

Chapter 7 – Programming with subroutines

How to avoid copy-pasting similar pieces of code in many places ?

Idea It is possible to break a program down into several sub-programs and execute each sub-program when needed. This allows for code reuse, because a sub-program (also known as a **subroutine**, a **function**, a **procedure**, a **method**, or many other names) can be written once and then **invoked** (aka **called**) several times from various locations in the main program.

In terms of implementation, this mechanism is very similar to the branching instructions from chapter 4: the processor can *jump* to another location in the program just by altering its program counter. However, there is a major difference: after a sub-routine is finished, we want the CPU to **return** (i.e. jump back) to where it was before and continue from there.

There are various strategies for saving this **return address**: some architectures (like x86) save it to memory ; others (like ARM, or SCAT) save it to a CPU register.

1 Subroutines in SCAT

Our assembler offers two instructions to write subroutines: CALL and RET, like illustrated below:

CALL label saves the address of the next instruction into register R14, then jumps to label.

Conversely, RET copies the contents of R14 back into PC. Because this register helps us *link* different procedures together, we will call it the **Link Register LR**.

```
main:
    leti r1, 0
    leti r2, 0
    call drawpixel

    leti r1, 0
    leti r2, 59
    call drawpixel

    leti r1, 79
    leti r2, 0
    call drawpixel

    leti r1, 79
    leti r2, 59
    call drawpixel

    bra +0

drawpixel:
    muli R1, R1, 4      ; horiz: 4 bytes per pixel
    muli R2, R2, 320    ; vertical: 320 bytes per line
    add R3, R2, R1
    leti R4, 0xB0000000 ; VRAM base address
    add R5, R4, R3
    leti R6, 0xFF00FF00 ; RGB hex triplet for magenta

    store [r5], r6

    ret
```

Exercise 1 Retype the program on the preceding page in a text file, assemble it and then execute it step-by-step in the simulator. Observe how the CPU saves the return address to LR at each function call, and how RET jumps back to the instruction immediately following the call site. On the listing, draw a control flow diagram illustrating these jumps with numbered arrows.

2 Implementation

In SCAT, both CALL and RET are pseudo-instructions. The processor only knows about a single machine instruction named Jump-And-Link, or JAL:

asm	Name	Description
jal rd, rs, imm	Jump-And-Link	rd = PC+4 ; PC = rs + sxt(imm)

When it encounters a function call, the assembler generates a Jump-And-Link with R14 (aka LR) as destination register and PC as a source register. The offset is computed as the distance between the current instruction (known as the **call site**) and the address of the function. Conversely, returning from a subroutine is achieved with JAL R0, LR, +0 (Remark: copying LR into PC could be done with various machine instructions. Using JAL to implement both CALL and RET is an arbitrary choice).

The binary format of Jump-And-Link is illustrated below:

31	28 27	24 23	20 19	16 15	0
0 1 0 1	ignored	rd	rs	imm	

3 Practice Exercises

Exercise 2 Modify the drawpixel procedure from the previous page so that it receives three input parameters: X/Y coordinates in R1/R2, and the desired color in R3. Then modify the main program so that each corner of the screen gets painted with a different color.

Exercise 3 Write a maximum function which receives two numbers in R1 and R2, finds the largest one of the two and returns it in R3. Write a main program which calls this function several times with different parameters.

Exercise 4 Take your graphical program from chapter 6 (bubble sort visualization, or bouncing ball) and rewrite the code so that it uses procedures.