

ELEC6027: VLSI Design Project  
Part 1: Microprocessor Research  
Topic: Subroutines

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# 1 Introduction

Subroutines, also known as procedures, methods, functions or just routines, are smaller sections of code inside larger program designed to perform certain tasks which is described in [2]. The motivation for subroutines is to produce code which is more efficient in size, easy to adapt and above all else maintain. They help form the foundations of third generation programming languages.

Designing hardware such that it is capable of executing subroutines only requires available memory and access to the program counter. Designing hardware to call and return from subroutines efficiently can vastly improve the performance of a processor.

## 2 Research

### 2.1 Subroutine Context Save

Context save allows a microprocessor to switch execution focus but retain data such that the previous focus can be fully restored. Using call and return instructions when running a subroutine may automatically save context, usually the program counter, but may also require additional instructions to guarantee safe execution. Nested and recursive subroutines, introduced in [4], require dealing with multiple context saves while retaining the data for all previous calls. The Intel 8086, discussed further in section 2.2.1, has support for procedure call instructions which automatically use the stack to organise data. Listing 1 holds subroutine written in C that recursively calls itself to compute the factorial of a number. Such applications require context save support.

```
int factorial(int n){
    return n*factorial(n-1);
}
```

Listing 1: Factorial subroutine

A stack, as discussed in [5], is a Last-In-First-Out (LIFO) data structure which is used as store when the immediately accessible registers do not provide enough memory. The stack can be thought of to grow in size where a register called a *stack pointer* (SP) holds the address of the top most element in main memory. Two operations can be performed on the stack; *push*, which adds an item to the stack and increments the stack pointer, together with *pull*, which performs the reverse therefore shrinking the stack. It is convention for the stack to occupy the main memory and grow down from the top

address towards memory allocated for other purposes; this can be seen in figure 1.

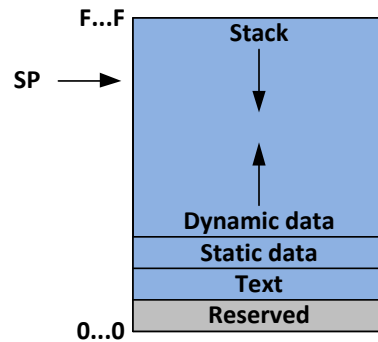


Figure 1: Allocation of the stack in main memory. Based on a MIPS architecture adapted from [5].

## 2.2 Operation of Stack Frames

### 2.2.1 8086

The assembly held in listing 2 and 3 is written for the Intel 8086 microprocessor. A basic example of how stack frames are built to pass parameters to and from a subroutine. The main program in listing 2 loads two immediate values into registers then begins building a stack frame by pushing them to the stack. The subroutine is called to act upon the arguments passed via the stack. When control is passed back to these set of instructions and the return value is extracted by using relative addressing from the base pointer then finally two stack pops completely destroy the stack frame.

```
main:                                ; Main loop
    MOV    bp,sp                    ; Init base ptr
    MOV    ax,42                    ; Load arg1
    MOV    bx,69                    ; Load arg2
    PUSH   bx                      ; Push arg1 to stack
    PUSH   ax                      ; Push arg2 to stack
    CALL   adder                   ; Call the subroutine
    MOV    cx,[bp-12]              ; Access return value
    POP    ax                      ; Restore all registers
    POP    bx
    JMP     main
```

Listing 2: 8086Caller.asm

When the subroutine, in listing 3, is called the return address is pushed onto the stack. This built-in support for the stack handles branching and next line address storage using a call function. To start the base pointer is placed on the stack so stack pointer has value to which to be restored. Reducing the value of the stack pointer allocates space for local variables. The first argument is placed in memory as local variable; this is unnecessary but serves as example. The second argument is loaded into a working register. The first local variable is added to the working register which is then placed in to the memory for the second local variable. Finally the stack pointer and the base pointer are restored and a return instruction hands control over the caller. This is all part of the calling convention for subroutines using stack frames on the 8086 [1].

