



EEL 4744C: µP Apps

# EEL 4744

## Menu

- Introduction to C for Atmel XMega



See Examples or Classes on web-site:  
Usage of simple ..., usart\_serial.c, ebi.c, ebi\_driver.h  
See Software/Docs:  
Getting Started Writing C ...,  
Info on C for the Atmel XMEGA, Tips to Optimize C Code  
For mixed C/Assembly:  
• "Mixed C and Assembly (for Atmel XMEGA)",  
• VectorAdd\_Mixed\_ASM.s, VectorAdd\_Mixed.c,  
• VectorADD\_Casm.c, Input\_Port\_C.c

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## Menu

- Motivation
- Overview of C Basics
- Variables, Types, and Definitions
- Conditionals
- Ports and Registers
- Interrupts
- Pointers
- C Example
- **NOT** covered, but possibly useful info after 4744  
>Using C with Assembly: slides 42-...

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## EEL 4744 Introduction to C & other High-level Languages

- Source Languages (e.g., C, C++, Java)
  - > Most modern programs are written in high-level languages (such as C), because it is generally easier than Assembly.
  - > A compiler is used to convert a source language into a target language (e.g., Assembly), resulting in object code (just as an assembler converts Assembly to object/machine code).
  - > A compiler is given limited time to “optimize” the object code in terms of speed, memory usage, etc.
  - > The resulting object code is not guaranteed to be as fast or efficient as can be done with Assembly code.

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## EEL 4744 Mixed C/Assembly

- Why Mixed Coding?
  - > Occasionally a programmer may want to take advantage of the increased specificity in Assembly to improve the resulting object code (usually for increased speed).
  - > When programming in high-level language, there may be limitations due to processor specific features.
    - Memory Mapping
    - External Bus Control

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## Costs/Benefits of Mixed C/Assembly versus C or Assembly

- Benefits of either C or Assembly (but not both)
  - > ... of C
    - Power of a high-level source language such as C
      - Libraries (Graphical, Math, etc.), String-processing functions, etc.
    - Use of C structures and layout
  - > ... of Assembly
    - Speed and control of assembler (optimization)
    - Direct control of code placement
    - Access to processor specific functions
- Drawbacks of mixed C/Assembly
  - > Assembly coding in mixed coding is slightly different from standard Assembly
    - Naming conventions, function usages
  - > Code is less portable (i.e., is often specific to the processor)

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## What is Mixed C/Assembly Coding?

- Use Assembly code to improve C code or take advantage of a specific processor's capabilities
- For our board, mixed coding is handled by the AVR-GCC toolchain for compiling with the GNU Assembler (GAS); previously used Eclipse toolchain.
- W/ XMEGA, 2 ways to mix C and Assembly code
  - > Use separate files for C code and Assembly code, the **.c** extension and **.s** extension respectively
  - > Inline Assembly code directly inserted into the C code
  - > You will **NOT** be expected to write mixed code
    - See the end of this lecture for more mixed C/Assembly info

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## Basic C Structures

- Overview
  - (The primary C structures are also used in Mixed C/Assembly)
  - Preprocessor Directives
  - Functions (prototypes)
  - Main Function
  - Function Calls

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## Basic C Structures

- C (or Mixed C/Assembly)  
start with a standard structure

> Example:

```
#define F_CPU 2000000
#include <avr/io.h>

// function prototype below
int add(int x, int y);
```

```
// main routine below
int main(void)
{
    int x=3, y=7, z;
    while(1)
    {
        z=add(x,y);
    }
}

// function is below
int add(int x, int y)
{
    return (x+y);
}
```

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## Basic C Structures

## Preprocessor Directives

- Preprocessor Directives (# sign)
  - > The **#define** is an “object-like” macro definition (similar to **.equ** or **.def**)
    - Allows us to define a value for a symbolic name that may be used in our code or the systems code
  - > The **#include** is a method used to include other files that include code (similar to **.include**)
    - If using brackets (< >), the file is expected in **standard compiler include paths**
    - If using quotation marks (" "), the path for the file will include the **current source directory**
  - > Example:
 

```
#define F_CPU 2000000
#include <avr/io.h>
```

