ASM+C & C+ASM ABI std. compliancy Code optimization

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Cross compiler

- A cross compiler is a compiler capable of creating executable code for a platform other than the one on which the compiler is running
- For example, a compiler that runs on a Windows 7 PC but generates a code that runs on ARM SoC is a cross compiler
- To cross compile is typical for embedded application written in C language
- When integrating ASM functions, a special care is needed
  - To correctly identify the argument
  - To use the proper resources to return a result
- The knowledge of the ABI standard is fundamental in this context.

Branch to main.c from startup.s

- Startup.s

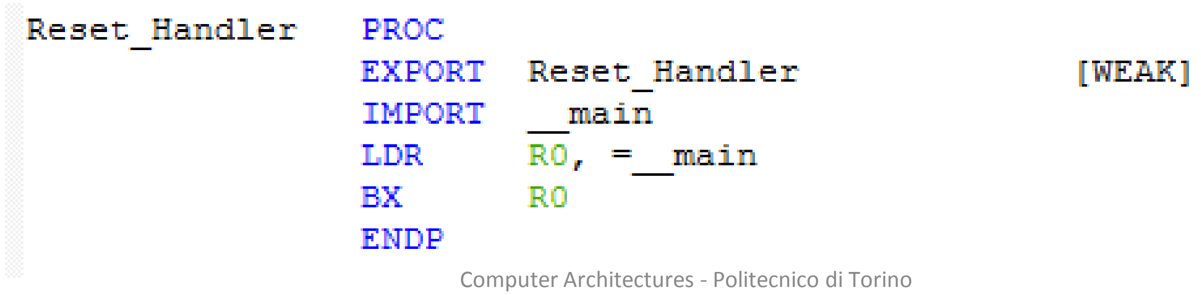
; Has to import the main function address

; Executes a linked branch to main

```
IMPORT  __main
LDR     R0, =__main
BX      R0
```

- Main.c

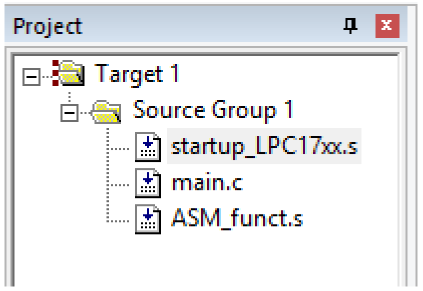
```
int main(){
    while(1) ;
}
```



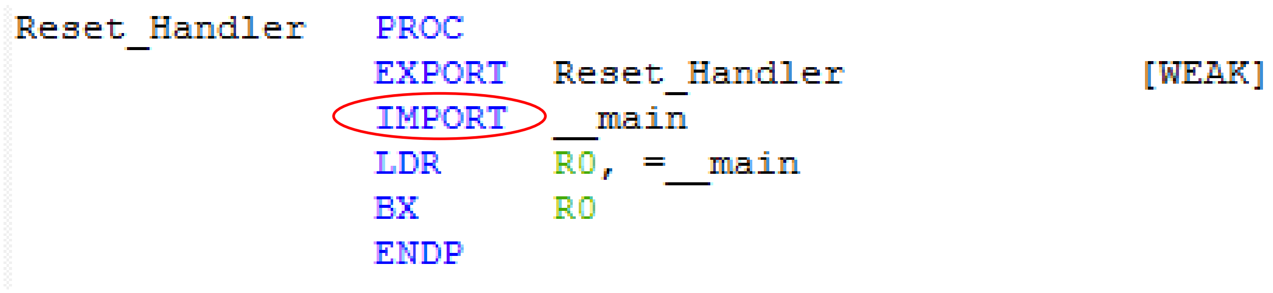
```
Reset_Handler    PROC
                 EXPORT  Reset_Handler             [WEAK]
                 IMPORT  __main
                 LDR     R0, =__main
                 BX      R0
                 ENDP
```

ABI_C+ASM project (I)
(in the software/example folder - startup_LPC17xx.s)

- In our setup we find the following source codes:
  - startup_LPC17xx.s
  - main.c
  - ASM_funct.s



