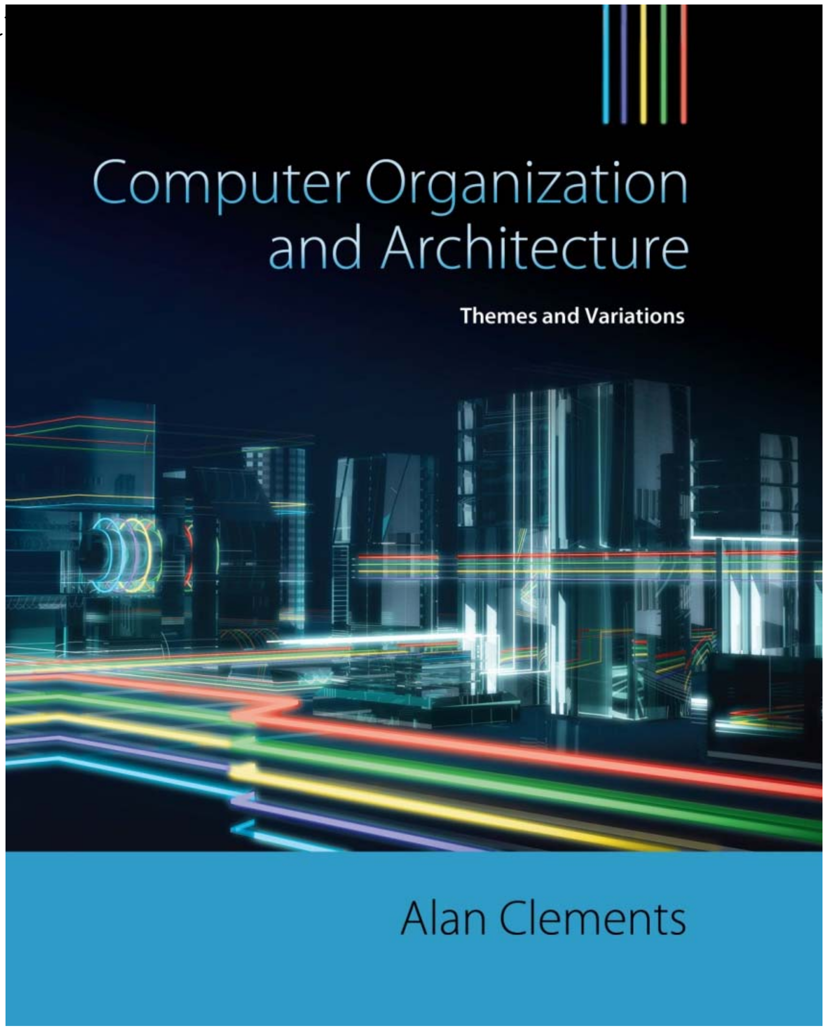
Part 2

Chapter 4

Computer Organization and Architecture



CENGAGE Learning

Calling a Subroutine Step-by-Step

- To call a subroutine, the following steps need to be performed:
  - ***Parameters*** need to be *passed* from the caller to the subroutine.
    This can be performed via the stack.
  - The ***address*** of the instruction immediately after the calling instruction needs to be *saved in a safe place* ***BEFORE*** branching to the subroutine.
    This can be performed by using BL instruction or via the stack, or both.
  - *Inside the subroutine*, we need to:
    - Push the values of all registers to be used inside the subroutine, as well as the FP (R11) and LR (R14).
    - Make the FP (R11) point to the bottom of the frame by copying the value of the SP (R13) to the FP (R11).
    - Create a space inside the stack for local variables.
    - Perform the subroutine instructions.
      The addresses of parameters and local variables are calculated relative to the value of the FP (R11).
    - *At the end of the subroutine*, deallocate all created local variables.
    - Pop all pushed registers but use PC (R15) instead of LR (R14).
  - *At the caller program*, all pushed parameters need to be popped.

Passing Parameters via the Stack

- You can pass a parameter to a subroutine
  - ***by value***
  - ***by reference***

- When passed ***by value***, the subroutine receives a **copy** of the parameter.
  - Passing a parameter by value causes the *parameter to be cloned* and the *cloned version of the parameter* to be used by the subroutine.
  - If the parameter is modified by the subroutine, the new value does not affect the value of the parameter elsewhere in the program.

- When passed ***by reference***, the subroutine receives a **pointer**, (i.e., an **address**) to the parameter.
  - *There is only one copy of the parameter* and the subroutine can access this value because it knows the address of the parameter.
  - If the subroutine modifies the parameter, it is modified the original value.

Passing Parameters via the Stack

- The subroutine `swap(int a, int b)` *intends* to exchange two values.
- Let's examine how parameters are passed to this subroutine.

```
void swap(int a, int b)   /* swaps the value of a and b */
{  int temp;
   temp = a;              /* copy a    to temp     */
   a    = b               /* copy b    to a,   and */
   b    = temp;           /* copy temp to b        */
}

void main(void)
{  int x = 2, y = 3;
   swap (x, y);           /* swap a and b */
}
```

Will it work?

Passing Parameters via the Stack

```
      AREA SwapVal, CODE, READONLY

      ENTRY
      ADR  sp,STACK          ;set up stack pointer
      MOV  fp,#0xFFFFFFFF    ;set up dummy fp for tracing
      B     main             ;jump to the function main

      SPACE 0x20
STACK DCD 0
```

FD Stack

You need to re-do it yourself using the other stack types.

```
;     void swap (int a, int b)
;     Parameter a    is at [fp]+4
;     Parameter b    is at [fp]+8
;     Variable  temp is at [fp]-4
```

FD Stack

Passing Parameters via the Stack

You need to re-do it yourself using the other stack types.

```
;       {
swap    SUB   sp,sp,#4       ;Create stack frame: decrement sp
        STR   fp,[sp]        ;push the frame pointer onto the stack
        MOV   fp,sp          ;frame pointer points at the base
;       int temp;
        SUB   sp,sp,#4       ;move sp up 4 bytes for temp
;       temp = a;
        LDR   r0,[fp,#4]     ;get parameter a from the stack
        STR   r0,[fp,#-4]    ;copy a to temp onto the stack frame
;       a    = b;
        LDR   r0,[fp,#8]     ;get parameter b from the stack
        STR   r0,[fp,#4]     ;copy b to a
;       b    = temp;
        LDR   r0,[fp,#-4]    ;get temp from the stack frame
        STR   r0,[fp,#8]     ;copy temp to b
;       }
                             ;Collapse stack frame created for swap
        MOV   sp,fp          ;restore the stack pointer
        LDR   fp,[sp]        ;restore old frame pointer from stack
        ADD   sp,sp,#4       ;move stack pointer down 4 bytes
        MOV   pc,lr          ;return by loading LR into PC
```

Passing Parameters via the Stack

```
;     void main(void)
;     {
main                         ;Create stack frame in main for x, y
      SUB   sp,sp,#4         ;move the stack pointer up
      STR   fp,[sp]          ;push the frame pointer onto the stack
      MOV   fp,sp            ;the frame pointer points at the base;
;     int x = 2, y = 3;
      SUB   sp,sp,#8         ;move sp up 8 bytes for 2 integers
      MOV   r0,#2            ;x = 2
      STR   r0,[fp,#-4]      ;put x in stack frame
      MOV   r0,#3            ;y = 3
      STR   r0,[fp,#-8]      ;put y in stack frame
;     swap(x, y);
      LDR   r0,[fp,#-8]      ;get y from stack frame
      STR   r0,[sp,#-4]!     ;push y on stack
      LDR   r0,[fp,#-4]      ;get x from stack frame
      STR   r0,[sp,#-4]!     ;push x on stack
      BL    swap             ;call swap, save return address in LR
      ADD   sp,sp,#8         ;Clean the stack from the parameters
;     }
      MOV   sp,fp            ;restore the stack pointer
      LDR   fp,[sp]          ;restore old frame pointer from stack
      ADD   sp,sp,#4         ;move stack pointer down 4 bytes
Loop  B     Loop             ;Stop
      END
```

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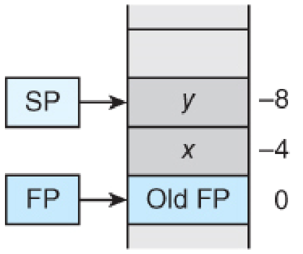
Passing Parameters via the Stack

- This code swaps the variables inside the stack frame
- When the return is made, the stack frame will be collapsed, and the effect of the swap will be lost.
- The variables in the calling environment are not affected.