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## Basic C Structures

## Preprocessor Directives

- There are various other types of preprocessor directives that may be used
  - > The given example shows
    - A defined rate to be used for the clock frequency of the XMEGA
    - A definitions file to be used for an AVR processor
  - > Example:
 

```
#define F_CPU 2000000
#include <avr/io.h>
```

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Basic C Structures  
Function Prototypes

- Function Prototypes
  - > Functions may not be called unless they have been defined with a **prototype**
    - Some compilers do not require this (including ours), **but 4744 does!**
  - > Function **prototypes** allow a function to be partially defined
    - Prototypes are typically found near the top of the file, below preprocessor directives (or in header files, i.e., .h)
    - Defines the function, but does not supply a body of code
    - Functions are defined later in the program with its body of code
    - Allows the function to be called before its complete definition
    - **Example:**

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## Overview of C Basics

- Main Functions
  - > One in every program, starting point for all code
- Functions
  - > Similar to subroutines in Assembly
  - > Organized scheme for holding code
  - > Allows passing of parameters and returning results
  - > Use of prototypes for organizing code
    - Prototypes should **ALWAYS** be used; they are **NOT** optional, even if Microchip/Atmel Studio does not require them in the present version
- Preprocessor Directives
  - > Defining names (or variables) as values
  - > Including extra files detailing code
  - > Creating Macros to detail functions or values

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## Basic C Structures

### Main Function

- Main Function
  - > A few properties of the **main** function
    - Resembles a standard function
    - A single **main** function is required for **each** project
    - Starting point for the project

#### > Example:

```
int main(void)
{
    while(1)
    {
        z = add(x, y);
    }
}
```

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## Basic C Structures

### Main Function

- > When the **main** function ends, the program ends
  - A **while** loop may be used to run a block of code “forever”
    - Like the “dog chasing its tail” loop used at the end of Assembly programs
- > The example also shows how a function may be called
  - The name of the function to be called is used
  - If the function requires arguments, they may be passed within parenthesis (x and y in the below example)

#### > Example:

```
int main(void)
{
    ...
    while(1)
    {
        add(x, y);
    }
}
```

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## Basic C Structures Function Prototypes

- Function Prototype

> **Example:**

```
int add(int x, int y);    // this is the prototype

int main(void)
{
    while(1)
    {
        add(x,y);        // this is the function call
    }
}

int add(int x, int y)    // this is the function
{
    return (x+y);
}
```

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## Overview of C Basics

- We can (and will) write programs entirely in C
- Values are defined using variables (not registers)
  - >No registers are directly referenced (although they will be used “underneath the hood,” i.e., after compilation)
- High-level conditional structures are available for flow control
  - >Easier use of comparisons
  - >No branch functions (used in Assembly) available (or necessary)
- Cleaner way of looking at port usage and interrupts

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# Variables

- Variables

- > Type

- Standard: int, char, float, double, etc.
    - Special: uint8\_t, uint16\_t, int8\_t, int16\_t, etc.

- > Scope of Variables

- Local: Declare at the beginning of a function in which it is to be used
    - Global: Declare outside of any function, typically at the top of the c file

- > Modifiers: causes variable to use more or less memory

The following are typical examples

- short (works on int)
    - long: 4 to 8 bytes (depending on the compiler/processor)
    - signed, unsigned, long, long long (twice as long as long)

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# How to use Variables

- When defining variables, there are many types available

**Example:**

```
char char1 = 'j';
char char2 = 0x6A;
char str[7] = "microp"
char str[] = "4744 #1"
char *str = "Hi!"
int x = 37;
int y = 0x37;
float = 0.00037;
double = 37.000001;
```