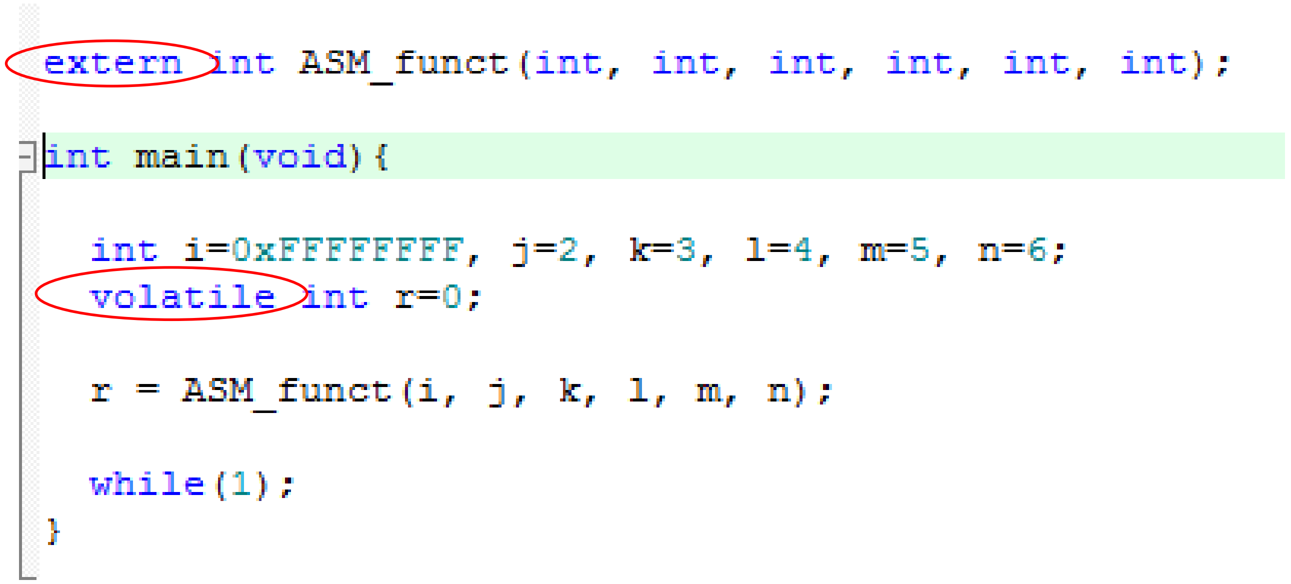
- The startup_LPC17xx.s file includes the banch to main in the reset handler



```
Reset_Handler   PROC
                EXPORT  Reset_Handler             [WEAK]
                IMPORT  __main
                LDR     R0, =__main
                BX      R0
                ENDP
```

ABI_C+ASM project (II)
(in the software/example folder - main.c)

- The main.c file is a C source code
  - It invokes a function called ASM_funct with 6 parameters
  - After executing the called function, it enters an endless loop.



```
extern int ASM_funct(int, int, int, int, int, int);

int main(void){

  int i=0xFFFFFFFF, j=2, k=3, l=4, m=5, n=6;
  volatile int r=0;

  r = ASM_funct(i, j, k, l, m, n);

  while(1);
}
```

ABI_C+ASM project (III)
(in the software/example folder - ASM_funct.s)

- Inline ASM

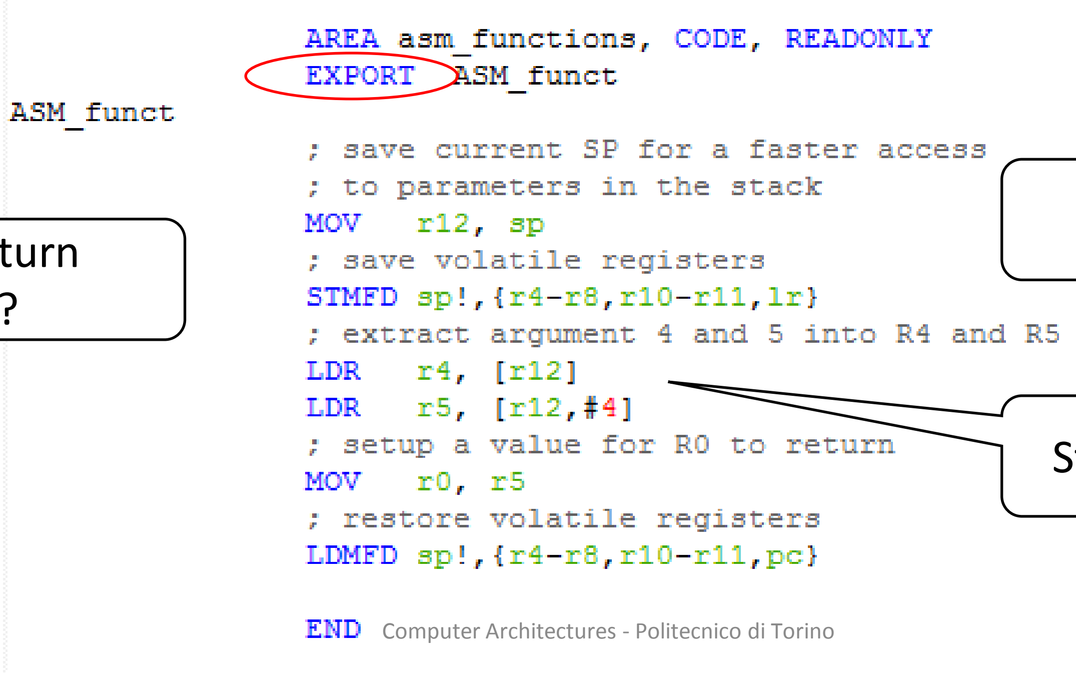
  __ASM("SVC #0x10");

- External ASM function invoked by a C function

  r = ASM_funct(i, j, k, l, m, n);

Where are parameters stored?