Passing Parameters via the Stack

FIGURE 4.8 Passing values to a subroutine by value



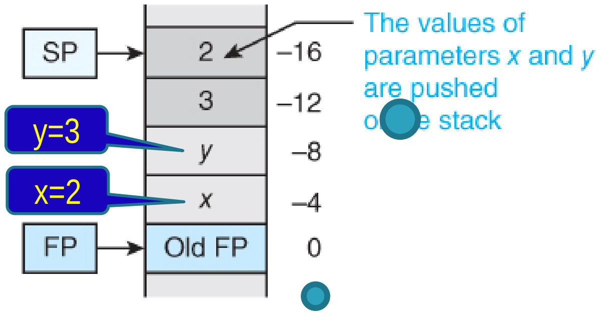
(a) State of the stack in main after creating stack frame with:

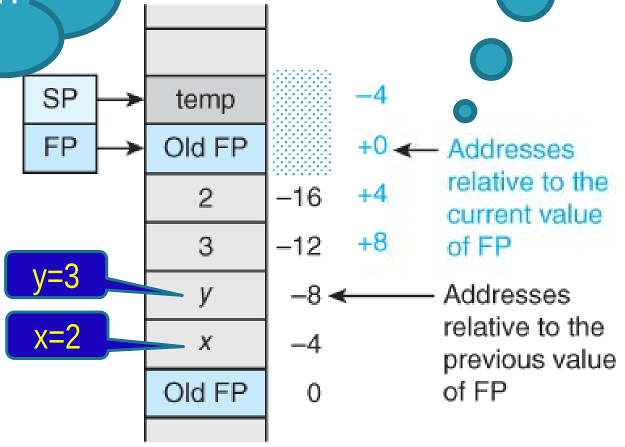
```
SUB sp,sp,#4
STR fp,[sp]
MOV fp,sp
SUB sp,sp,#8
```

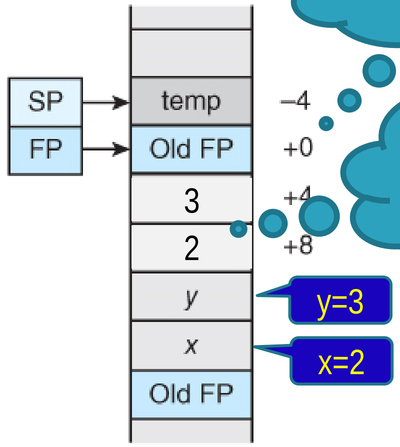
FP not SP. Not correct in page 245

The location of the addresses relative to the FP needs to be shifted down one cell. It is not correct in page 245

Same thing




SP
temp
−4
FP
Old FP
+0
2
−16
+4
3
−12
+8
y=3
y
−8
x=2
x
−4
Old FP
0
Addresses relative to the current value of FP
Addresses relative to the previous value of FP



The values of the parameters are not correct in page 245

(b) The stack in main after putting two parameters in the stack frame with:

```
MOV r0,#2
STR r0,[fp,#-4]
MOV r0,#3
STR r0,[fp,#-8]
```

Then pushing two parameters on the stack

```
LDR r0,[fp,#-8]
STR r0,[sp,#-4]!
LDR r0,[fp,#-4]
STR r0,[sp,#-4]!
```

(c) The stack after the creation of a stack frame in swap. The new stack frame is four bytes deep and holds the variable temp. The frame is created by:

```
SUB sp,sp,#4
STR fp,[sp]
MOV fp,sp
SUB sp,sp,#4
```

(d) The stack after executing the body of swap. Note that all data is referenced to FP.

```
LDR r0,[fp,#4]
STR r0,[fp,#-4]
LDR r0,[fp,#8]
STR r0,[fp,#4]
LDR r0,[fp,#-4]
STR r0,[fp,#8]
```

Passing Parameters via the Stack

- In the next example, we pass parameters by reference

```
void swap(int *a, int *b)   /* A function to swap two parameters
                               in calling program          */
{ int temp;                 /* copy *a   to temp          */
  temp = *a;                /* copy *b   to *a,  and      */
  *a   = *b;                /* copy temp to *b            */
  *b   = temp;
}

void main(void)
{ int x = 2, y = 3;
  swap(&x, &y);             /* call swap and pass
                               addresses of parameters     */
}
```

Passing Parameters via the Stack

```
      AREA SwapVal, CODE, READONLY

      ENTRY
      ADR   sp, STACK           ;set up stack pointer
      MOV   fp,#0xFFFFFFFF      ;set up dummy fp for tracing
      B     main                ;jump to main function

      SPACE 0x20
STACK DCD 0

  ;   void swap (int *a, int *b)
  ;   Parameter *a   is at [fp]+4
  ;   Parameter *b   is at [fp]+8
  ;   Variable  temp is at [fp]-4
```

Passing Parameters via the Stack

```
;       {
swap    SUB   sp,sp,#4        ;Create stack frame: decrement sp
        STR   fp,[sp]         ;push the frame pointer onto the stack
        MOV   fp,sp           ;frame pointer points at the base
;       int temp;
        SUB   sp,sp,#4        ;move sp up 4 bytes for temp
;       temp = *a;
        LDR   r1,[fp,#4]      ;get address of parameter a
        LDR   r2,[r1]         ;get value of parameter a (i.e., *a)
        STR   r2,[fp,#-4]     ;store *a in temp in stack frame
;       *a = *b;
        LDR   r0,[fp,#8]      ;get address of parameter b
        LDR   r3,[r0]         ;get value of parameter b (i.e., *b)
        STR   r3,[r1]         ;store *b in *a
;       *b = temp;
        LDR   r3,[fp,#-4]      ;get temp
        STR   r3,[r0]          ;store temp in *b
;       }
                              ;Collapse stack frame created for swap
        MOV   sp,fp           ;restore the stack pointer
        LDR   fp,[sp]         ;restore old frame pointer from stack
        ADD   sp,sp,#4        ;move stack pointer down 4 bytes
        MOV   pc,lr           ;return by loading LR into PC
```

Missing the *
in page 247

Passing Parameters via the Stack

```
;      void main(void)
;      {
main                           ;Create stack frame in main for x, y
       SUB   sp,sp,#4          ;move the stack pointer up
       STR   fp,[sp]           ;push the frame pointer onto the stack
       MOV   fp,sp             ;the frame pointer points at the base;
;      int x = 2, y = 3;
       SUB   sp,sp,#8          ;move sp up 8 bytes for 2 integers
       MOV   r0,#2             ;x = 2
       STR   r0,[fp,#-4]       ;put x in stack frame
       MOV   r0,#3             ;y = 3
       STR   r0,[fp,#-8]       ;put y in stack frame
;      swap(&x, &y);
       SUB   r0,fp,#8          ;get  address of y in stack frame
       STR   r0,[sp,#-4]!      ;push address of y on stack
       SUB   r0,fp,#4          ;get  address of x in stack frame
       STR   r0,[sp,#-4]!      ;push address of x on stack
       BL    swap              ;call swap, save return address in LR
       ADD   sp,sp,#8          ;Clean the stack from the parameters
;      }
       MOV   sp,fp             ;restore the stack pointer
       LDR   fp,[sp]           ;restore old frame pointer from stack
       ADD   sp,sp,#4          ;move stack pointer down 4 bytes
Loop   B     Loop              ;Stop
       END
```

Bold is not correct in page 244

Passing Parameters via the Stack

- In the function main, the addresses of the *parameters are pushed onto the stack* by means of the following instructions:

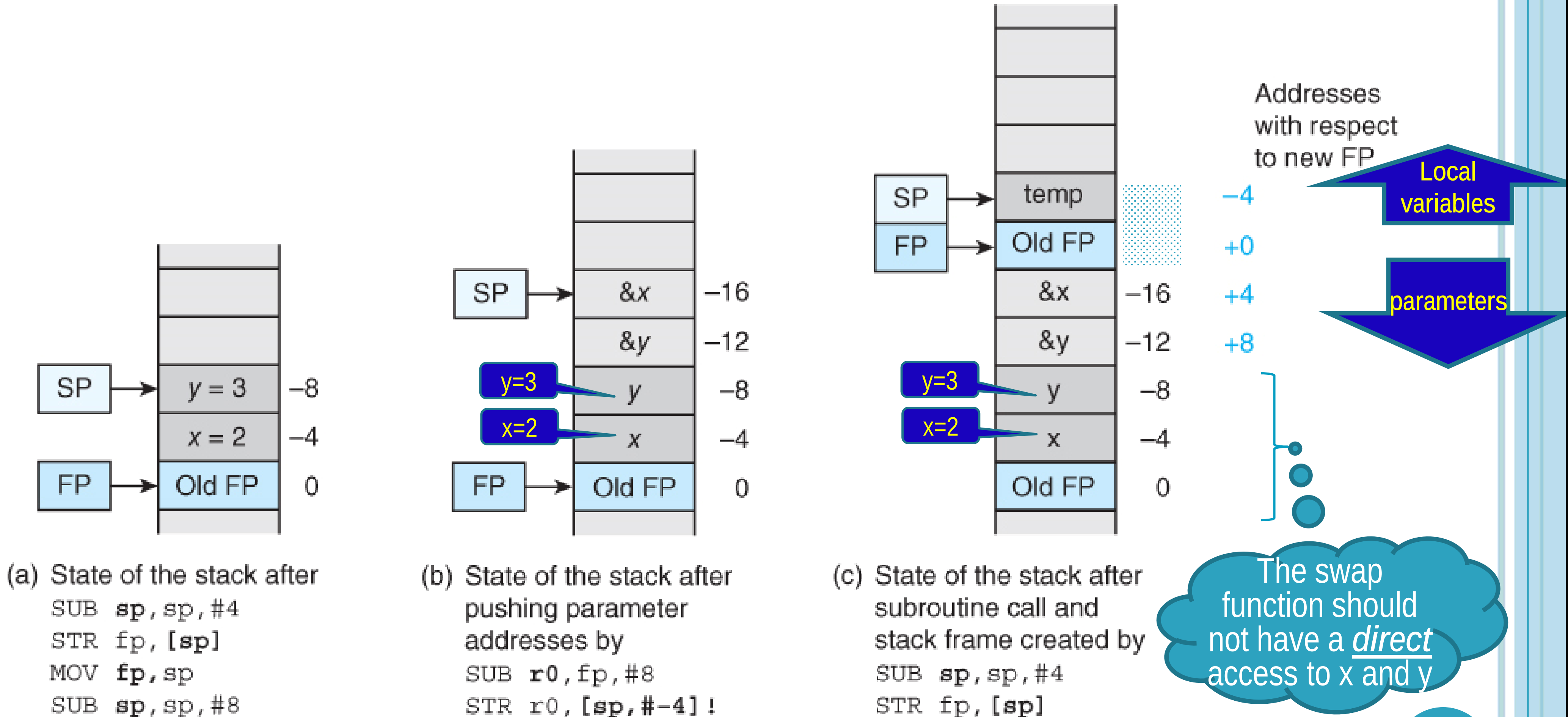
```
SUB   r0,fp,#8       ;get  address of y in stack frame
STR   r0,[sp,#-4]! ;push address of y on stack
SUB   r0,fp,#4       ;get  address of x in stack frame
STR   r0,[sp,#-4]! ;push address of x on stack
```

