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
- Cross compiling is a typical step for embedded application written in C language
- When integrating ASM functions, a special care is needed
  - To correctly identify the functions arguments
  - 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

; Have to import the main function address

; Executes a linked branch to main

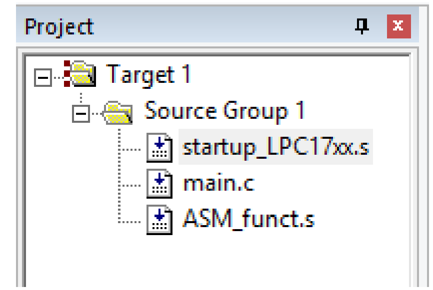
```
IMPORT  __main
LDR     R0, =__main
BX      R0
```

- 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 branch 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 in an endless loop.

```c
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 parameters are 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)

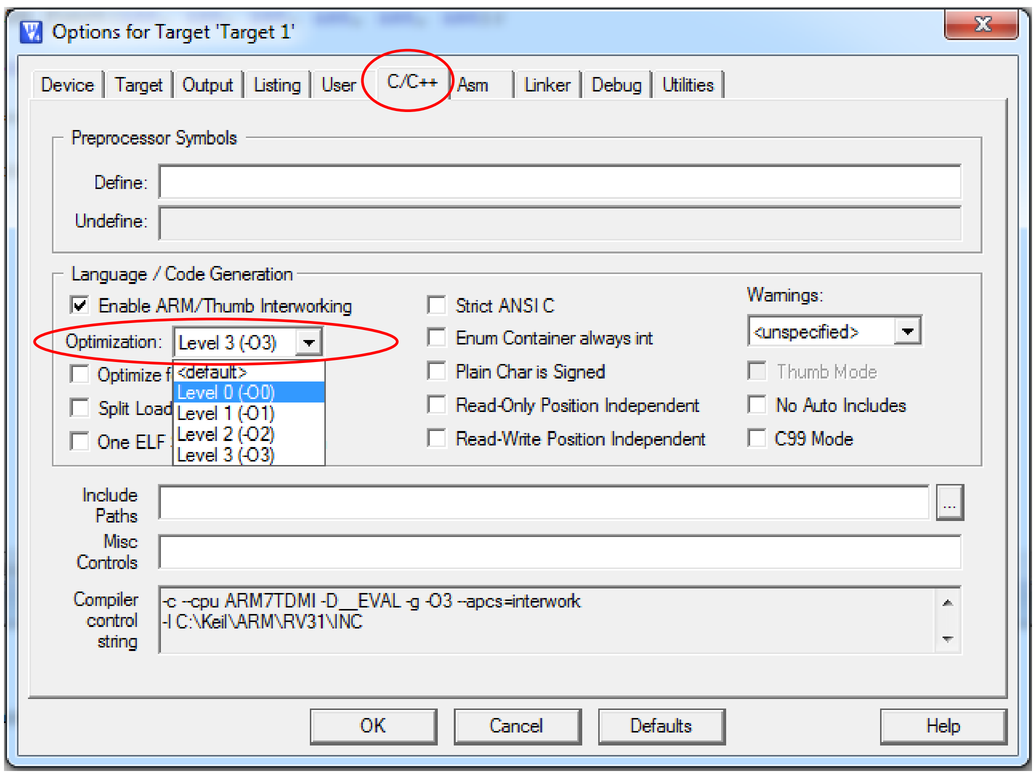
Stacked parameters

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 other file (where it is defined)

COMPILER OPTIMIZATION

- As we are now working in C language, the compiler can be asked to optimize the resulting executable file (i.e., the actual machine code).



Compiler optimization and the <u>volatile</u> 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 <u>volatile</u> 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	Volatile version of buffer loop

<pre>int buffer_full;
int read_stream(void)
{
    int count = 0;
    while (!buffer_full)
    {
        count++;
    }
    return count;
}</pre>
	<pre>volatile int buffer_full;
	int read_stream(void)
	{
	    int count = 0;
	    while (!buffer_full)
	    {
	        count++;
	    }
	    return count;
	}</pre>

Table 13. Disassembly for nonvolatile and volatile buffer loop

Nonvolatile version of buffer loop	Volatile version of buffer loop

<pre>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</pre>
	<pre>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</pre>

ABI standard for ARM

ARM

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 [illegible]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?

Disassembly

```
     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 considered as “void” function

Example on volatile variables

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;
}
```

Example on volatile variables

Nonvolatile version of buffer loop

```
int buffer_full;
i
{

}
```

```
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

```
volatile int buffer_full;
in
{

}
```

```
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
```