How to return results?



```
                AREA asm_functions, CODE, READONLY
                EXPORT ASM_funct
ASM_funct
                ; save current SP for a faster access
                ; to parameters in the stack
                MOV   r12, sp
                ; save volatile registers
                STMFD sp!,{r4-r8,r10-r11,lr}
                ; extract argument 4 and 5 into R4 and R5
                LDR   r4, [r12]
                LDR   r5, [r12,#4]
                ; setup a value for R0 to return
                MOV   r0, r5
                ; restore volatile registers
                LDMFD sp!,{r4-r8,r10-r11,pc}

                END
```

Parameters are in R0-R3 (a1-a4)

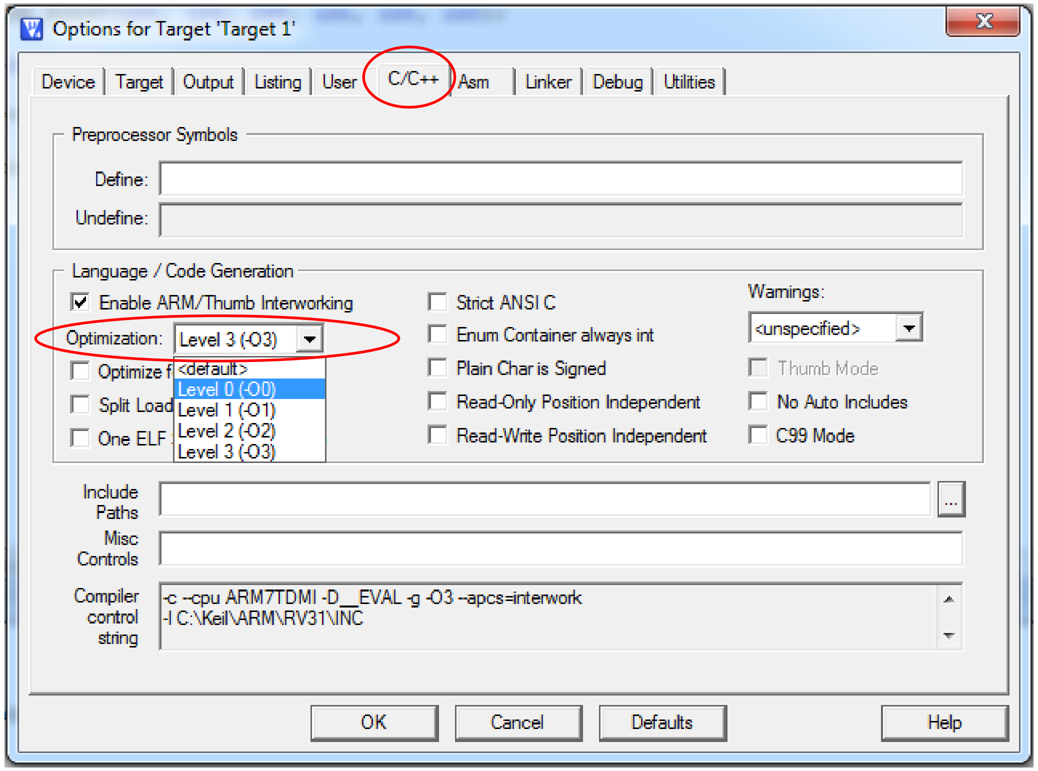
Stacked parameters

C and ASM helpful directives

- EXPORT : makes visible a function outside the file defining it
- IMPORT : makes visible a function from other files
- extern : permits to import a variable from another file (where it is defined)

COMPILER OPTIMIZATION

- As we are now working in C language, the compiled can be asked to optimize the produced machine code.



Options for Target 'Target 1'

Device | Target | Output | Listing | User | C/C++ | Asm | Linker | Debug | Utilities

Preprocessor Symbols

Define:

Undefine:

Language / Code Generation

[✓] Enable ARM/Thumb Interworking

Optimization: Level 3 (-O3)

<default>
Level 0 (-O0)
Level 1 (-O1)
Level 2 (-O2)
Level 3 (-O3)

[ ] Optimize f

[ ] Split Load

[ ] One ELF

[ ] Strict ANSI C

[ ] Enum Container always int

[ ] Plain Char is Signed

[ ] Read-Only Position Independent

[ ] Read-Write Position Independent

Warnings: <unspecified>

[ ] Thumb Mode

[ ] No Auto Includes

[ ] C99 Mode

Include Paths

Misc Controls

Compiler control string

```
-c --cpu ARM7TDMI -D__EVAL -g -O3 --apcs=interwork
-I C:\Keil\ARM\RV31\INC
```

OK | Cancel | Defaults | Help

Compiler optimization and the volatile attribute

- Higher optimization levels can reveal problems in some programs that are not apparent at lower optimization levels
- This happens when, for example, missing the volatile qualifiers
- The declaration of a variable as volatile tells the compiler that the variable can be modified at any time externally to the implementation
    - by the operating system,
    - by another thread of execution such as an interrupt routine or signal handler,
    - by hardware.