- In the function swap, the addresses of *parameters are read from the stack* by means of

```
;    temp = *a;
     LDR   r1,[fp,#4]  ;get address of parameter a
     LDR   r2,[r1]     ;get value of parameter a (i.e., *a)
     STR   r2,[fp,#-4] ;store *a in temp in stack frame
;    *a = *b;
     LDR   r0,[fp,#8]  ;get address of parameter b
     LDR   r3,[r0]     ;get value of parameter b (i.e., *b)
     STR   r3,[r1]     ;store *b in *a
;    *b = temp;
     LDR   r3,[fp,#-4]  ;get temp
     STR   r3,[r0]      ;store temp in *b
```

Passing Parameters via the Stack

FIGURE 4.9 Passing values to a subroutine by reference



SP
FP
y = 3
x = 2
Old FP
−8
−4
0
&x
&y
y
x
−16
−12
y=3
x=2
temp
Addresses with respect to new FP
Local variables
parameters
−4
+0
+4
+8
The swap function should not have a *direct* access to x and y

(a) State of the stack after

```
SUB sp,sp,#4
STR fp,[sp]
MOV fp,sp
SUB sp,sp,#8
MOV r0,#2
STR r0,[fp,#-4]
MOV r0,#3
STR r0,[fp,#-8]
```

in function main

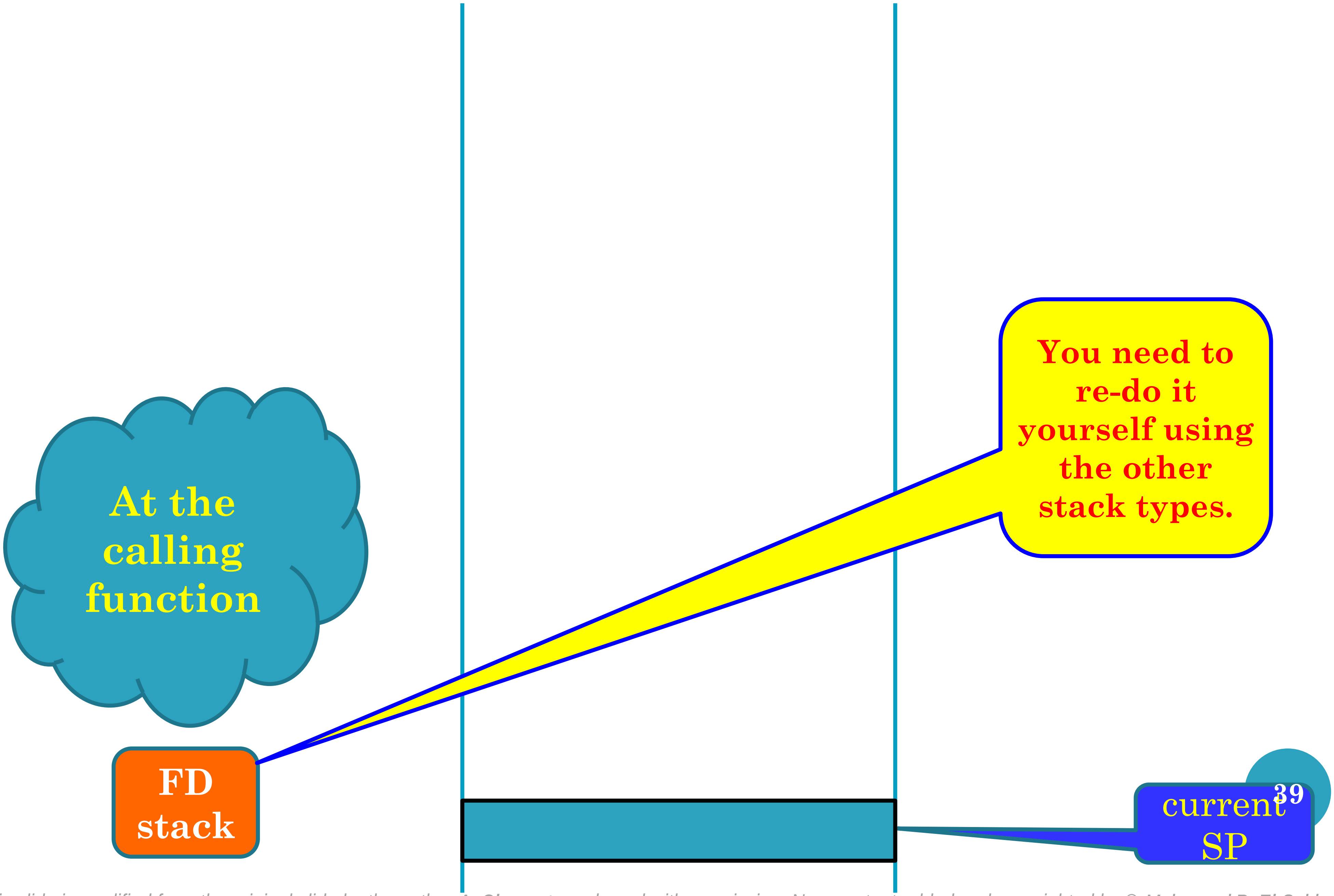
(b) State of the stack after pushing parameter addresses by

```
SUB r0,fp,#8
STR r0,[sp,#-4]!
SUB r0,fp,#4
STR r0,[sp,#-4]!
```

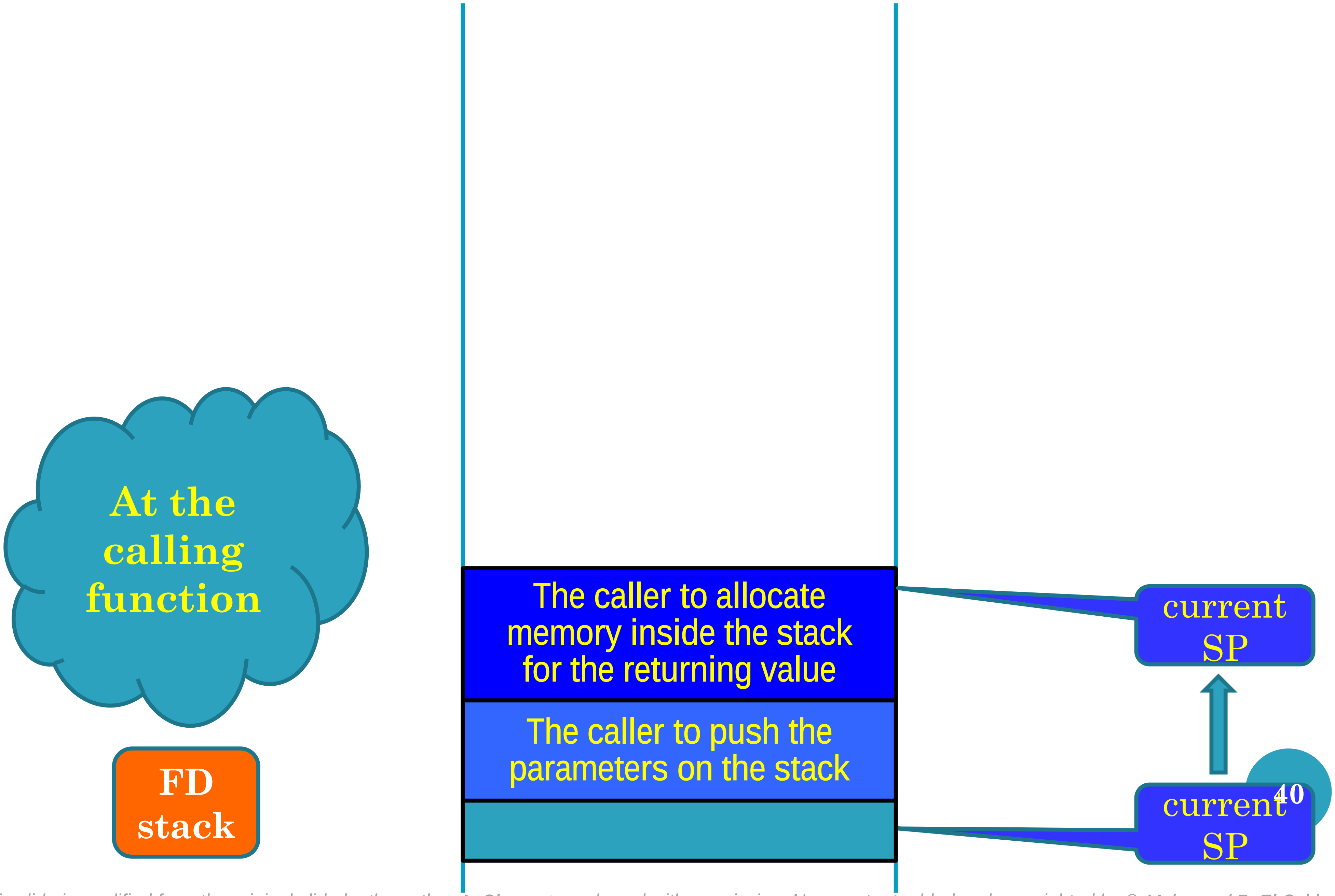
(c) State of the stack after subroutine call and stack frame created by

```
SUB sp,sp,#4
STR fp,[sp]
MOV fp,sp
SUB sp,sp,#4
```