Type	Expression
char	
standard	'j'
ascii	106, 0x6A
string	"microp"
int	
decimal	37
hex	0x37
binary	0b110111
float	0.00037
double	37.000001

- When quotes (") are used, the **string** terminates with a null (0) character
- When arrays uses brackets ([ ]), then the size depends on the number of elements in the brackets; if empty, then "unlimited"

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## Pointers and Addresses

- When there is an \* in a declaration, then it means that it is a pointer variable
  - > \*x means that x is a pointer variable
  - > char \*x = "Hi!" // x is a pointer variable
  - > \*x = "Bye" // value, starting at address x is now "Bye"
- &x means "address of x"
  - > &x[0] means address of x or the address of x[0]
  - > &x[2] means address of x, plus 2; which is the address of x[2]

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## Arrays

- An Array is a method of grouping a series of same type elements in a single variable located in contiguous memory locations
  - > Syntax: *type name [elements] = {initialized value list};*
    - Type may be any variable type
    - Elements states the size or number of variables in the array
    - The initialized value list represents the initial values populating the array
      - If defining an initial list, the value of elements may be omitted
  - > Examples:
 

```
uint8_t buffer[20]; // unsigned character (8 bits)
char message[] = {'m', 'i', 'c', 'r', 'o', 'p'}
                // no 0x0 appended
char string[] = "microp"; // an 0x0 is appended
```

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## Conditionals

- Conditionals controls flow of code given programmer defined conditions
- Handles the concept of comparisons and branches (that were used in Assembly)

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## If, Else If, Else

- Check conditional statements for truth values
  - > **if** conditional
    - If expression is true, execute expressions within conditional block
    - If expression is false, check any following conditionals tied to *if* conditional
  - > **else if** conditional (may be omitted)
    - Follows same concept as *if* conditional, giving more conditional checks
  - > **else** conditional (may be omitted)
    - If all other conditionals fail, this block is executed

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simple\_if\_statements.c 22

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# If, Else If, Else

>Syntax:

```


if (expression) {
    <statements>
} else if (expression) {
    <statements>
} else {
    <statements>
}
    
```



simple\_if\_statements.c

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# Relational Operators

- To create a conditional expression, utilize one of relational operators

Relational Operator	Definition	Example (True results)
>	Greater than	47 > 37
>=	Greater than or equal to	47 >= 47
<	Less than	37 < 47
<=	Less than or equal to	37 <= 47
==	Equal to	47 == 47
!=	Not equal to	37 != 47

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# Boolean Operators

- To create more complex conditional expressions, Boolean operators may be used

Boolean Operator	Definition	Example (True results)
&&	AND two expressions	((47 >= 47) && (47 > 37))
	OR two expressions	((37 != 47)    (37 > 47))
!	Complement expression	!(37 > 47)




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# While and Do While

- While** loops allow for repetition
  - > If expression is true, execute expressions within conditional block and continue to execute until false
  - > If expression is false, exit conditional block and continue with code following the while block
- Do While** loops allow for repetition
  - > Follows same concept as While loop, except condition expression happens at the end of the code
  - > Will execute code block at least once

- Syntax:

```
while (expression) {
    <statements>
}
```



```
simple_whiles_loops.c
multiple_whiles_loops.c
do {
    <statements>
} while (expression)
```



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## For Loop

- **For** loops allow for repetition while also iterating
  - > Has a start value, e.g., `int i = 0`
  - > Loops until an end condition has been met, e.g., `i < 10`
  - > Every loop, the start value will either be increase or decrease, e.g., `i++` or `i--`
  - > Syntax:
 

```
for (start value; end condition; inc/dec value) {
    <statements>
}
```