Example

Table 12. C code for nonvolatile and volatile buffer loops

Nonvolatile version of buffer loop

```
int buffer_full;
int read_stream(void)
{
    int count = 0;
    while (!buffer_full)
    {
        count++;
    }
    return count;
}
```

Volatile version of buffer loop

```
volatile int buffer_full;
int read_stream(void)
{
    int count = 0;
    while (!buffer_full)
    {
        count++;
    }
    return count;
}
```

Table 13. Disassembly for nonvolatile and volatile buffer loop

Nonvolatile version of buffer loop

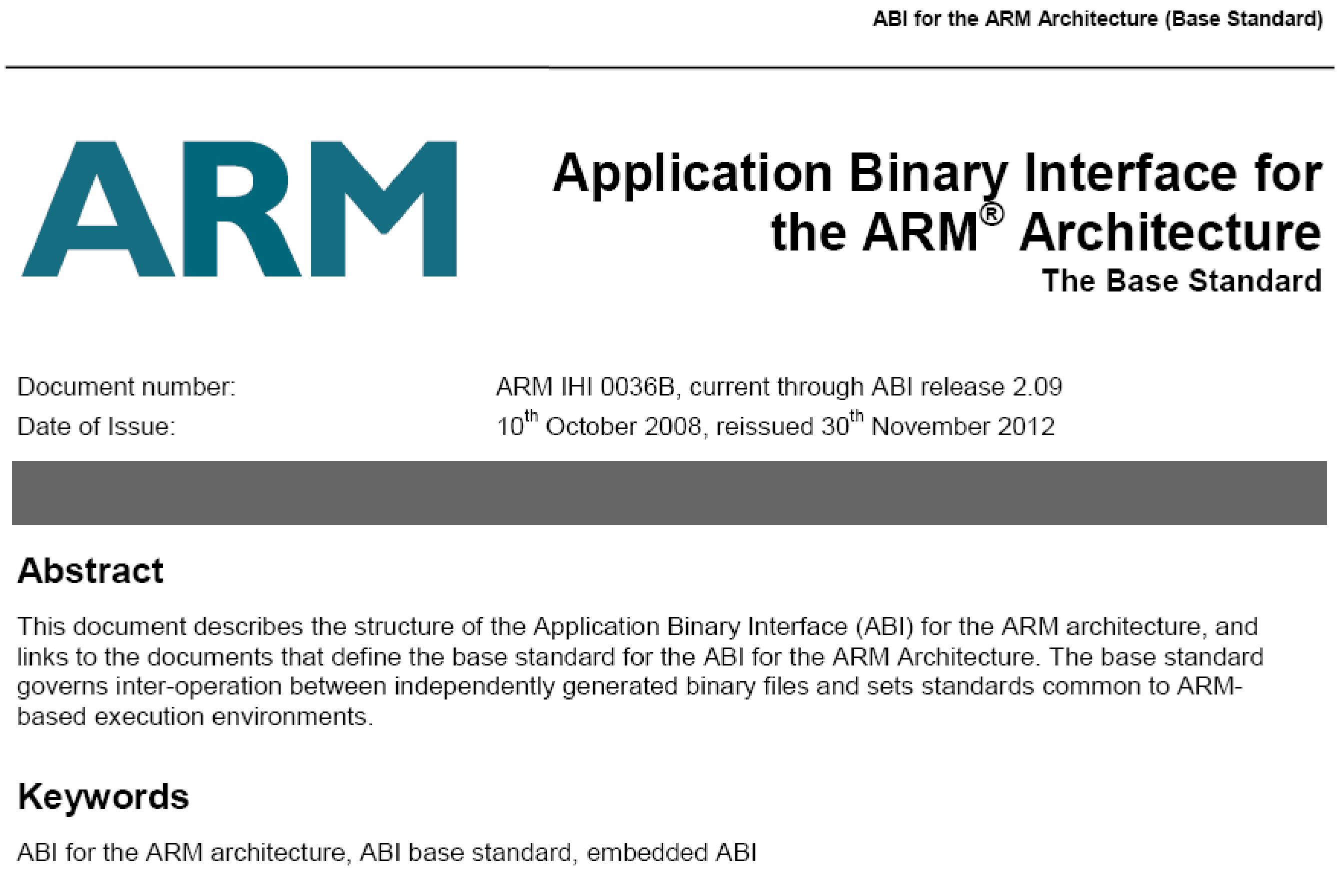
```
read_stream PROC
    LDR      r1, |L1.28|
    MOV      r0, #0
    LDR      r1, [r1, #0]
|L1.12|
    CMP      r1, #0
    ADDEQ    r0, r0, #1
    BEQ      |L1.12|       ; infinite loop
    BX       lr
    ENDP
|L1.28|
    DCD      ||.data||
    AREA ||.data||, DATA, ALIGN=2
buffer_full
    DCD      0x00000000
```

Volatile version of buffer loop

```
read_stream PROC

    LDR      r1, |L1.28|
    MOV      r0, #0
|L1.8|
    LDR      r2, [r1, #0];  ; buffer_full
    CMP      r2, #0
    ADDEQ    r0, r0, #1
    BEQ      |L1.8|
    BX       lr
    ENDP
|L1.28|
    DCD      ||.data||
    AREA ||.data||, DATA, ALIGN=2
    buffer_full
    DCD      0x00000000
```