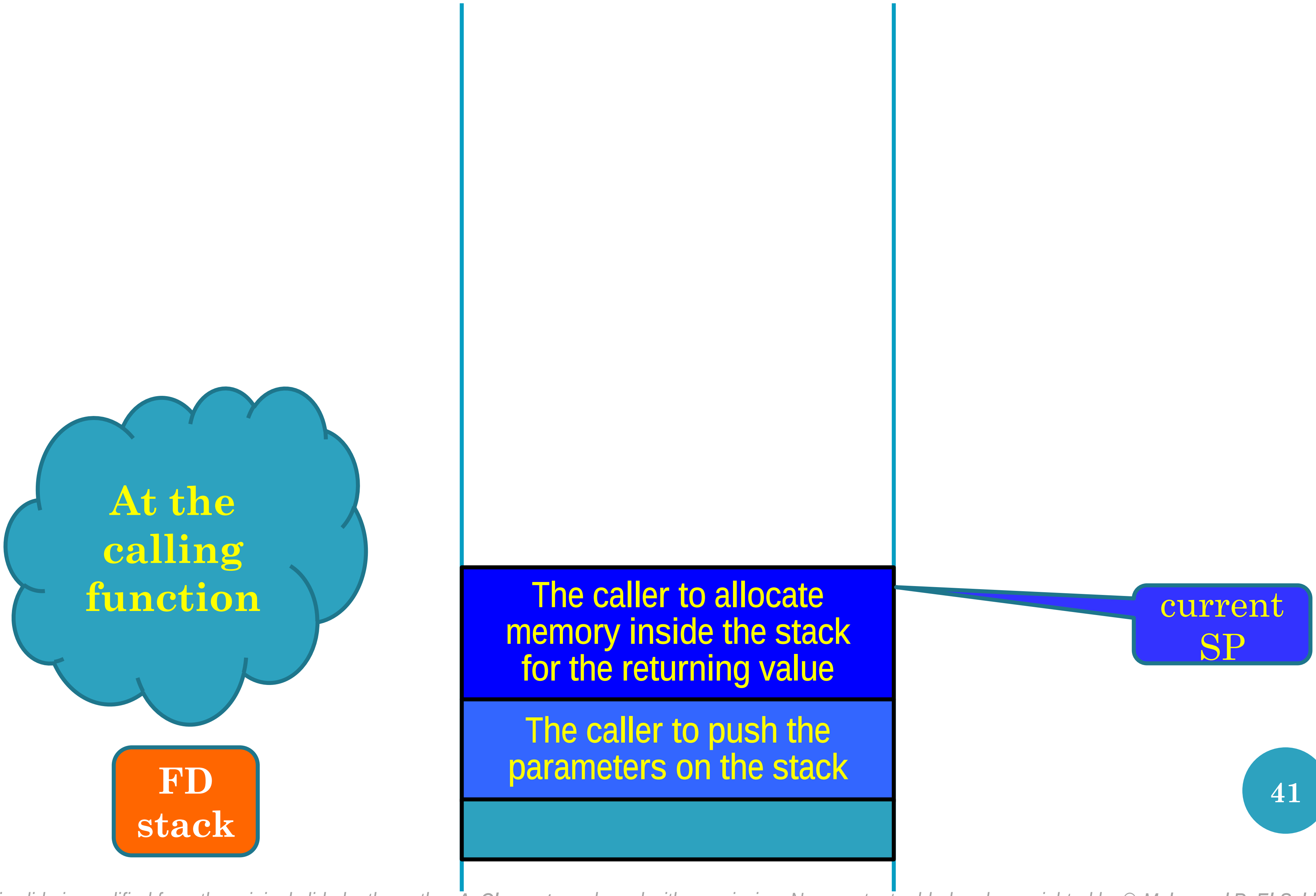
The Traditional Call/Return Mechanism



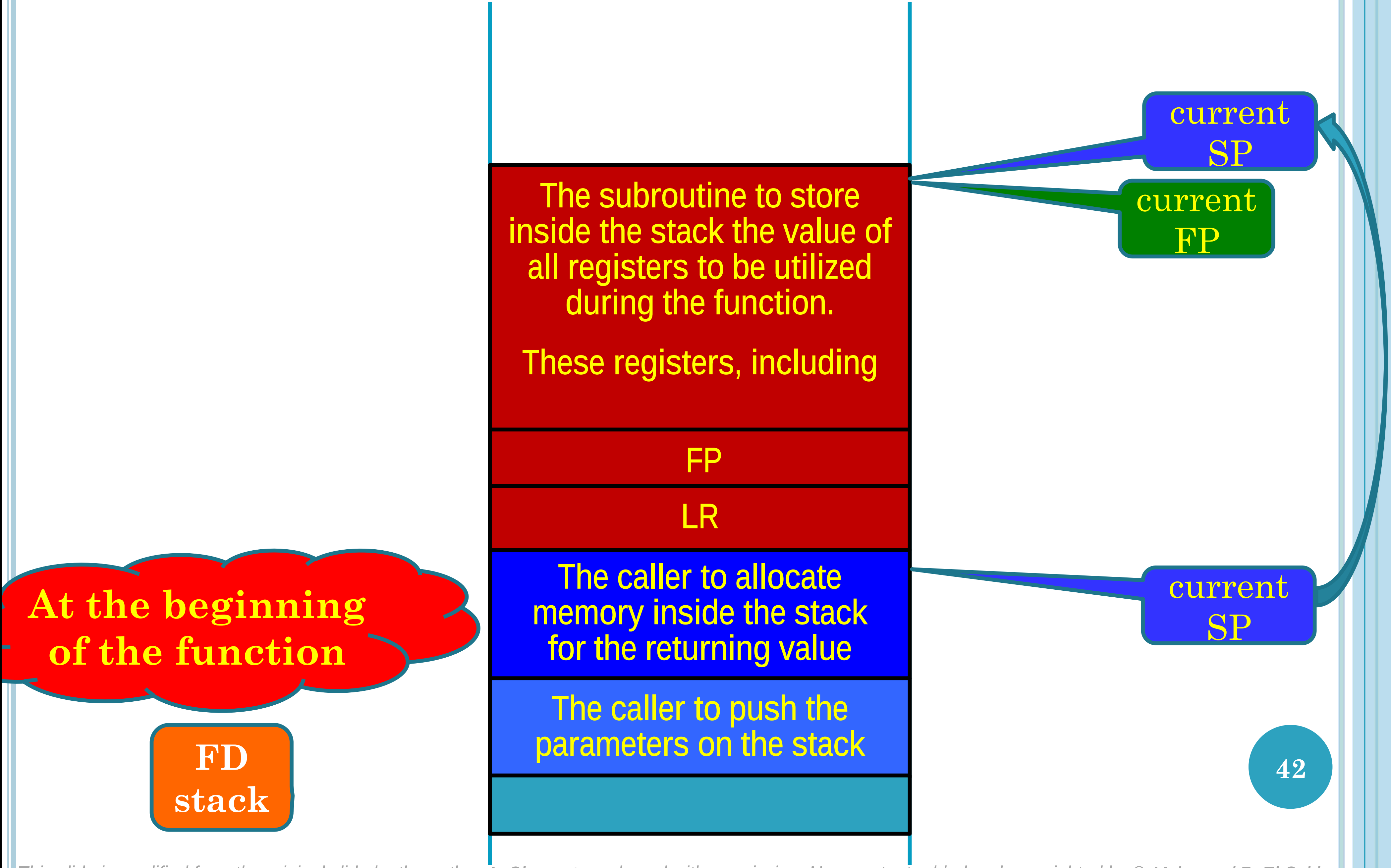
The Traditional Call/Return Mechanism


At the calling function
FD stack
The caller to allocate memory inside the stack for the returning value
The caller to push the parameters on the stack
current SP
current SP