>Example:

```
for (int i = 0; i < 10; i++) {
    <statements>
}
```



if\_and\_for\_loops.c

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## Switch Statements

- **Switch** statements acts as selection control, changing the code flow through a multi-way branch
  - > Multi conditional system such as a large **if** conditional structure
  - > May also be used to create a state machine
  - > Has a single variable that compared to multiple values, executing different code for potentially each value.
  - > Syntax:

```
switch (
variable )
{
case value1:
    <statements>
    break;
```

```
case value2:
    <statements>
    break;
default:
    <statements>
    break;
}
```



switch\_statements.c

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## Break

- While running loops, it is possible to break out of the code at anytime using the break expression
  - > If using nested loops, the break expression will break out of all loops
  - > Can use labels to jump to the outer loop
- Example:

```
outer_loop:
for (int i = 0; i < 10; i++) {
    for (int j = 0; j < 10; j++) {
        if ( (i * j) == 37 ) // Won't happen!
            break outer_loop;
    }
}
```

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## Volatile

```
asm volatile ("nop");
-----
void RoughDelay1sec(void)
{
    volatile uint32_t ticks;
    //Volatile prevents compiler optimization
    for(ticks=0;ticks<=F_CPU;ticks++);
    //increment 2e6 times -> ~ 1 sec
}
```

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 if\_and\_for\_loops.c

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## PORT / Modules

- May access Ports similarly to Assembly, use the **header** file
  - #include <avr/io.h>
  - >HINT: Right mouse click on variable name and choose goto implementation
- When programming, make use of intelli-sense
- Naming follows the AVR Manuals
- Access PORTS (or modules) by name directly
  - >Examples:

```
PORTA_DIRCLR = 0xFF
USARTC0_CTRLA = 0xFF
```

```
simple_whiles_loops.c
multiple_whiles_loops.c
```

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## Registers

- It is possible to use C syntax and **structures** to access registers of various modules in a cleaner manner
- Instead of typing the entire name, you can
  - >Enter the module name
  - >Enter a period
  - >Enter the register name (with autocomplete)
  - >Example:

```
PORTA.DIRCLR = 0xFF
USARTC0_CTRLA = 0xFF
```


```
simple_whiles_loops.c
multiple_whiles_loops.c
```

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# Bitwise and Compound Operators

- When modifying ports and registers, bitwise operators are often used.
- `&`, `|`, and `^` may be tied to equal sign to simply AND or OR the variable with another variable
- Examples:
 


```
PORTB_DIRCLR |= 0xF0;
X <<= 2; // X=X<<2
```
- Can also do this with `+`, `-`, `*`, `/`, etc.
  - >Example:
 

```
Var1 += 37; // Var1 = Var1 + 37
```

Symbol	Bitwise Operation
<code>&amp;</code>	AND
<code> </code>	OR
<code>^</code>	Exclusive OR
<code>&lt;&lt;</code>	Left Shift
<code>&gt;&gt;</code>	Right Shift
<code>~</code>	One's Complement

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# Bitmasks

- Programming in C allows a user to use various defined enumerations or structures when working with PORTs and control registers
- Standard bitmasks allow a user to change only specific bits in a register when desired (noted by `bm`)
- >Example:
 


```
PORTB_DIRCLR = PIN2_bm | PIN4_bm;
PORTB_DIRCLR = PIN2_bm | PIN4_bm;
```



`usart_serial.c`

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# Bitmasks

- Group **Configuration Bitmasks** allow a user to change only multiple bits representing aspects of a control register

> Example

```
USARTC0.CTRLC = USART_CMODE_ASYNCHRONOUS_gc |
                USART_PMODE_DISABLED_gc |
                USART_CHSIZE_8BIT_gc;
```




usart\_serial.c

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# Interrupts

- First must include the interrupt header file  
> `#include <avr/interrupt.h>`
- After defining interrupts use module registers, enable or clear the global interrupts as needed  
> `sei();`  
> `cli();`
- Finally, write the interrupt service routine for the required interrupt vector

```
ISR(USARTC0_RXC_vect)
{
    USARTC0.DATA = USARTC0.DATA;
}
```



usart\_serial.c

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## Interrupts

- Occasionally clearing the interrupts is necessary, but preserving the status register is **ALMOST ALWAYS** required (and always, in Assembly, but **NOT** in C)
- In the XMEGA (and likely most processors) the below is automatically done (so **UNNECESSARY**) in C; but if it isn't, this could be done