ABI standard for ARM



ABI for the ARM Architecture (Base Standard)

Application Binary Interface for the ARM® Architecture
The Base Standard

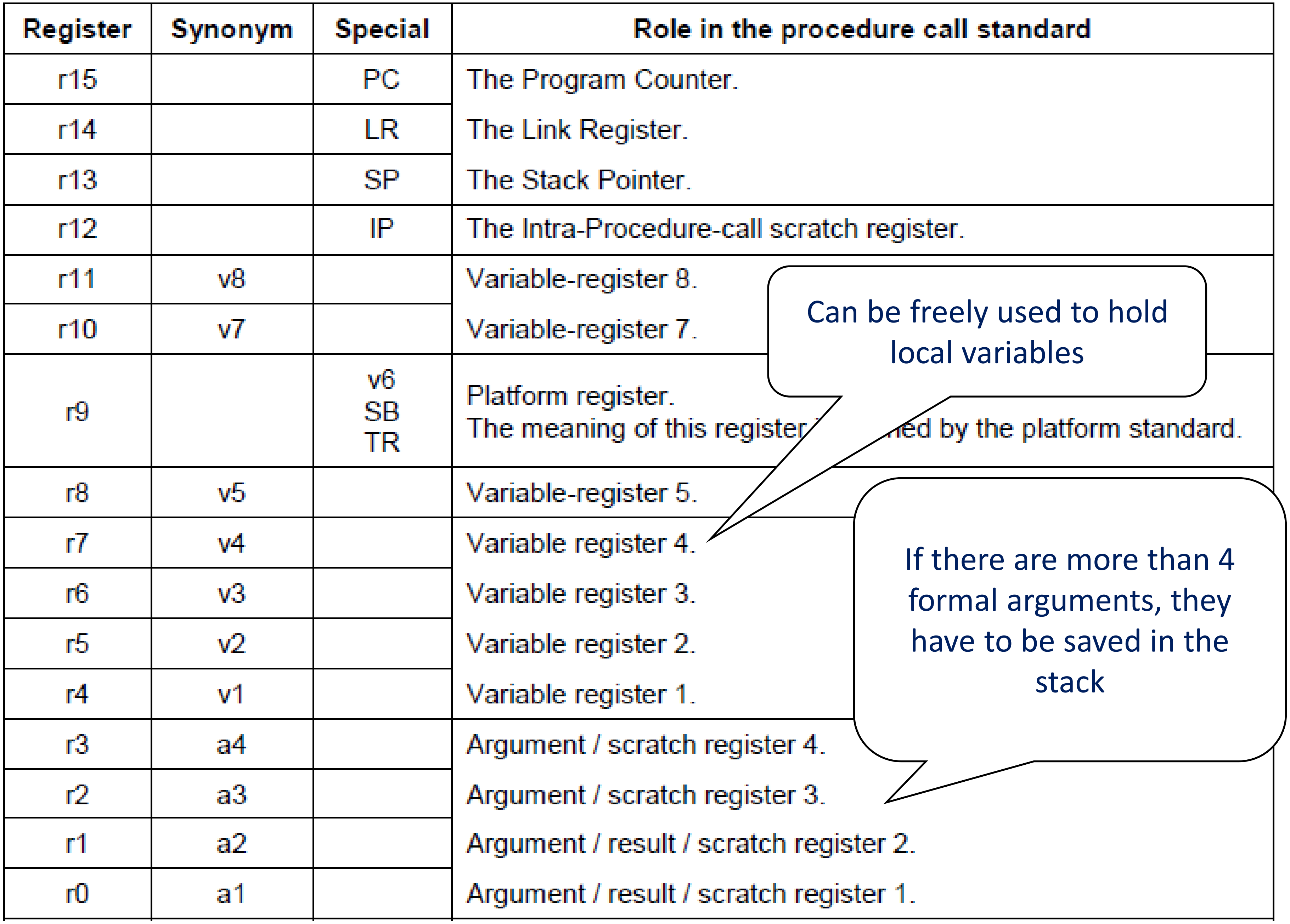
Document number:	ARM IHI 0036B, current through ABI release 2.09
Date of Issue:	10th October 2008, reissued 30th November 2012

Abstract

This document describes the structure of the Application Binary Interface (ABI) for the ARM architecture, and links to the documents that define the base standard for the ABI for the ARM Architecture. The base standard governs inter-operation between independently generated binary files and sets standards common to ARM-based execution environments.

Keywords

ABI for the ARM architecture, ABI base standard, embedded ABI



Register	Synonym	Special	Role in the procedure call standard
r15		PC	The Program Counter.
r14		LR	The Link Register.
r13		SP	The Stack Pointer.
r12		IP	The Intra-Procedure-call scratch register.
r11	v8		Variable-register 8.
r10	v7		Variable-register 7.
r9		v6 SB TR	Platform register. The meaning of this register i ned by the platform standard.
r8	v5		Variable-register 5.
r7	v4		Variable register 4.
r6	v3		Variable register 3.
r5	v2		Variable register 2.
r4	v1		Variable register 1.
r3	a4		Argument / scratch register 4.
r2	a3		Argument / scratch register 3.
r1	a2		Argument / result / scratch register 2.
r0	a1		Argument / result / scratch register 1.