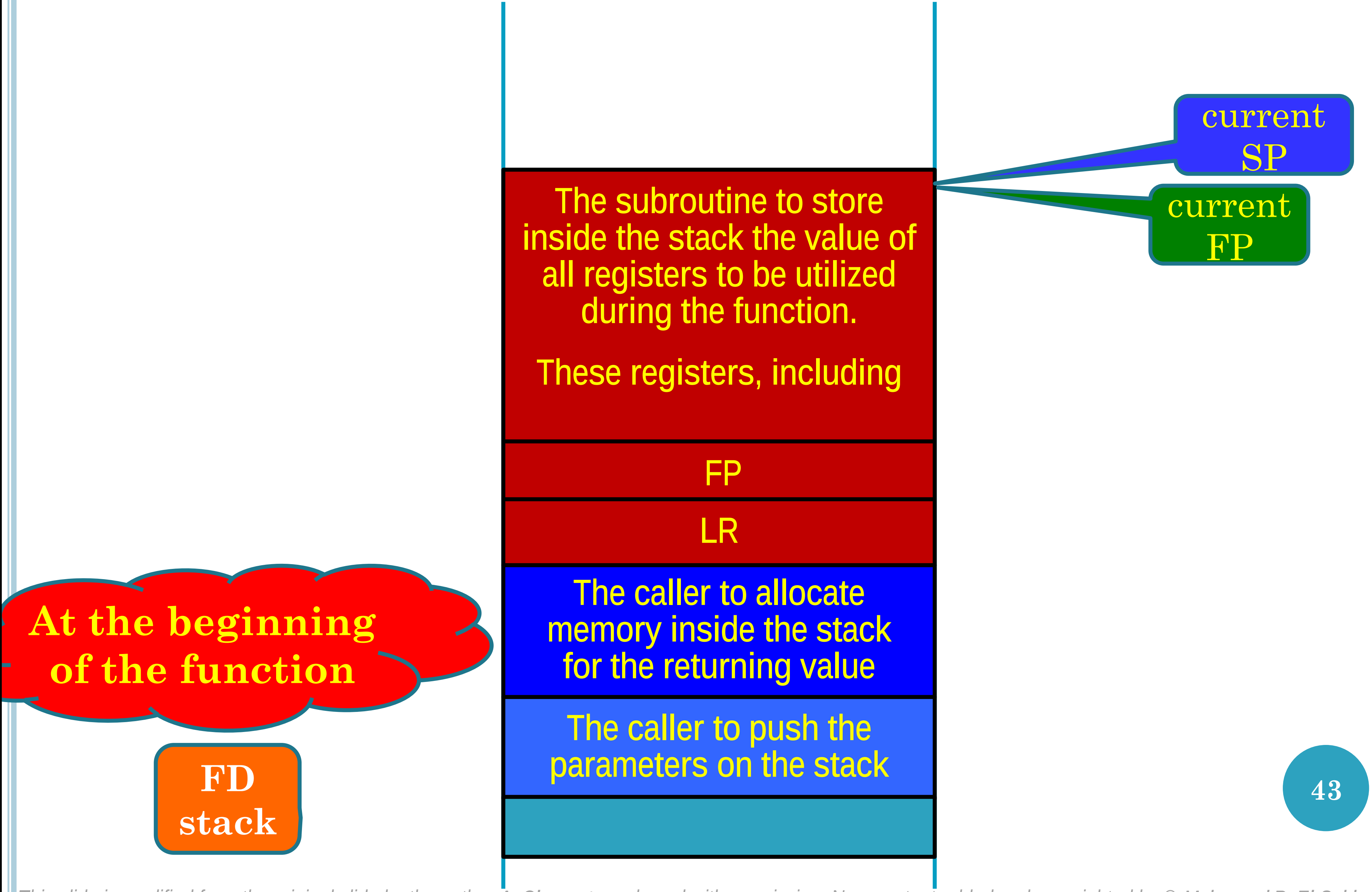
The Traditional Call/Return Mechanism


At the calling function
FD stack
The caller to allocate memory inside the stack for the returning value
The caller to push the parameters on the stack
current SP

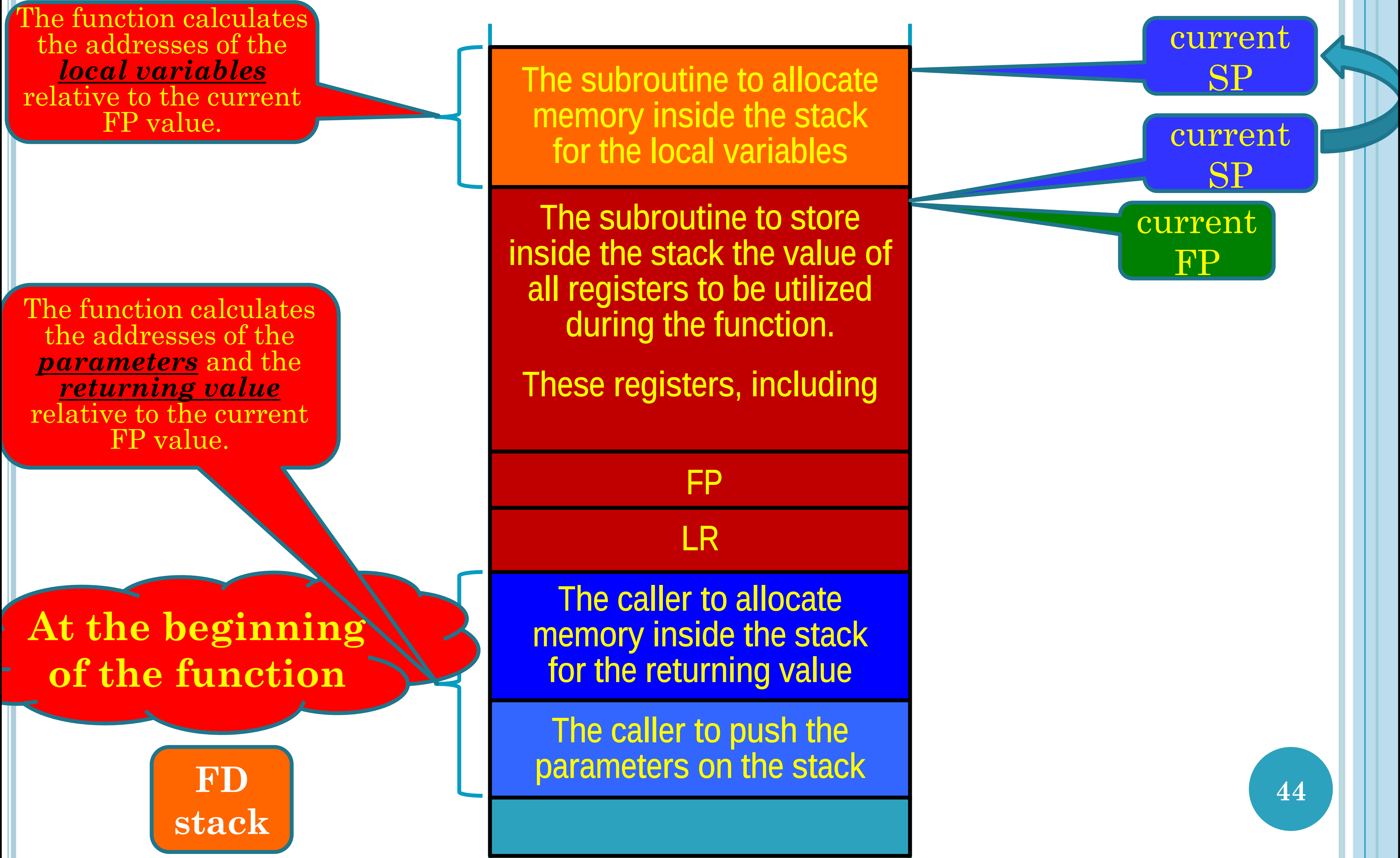
The Traditional Call/Return Mechanism


The subroutine to store inside the stack the value of all registers to be utilized during the function.
These registers, including
FP
LR
The caller to allocate memory inside the stack for the returning value
The caller to push the parameters on the stack
current SP
current FP
current SP
At the beginning of the function
FD stack