adder	PROC		; Subroutine
	PUSH	bp	; Push base ptr to stack
	MOV	bp,sp	; Set base ptr to stack ptr
	SUB	sp,4	; Allocate local variable space (2 ints)
	MOV	ax,[bp+4]	; Load arg1 into Working
	MOV	[bp-2],ax	; Load arg1 into Local1
	MOV	ax,[bp+6]	; Load arg2 into Working
	ADD	ax,[bp-2]	; Add to contents of working reg
	MOV	[bp-4],ax	; Write Local2 with result
	MOV	sp,bp	; Return stack ptr
	POP	bp	; Restore base ptr
	RET		; Done
adder	ENDP		

Listing 3: 8086Callee.asm

This code was tested upon an 8086 emulator [8]. The emulator provides a complete overview of the flow of data within the processor including the stack. Figure 2a shows the emulator during the execution of the subroutine just before the stack pointer is overwritten with the base pointer. Figure 2b is an abstraction of the stack with data label corresponding to the subroutine.

### 2.2.2 ARM7TDMI using Arm Thumb

The ARM7TDMI is a 32-bit RISC microprocessor with an emphasis on low-power design and pipelining for high throughput which is detailed in [6]. It has two instruction sets. One of which is Arm Thumb, explained in [7], a low density compressed 16-bit subset of the ARM assembly language where the benefits are considered in [3]. It most notably assisted ARM into moving into the mobile phone market by reducing required program memory. A user selectable flag is set to switch between instruction sets.

registers			stack		
	H	L			
AX	00	6F	0100:FFFF	FF00	
BX	00	45	0100:FFFC	0045	
CX	00	00	0100:FFFA	002A	
DX	00	00	0100:FFF8	000D	
			0100:FFF6	FFFF	
			0100:FFF4	002A	
CS	0100		0100:FFF2	006F <	
IP	0029		0100:FFF0	0000	
SS	0100		0100:FFEE	0000	
SP	FFF2		0100:FFEC	0000	
BP	FFF6		0100:FFEA	0000	
SI	0000		0100:FFE8	0000	
DI	0000		0100:FFE6	0000	
ES	0100		0100:FFE4	0000	
			0100:FFE2	0000	
			0100:FFE0	0000	
			0100:FFDE	0000	
			0100:FFDC	0000	
			0100:FFDA	0000	
			0100:FFD8	0000	

(a) Emulator registers and stack

0xFFFFC	arg2	0x0045	
0xFFFFA	arg1	0x002A	
0xFFFF8	PC	0x000D	
0xFFFF6	BP	0xFFFFE	← Frame Pointer
0xFFFF4	local1	0x002A	
0xFFFF2	local2	0x006F	← Stack Pointer

(b) Stack frame configuration

Figure 2: 8086 stack operation

This architecture does not have built-in support for calling subroutines using the stack. When the branch instruction is used, as seen in listing 4, the program counter is overwritten with the address of the corresponding label. The address of the next line of code, which should be returned to after the subroutine, is placed into the link register. Calling conventions suggests leaving this register untouched and simply moving the data back into the program counter on a return.

```

main  MOV    r0,#42    ; Load arg1
      MOV    r1,#69    ; Load arg2
      PUSH   r0        ; Push arg1 to stack
      PUSH   r1        ; Push arg2 to stack
      BL     adder     ; Branch to subroutine
      POP    r0        ; This line is held in the link register
      POP    r0        ; Result pop from arg1 spot
      BL     main

```

Listing 4: ArmCaller.asm

In this case the link register is pushed onto the stack from the subroutine therefore requiring the subroutine to pop the value into the program counter in order to return. Listing 5 holds the subroutine and handles placing the return address on the stack. Relative addressing on the stack is required to draw the two arguments out and replace the first with the output of the function.

```

adder PUSH   {r5-r7,lr} ; Link register holds return address
      SUB    sp,sp,#4    ; Make space for locals on the stack
      LDR    r0,[sp,#12] ; Get arg1 off stack
      LDR    r1,[sp,#8]  ; Get arg2 off stack
      ADD    r0,r1       ; Do the add

```

STR	r0,[sp,#0]	; Store the add as a local
ADD	sp,sp,#4	; Destroy local variable space
POP	{r5-r7,pc}	; Restore program counter and return

Listing 5: ArmCallee.asm

### 3 Conclusion

It is clear that whether a microprocessor has built-in support for a stack or not the ability to call subroutines is unaffected. The support does make calling more efficient and easier to code.

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