Table 2, Core registers and AAPCS usage

Can be freely used to hold local variables

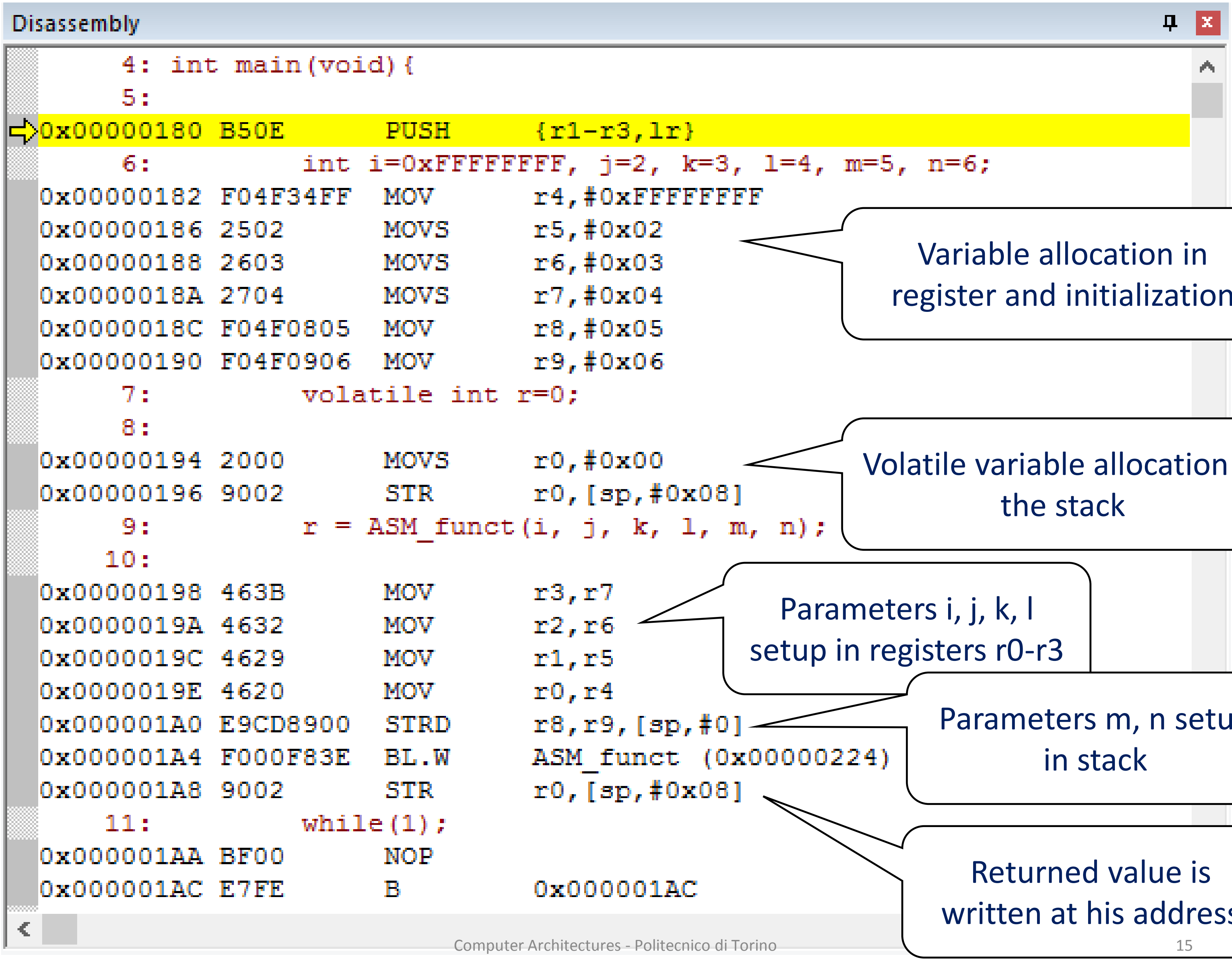
If there are more than 4 formal arguments, they have to be saved in the stack

Passing arguments

- The first four registers r0-r3 (a1-a4) are used to pass argument values into a subroutine and to return a result value in r0-r1 from a function.
  - A subroutine must preserve the contents of the registers r4-r8, r10, r11 and SP
- The base standard provides for passing arguments in core registers (r0-r3) and on the stack.
  - For subroutines that take a small number of parameters, only registers are used, greatly reducing the overhead of a call.

STACK management

- The stack implementation is *full-descending*, with the current extent of the stack held in the register SP (r13).
- The stack will, in general, have both a *base* and a *limit* though in practice an application may not be able to determine the value of either.