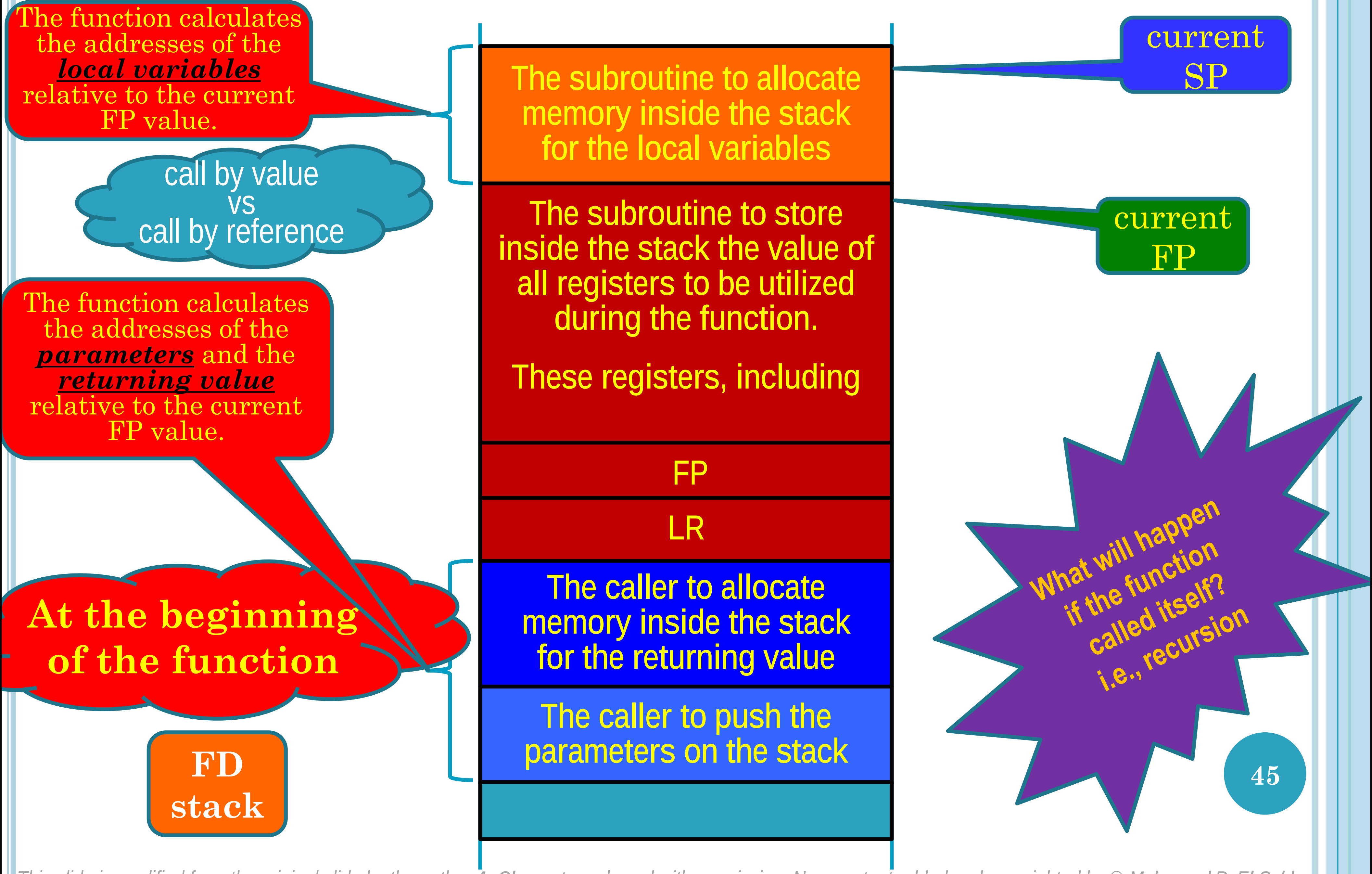
The Traditional Call/Return Mechanism


current SP
current FP
The subroutine to store inside the stack the value of all registers to be utilized during the function.
These registers, including
FP
LR
The caller to allocate memory inside the stack for the returning value
The caller to push the parameters on the stack
At the beginning of the function
FD stack

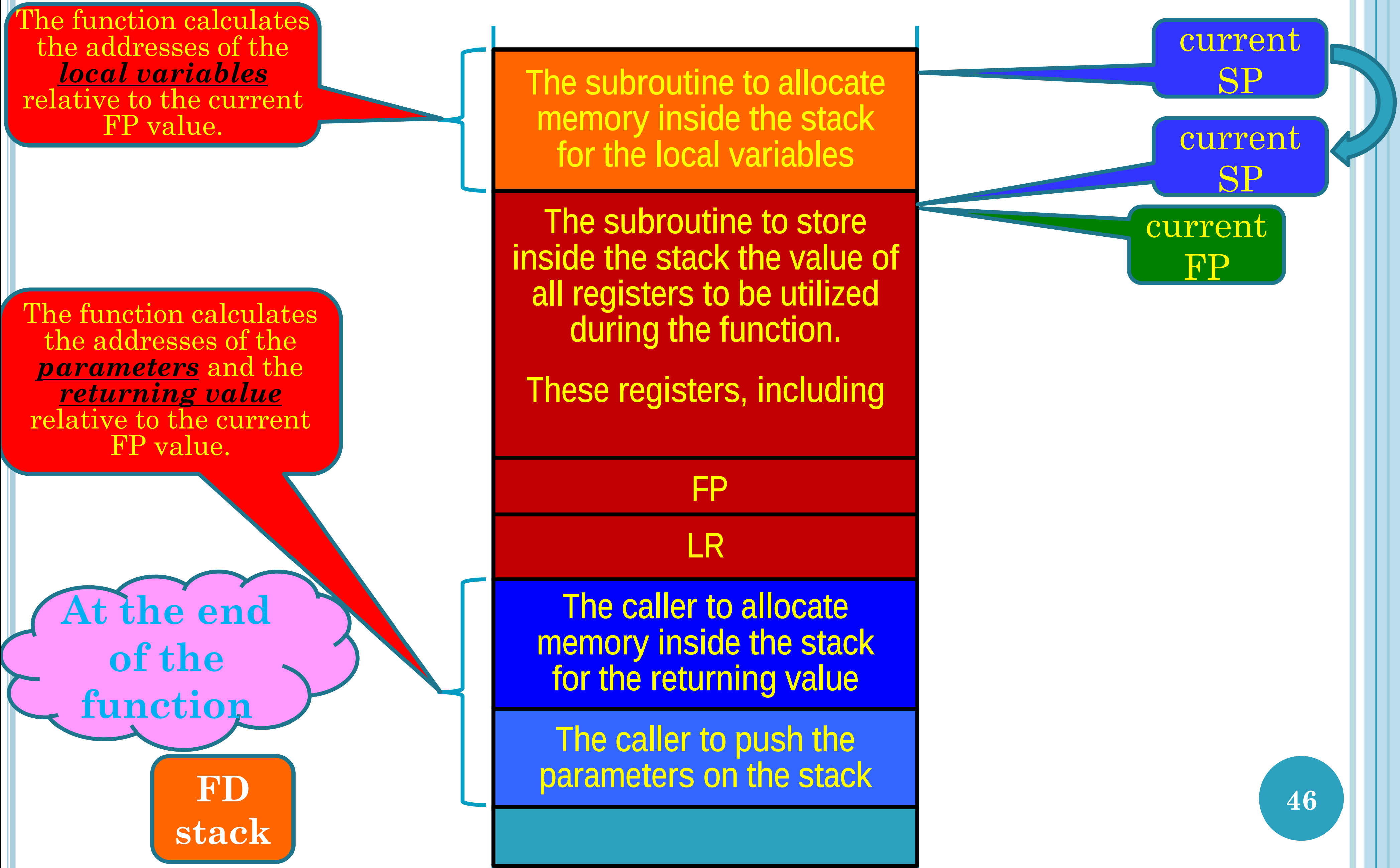
The Traditional Call/Return Mechanism


The function calculates the addresses of the ***local variables*** relative to the current FP value.
The subroutine to allocate memory inside the stack for the local variables
current SP
current SP
The subroutine to store inside the stack the value of all registers to be utilized during the function.
These registers, including
current FP
The function calculates the addresses of the ***parameters*** and the ***returning value*** relative to the current FP value.
FP
LR
At the beginning of the function
The caller to allocate memory inside the stack for the returning value
The caller to push the parameters on the stack
FD stack

