ldr r0, fp, 2
34          ; save f's fp
35          push fp
36          ; restore fp with caller's fp
37          ldr fp, fp, 0
38          ; call thunk
39          blr r0
40          ; restore fp with called function's fp
41          pop fp
42          ; dereference address returned by thunk
43          ldr r0, r0, 0
44          ; display value returned
45          dout r0
46          nl
47
48          mov sp, fp        ; }
49          pop fp
50          pop lr
51          ret
```

```
52 ;=============================================================
53 main:     push lr          ; int main()
54           push fp          ; {
55           mov fp, sp
56
57           mov r0, 2        ;    int b = 2;
58           push r0
59
60           ; branch over thunk
61           br @L0           ;    f(a+b);
62
63           ; thunk
64 @L1:      ld r0, a
65           ldr r1, fp, -1
66           add r0, r0, r1
67           str r0, fp, -2
68           add r0, fp, -2
69           ret
70
71           ; calling sequence
72 @L0:      sub sp, sp, 1
73           lea r0, @L1
74           push r0
75           bl f
76           add sp, sp, 2
77
78           mov r0, 0        ;    return 0;
79           mov sp, fp
80           pop fp
81           pop lr
82           ret
83                            ; }
```



The effect of passing an argument by name is to substitute it for the corresponding parameter in the called function. For example, in the program above, the argument `a+b` in effect is substituted for `x` in `f`, changing the `printf` statements from

```
      printf("%d\n", x);
```

to

```
      printf("%d\n", a+b);


      f(a);
```

then the compiler generates the following thunk and calling sequence:

```
 1            br @L0
 2
 3 @L1:       lea r0, a      ; thunk returns address of single-var argument
 4            ret
 5
 6 @L0:       lea r0, @L1
 7            push r0
 8            bl f
 9            add sp, sp, 1
```

A name parameter that appears on the left side of an assignment statement is handled differently from name parameters that appear elsewhere. For example, consider the following program in which the name parameter `x` on line 6 appears on the left side of an assignment statement:

```
 1 // ex0805.c  Pass by name (not supported by C)
 2 #include <stdio.h>
 3 int a;
 4 void f(int #x)
 5 {
 6    x = 5;
 7 }
 8 //===================
 9 int main()
10 {
11    f(a);
12    return 0;
13 }
```

For line 6, the code does not *load* the value at the address returned by the thunk. Instead, it *stores* 5 (the value of the right side of the assignment statement) at the address returned by the thunk:

```
 1          ; get the address of the thunk
 2          ldr r0, fp, 2    ;    x = 5;
 3          ; save f's fp
 4          push fp
 5          ; restore fp with caller's fp
 6          ldr fp, fp, 0
 7          ; call thunk
 8          blr r0
 9          ; restore fp with f's fp
10          pop fp
11
12          mov r1, 5
13          str r1, r0, 0
```