Disassembly

```
      4: int main(void){
      5:
0x00000180 B50E       PUSH      {r1-r3,lr}
      6:         int i=0xFFFFFFFF, j=2, k=3, l=4, m=5, n=6;
0x00000182 F04F34FF   MOV       r4,#0xFFFFFFFF
0x00000186 2502       MOVS      r5,#0x02
0x00000188 2603       MOVS      r6,#0x03
0x0000018A 2704       MOVS      r7,#0x04
0x0000018C F04F0805   MOV       r8,#0x05
0x00000190 F04F0906   MOV       r9,#0x06
      7:         volatile int r=0;
      8:
0x00000194 2000       MOVS      r0,#0x00
0x00000196 9002       STR       r0,[sp,#0x08]
      9:         r = ASM_funct(i, j, k, l, m, n);
     10:
0x00000198 463B       MOV       r3,r7
0x0000019A 4632       MOV       r2,r6
0x0000019C 4629       MOV       r1,r5
0x0000019E 4620       MOV       r0,r4
0x000001A0 E9CD8900   STRD      r8,r9,[sp,#0]
0x000001A4 F000F83E   BL.W      ASM_funct (0x00000224)
0x000001A8 9002       STR       r0,[sp,#0x08]
     11:         while(1);
0x000001AA BF00       NOP
0x000001AC E7FE       B         0x000001AC
```

Variable allocation in register and initialization

Volatile variable allocation in the stack

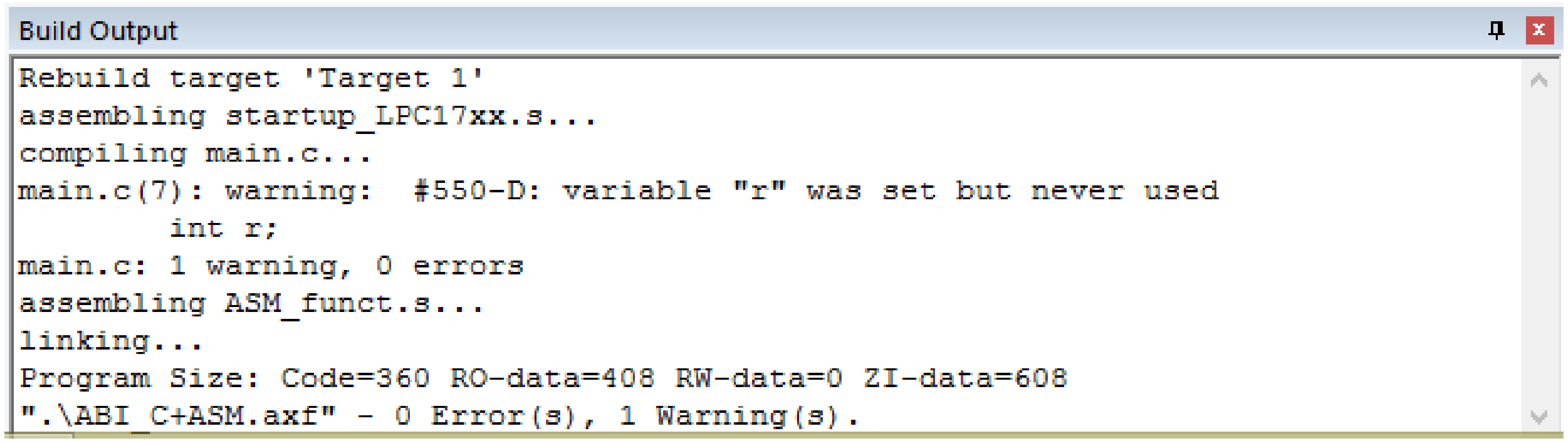
Parameters i, j, k, l setup in registers r0-r3