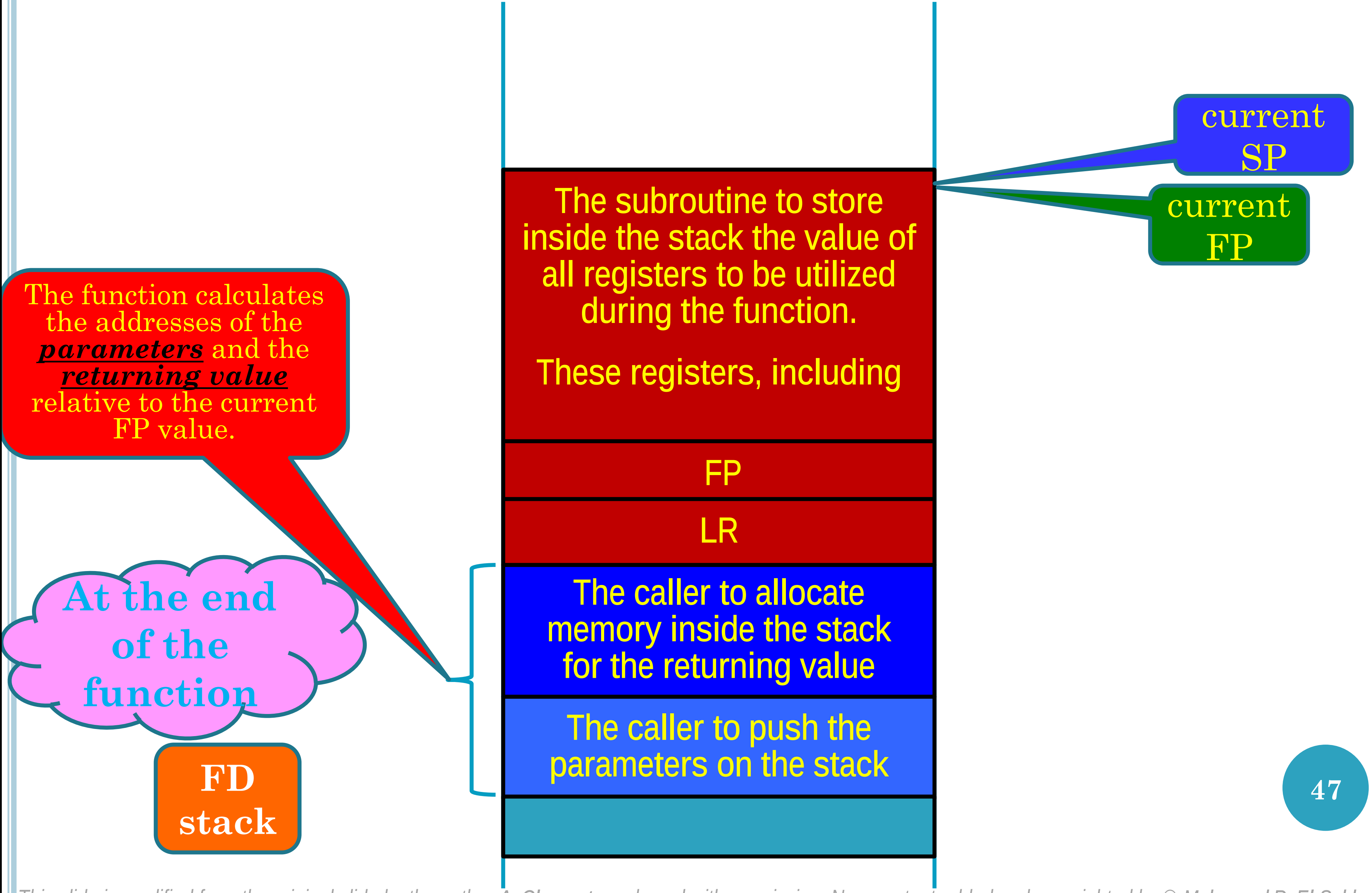
The Traditional Call/Return Mechanism


The function calculates the addresses of the ***local variables*** relative to the current FP value.
call by value vs call by reference
The function calculates the addresses of the ***parameters*** and the ***returning value*** relative to the current FP value.
At the beginning of the function
FD stack
The subroutine to allocate memory inside the stack for the local variables
The subroutine to store inside the stack the value of all registers to be utilized during the function.
These registers, including
FP
LR
The caller to allocate memory inside the stack for the returning value
The caller to push the parameters on the stack
current SP
current FP
What will happen if the function called itself? i.e., recursion

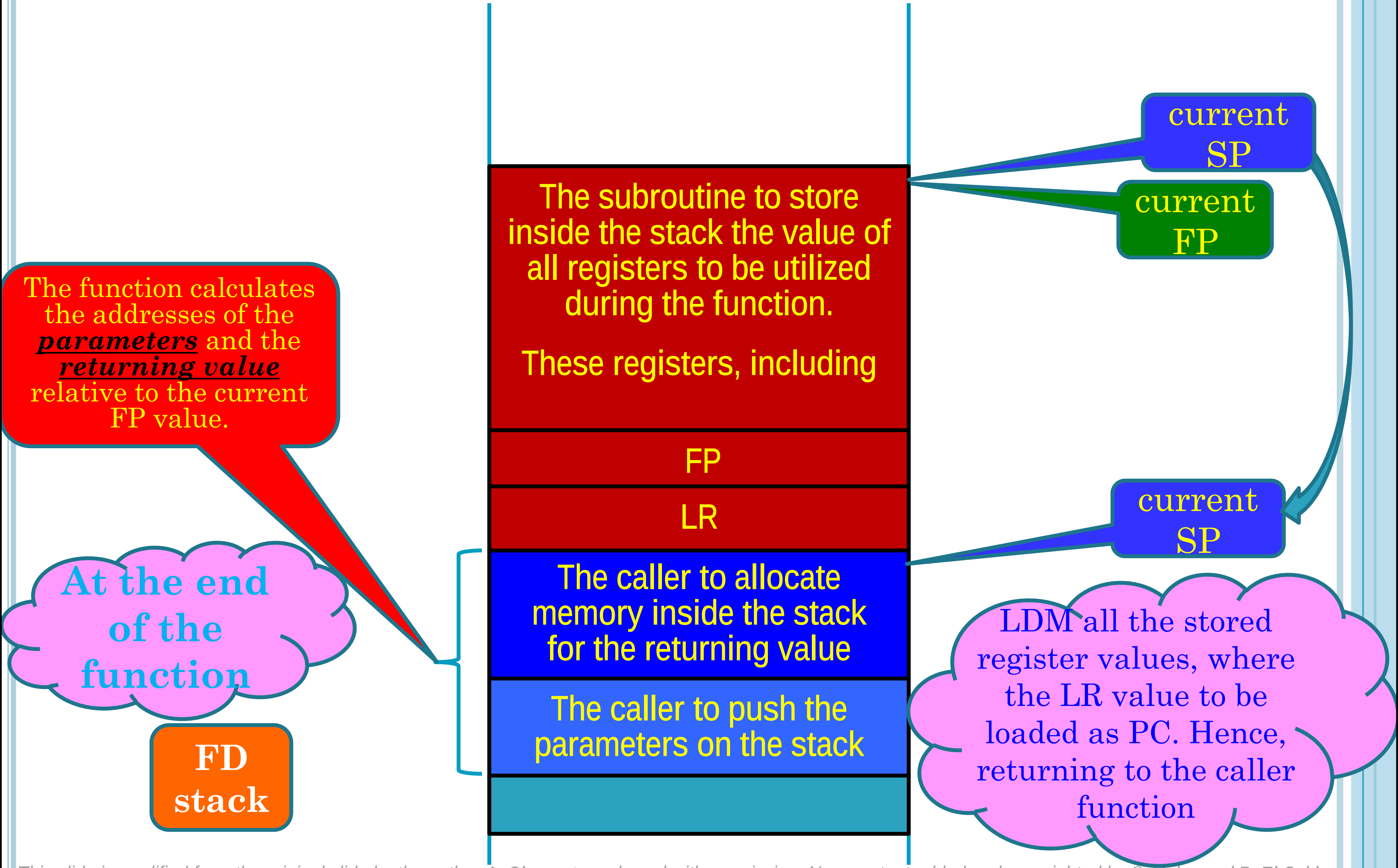
The Traditional Call/Return Mechanism


The function calculates the addresses of the ***local variables*** relative to the current FP value.
The subroutine to allocate memory inside the stack for the local variables
current SP
current SP
The subroutine to store inside the stack the value of all registers to be utilized during the function.
These registers, including
current FP
The function calculates the addresses of the ***parameters*** and the ***returning value*** relative to the current FP value.
FP
LR
At the end of the function
The caller to allocate memory inside the stack for the returning value
The caller to push the parameters on the stack
FD stack

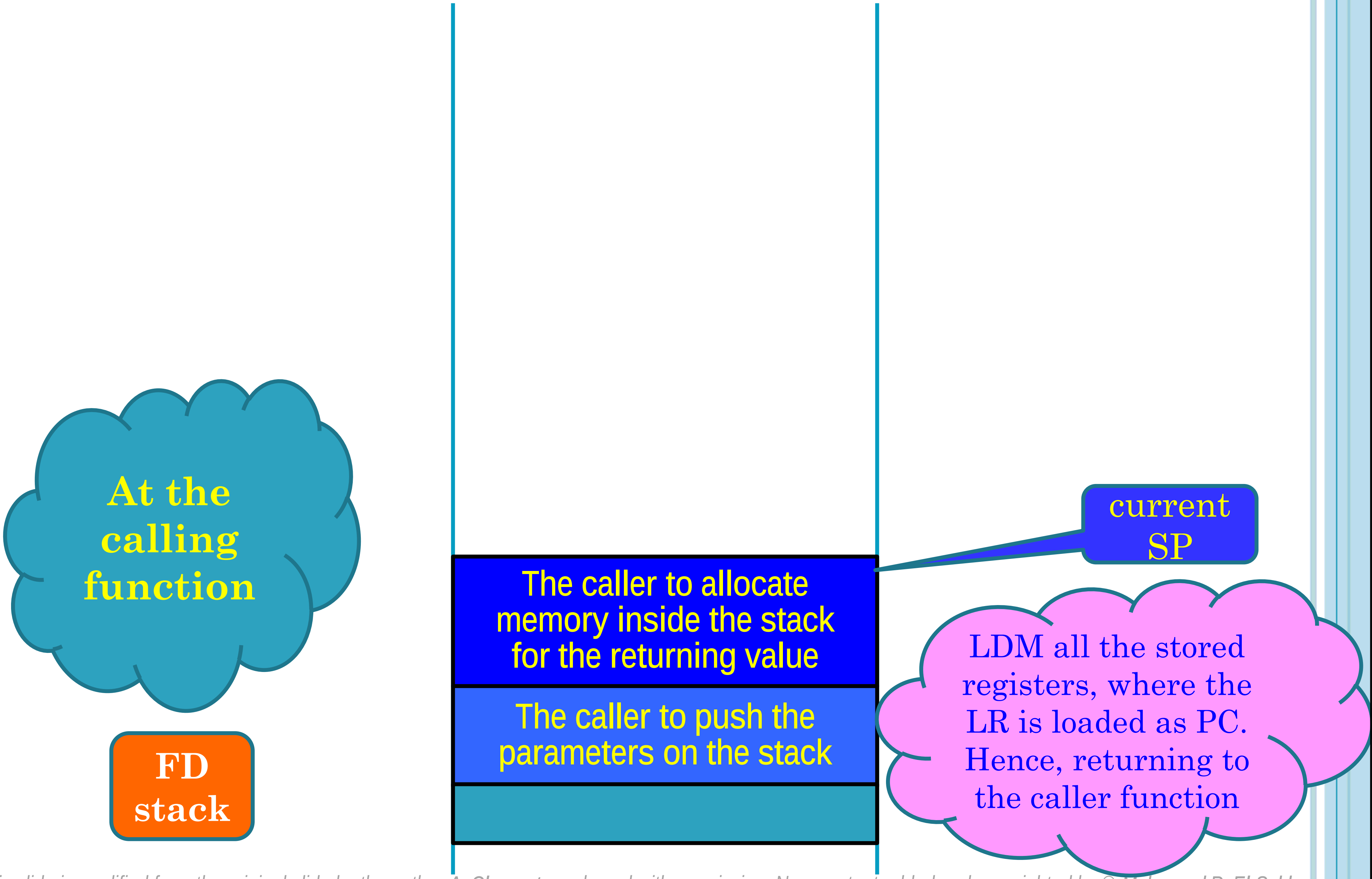
The Traditional Call/Return Mechanism


current SP
current FP
The subroutine to store inside the stack the value of all registers to be utilized during the function.
These registers, including
FP
LR
The caller to allocate memory inside the stack for the returning value
The caller to push the parameters on the stack
The function calculates the addresses of the ***parameters*** and the ***returning value*** relative to the current FP value.
At the end of the function
FD stack

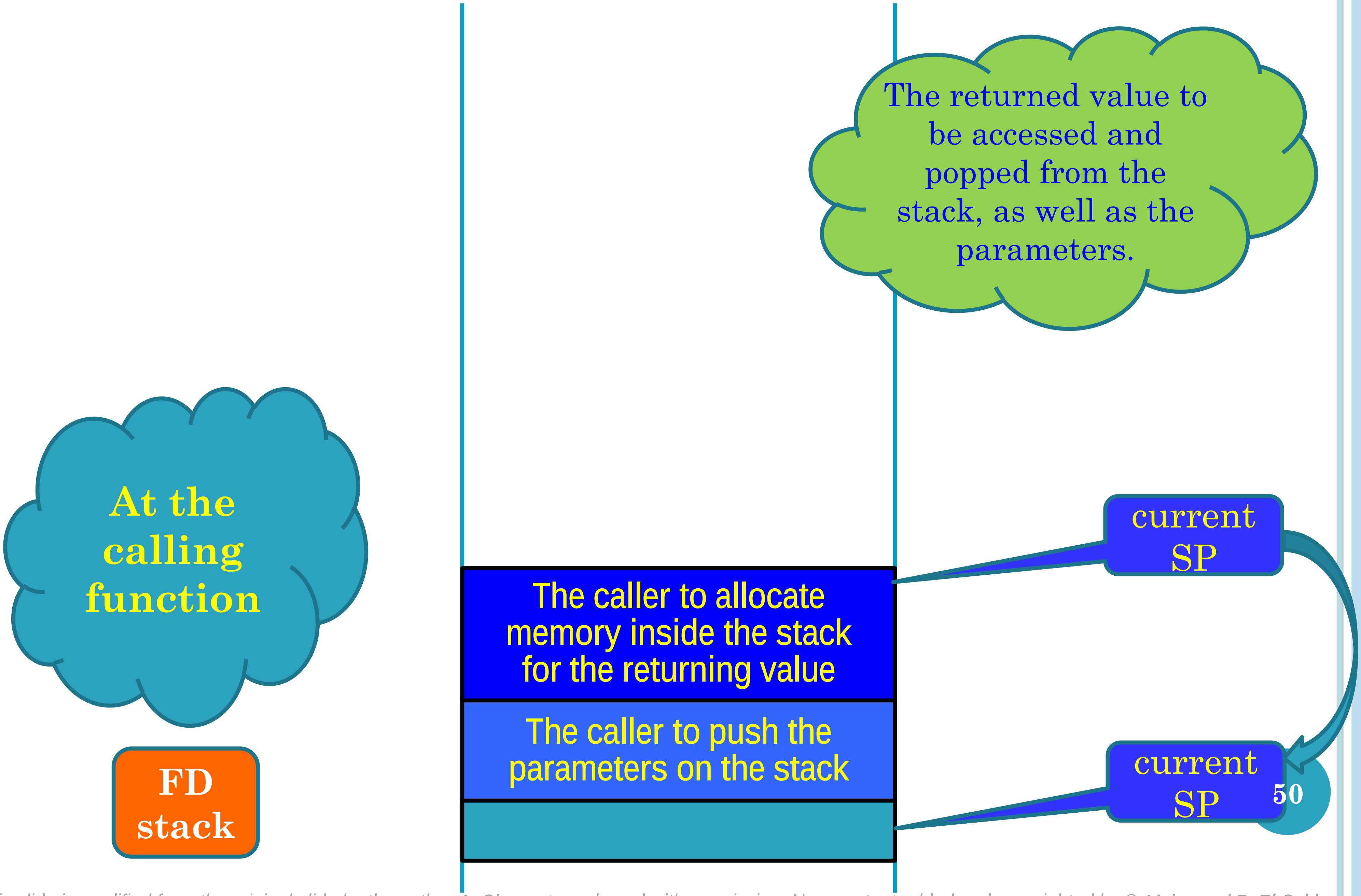
The Traditional Call/Return Mechanism


current SP
current FP
The subroutine to store inside the stack the value of all registers to be utilized during the function.
These registers, including
FP
LR
The caller to allocate memory inside the stack for the returning value
The caller to push the parameters on the stack
current SP
The function calculates the addresses of the ***parameters*** and the ***returning value*** relative to the current FP value.
At the end of the function
FD stack
LDM all the stored register values, where the LR value to be loaded as PC. Hence, returning to the caller function

The Traditional Call/Return Mechanism

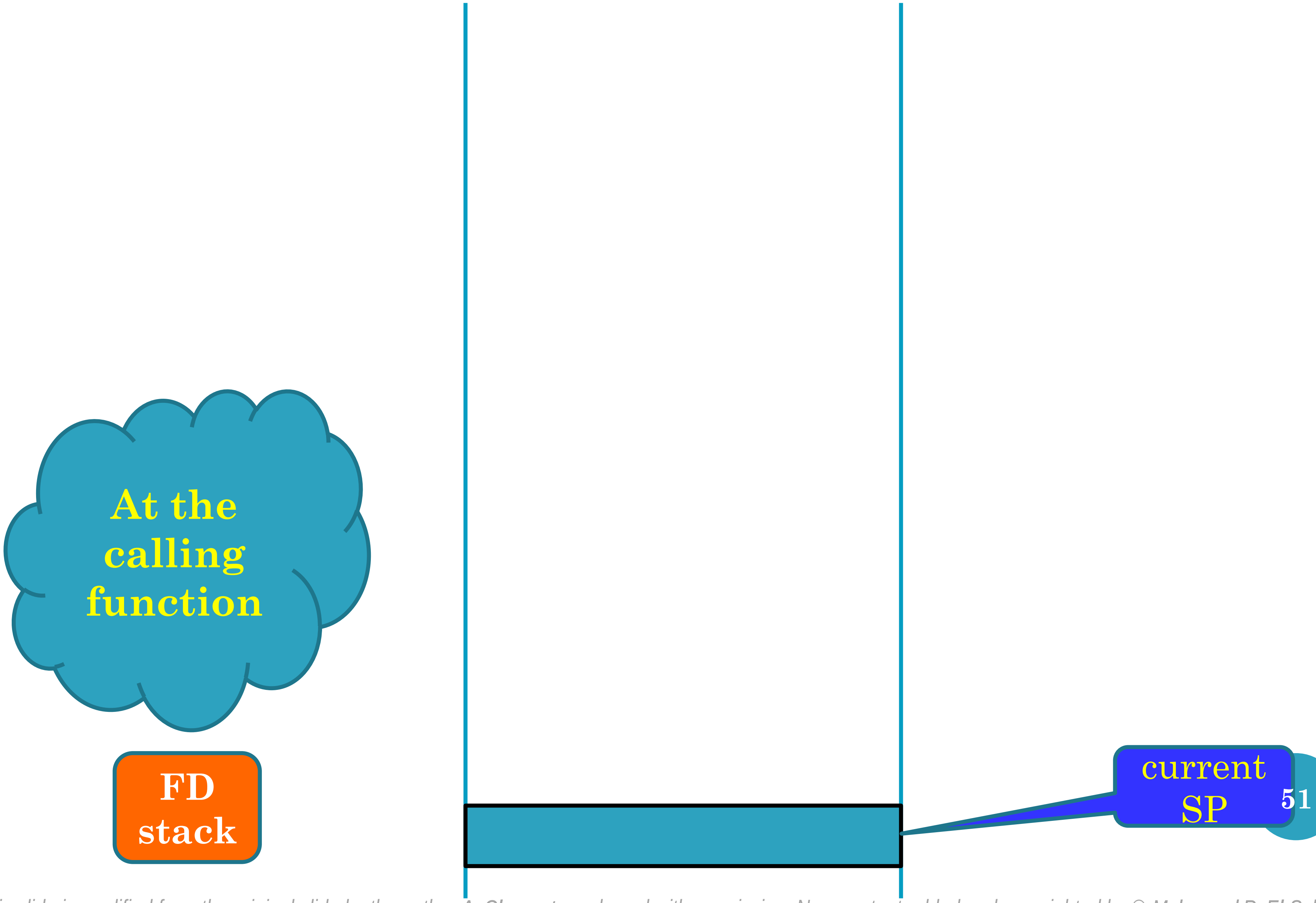

At the calling function
FD stack
The caller to allocate memory inside the stack for the returning value
The caller to push the parameters on the stack
current SP
LDM all the stored registers, where the LR is loaded as PC. Hence, returning to the caller function

The Traditional Call/Return Mechanism



The returned value to be accessed and popped from the stack, as well as the parameters.
At the calling function
FD stack
The caller to allocate memory inside the stack for the returning value
The caller to push the parameters on the stack
current SP
current SP

The Traditional Call/Return Mechanism


At the calling function
FD stack
current SP