Parameters m, n setup in stack

Returned value is written at his address

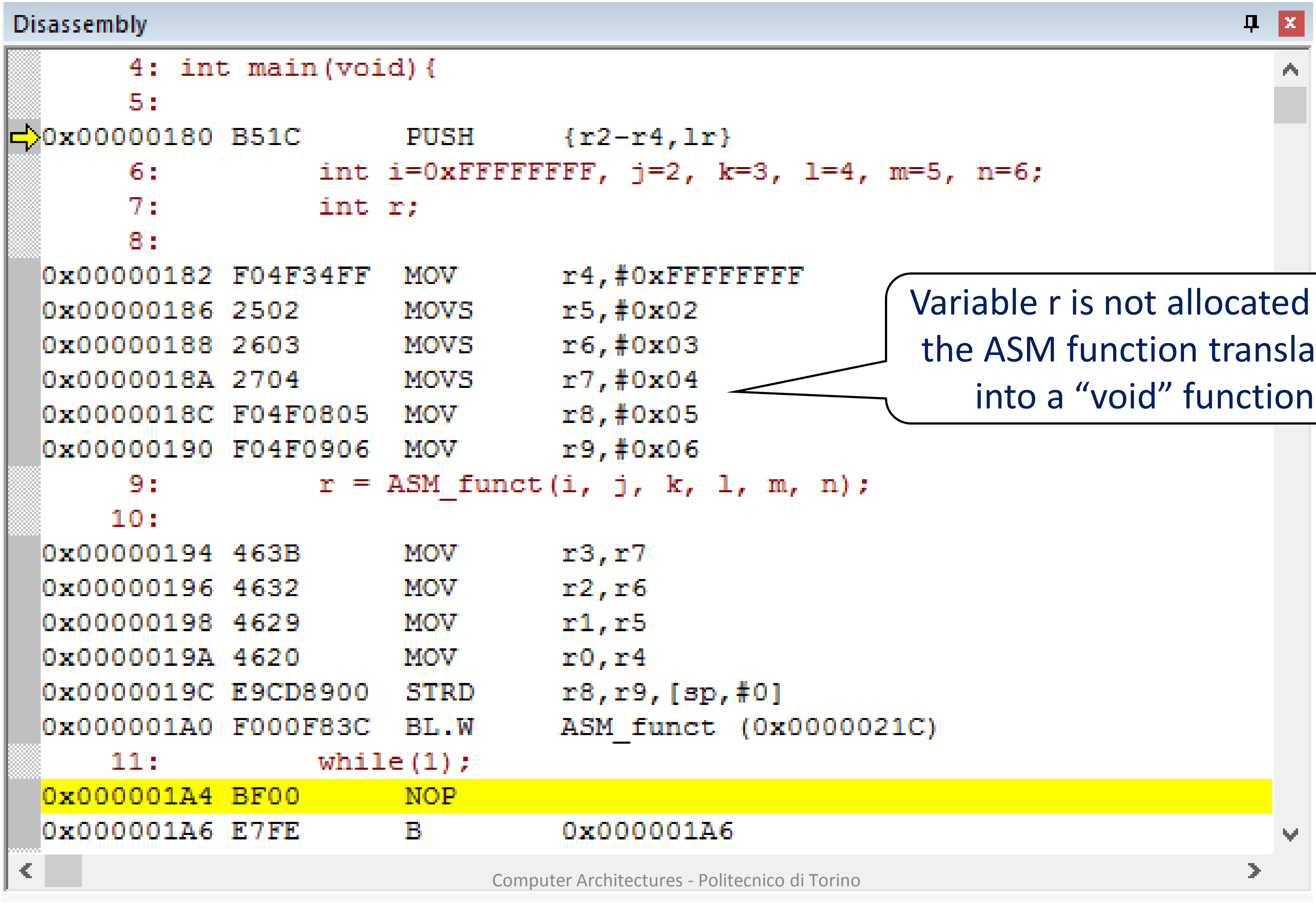
What happens if don’t declare r as volatile?

- A warning is signaled about missing usesfuleness of variable r
- An optimization of the machine code is implemented by the compiler.


Build Output

```
Rebuild target 'Target 1'
assembling startup_LPC17xx.s...
compiling main.c...
main.c(7): warning:  #550-D: variable "r" was set but never used
        int r;
main.c: 1 warning, 0 errors
assembling ASM_funct.s...
linking...
Program Size: Code=360 RO-data=408 RW-data=0 ZI-data=608
".\ABI_C+ASM.axf" - 0 Error(s), 1 Warning(s).
```

What happens if don’t declare r as volatile?



```
       4: int main(void){
       5:
0x00000180 B51C       PUSH     {r2-r4,lr}
       6:         int i=0xFFFFFFFF, j=2, k=3, l=4, m=5, n=6;
       7:         int r;
       8:
0x00000182 F04F34FF   MOV      r4,#0xFFFFFFFF
0x00000186 2502       MOVS     r5,#0x02
0x00000188 2603       MOVS     r6,#0x03
0x0000018A 2704       MOVS     r7,#0x04
0x0000018C F04F0805   MOV      r8,#0x05
0x00000190 F04F0906   MOV      r9,#0x06
       9:         r = ASM_funct(i, j, k, l, m, n);
      10:
0x00000194 463B       MOV      r3,r7
0x00000196 4632       MOV      r2,r6
0x00000198 4629       MOV      r1,r5
0x0000019A 4620       MOV      r0,r4
0x0000019C E9CD8900   STRD     r8,r9,[sp,#0]
0x000001A0 F000F83C   BL.W     ASM_funct (0x0000021C)
      11:         while(1);
0x000001A4 BF00       NOP
0x000001A6 E7FE       B        0x000001A6
```

Variable r is not allocated and the ASM function translated into a “void” function

Some extra C types

```
// testValue
unsigned long long testValue     = 0xFFFFFFFFFFFFFFFF; // 18446744073709551615

// 1 byte -> [0-255] or [0x00-0xFF]
uint8_t                  number8     = testValue; // 255
unsigned char        numberChar    = testValue; // 255

// 2 bytes -> [0-65535] or [0x0000-0xFFFF]
uint16_t                 number16     = testValue; // 65535
unsigned short       numberShort    = testValue; // 65535

// 4 bytes -> [0-4294967295] or [0x00000000-0xFFFFFFFF]
uint32_t                 number32     = testValue; // 4294967295
unsigned int           numberInt    = testValue; // 4294967295

 // 8 bytes -> [0-18446744073709551615] or [0x0000000000000000-0xFFFFFFFFFFFFFFFF]
uint64_t                  number64        = testValue; // 18446744073709551615
unsigned long long numberLongLong    = testValue; // 18446744073709551615
```