>Example:

```
uint8_t sreg = SREG; // save status reg
cli();
<statements>
SREG = sreg;          // restore status reg
```

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## Using C with Assembly

- It is possible to use C and Assembly more seamlessly by creating variables and functions in C and using them in various ways with Assembly
  - >This puts less emphasis on the Assembly code, using it only as needed to improve code
  - >When using more of C's capabilities, some extra considerations must be placed on the choice of Registers in Assembly (as described in the lecture *Intro to Mixed C and Assembly*)

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## EEL 4744 Using C with Assembly Passing Arguments

- Arguments are passed to Assembly functions in register pairs or via the stack if more than 9 arguments
  - > **Word Data** takes both registers
  - > **Byte Data** takes the lower register

Argument	Registers
1	r25:r24
2	r23:r22
3	r21:r20
....	
9	r9:r8

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## EEL 4744 Using C with Assembly Returning Values


- Return values always use the following convention

Type	Registers
8 bit data (sign or zero extended)	r25:r24
32 bit data	r25:r22
64 bit data	r25:r18

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# Pointers

- Pointers may be used to contain the address of a variable. You create pointers using the `*` symbol
 


```
>int value = 5;    // A variable holding a value of type int
>int *valuePtr;   // A pointer to a value of type int
```
- To reference the address of the pointer you use the `&` symbol
 

```
>valuePtr = &value; // Place address of value in pointer
```
- To get the data that the pointer points to, you can “dereference it” by using the `*` symbol on the pointer
 

```
>int data = *valuePtr; // Get data pointed to by pointer
```

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# Examples


- External Bus Interface (EBI) example:
 

```
ebi.c
ebi_driver.h
```
- Asynchronous Serial example:
 

```
usart_serial.c
```

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## Mixed C/Assembly

You are not responsible for the following pages

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## C Projects and **Inline** Assembly

- If it is only desired to add a few lines of assembly code to a C Project, it is possible to add assembly “inline”
- Inline assembly uses the `asm` function with the following template  

```
asm volatile(asm-template : output-operand-list :
                list-input-operand : clobber list )
```
- When using the **asm** function, the compiler will have a harder time optimizing code
- The **volatile** keyword may be used to prevent the compiler from attempting to optimize the line
  - > The keyword `volatile` may be omitted, but then the compiler might optimize away your intended structure

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## EEL 4744 Inline Assembly

asm volatile ( asm-template : output-operand-list :  
list-input-operand : clobber list )

- The *asm-template* component of the asm function follows standard Assembly with small changes
  - > The *Mixed C and Assembly (for Atmel XMEGA)* document detail any required changes

– Example:

asm volatile (“STS %0, r18” : “=m” (EBI\_CTRL));

- STS command above is used to define EBI\_CTRL
- The %0 is a place holder showing that the defined operand will come later in the template
- The output operand section, EBI\_CTRL, is defined as an output only memory (“=m”) location address




## EEL 4744 Inline Assembly

asm volatile ( asm-template : output-operand-list :  
list-input-operand : clobber list )

- The *asm-template* may use “%” expressions to define placeholders replaced by operands in the *output-operand-list* and *list-input-operand*

Placeholder	Replaced by
% n	By argument in operands where n = 0 to 9 for argument
A% n	The first register of the argument n (bits 0 to 7)
% B n	The second register of the argument n (bits 8 to 15)
% C n	The third register of the argument n (bits 16 to 23)
% D n	The fourth register of the argument n (bits 24 to 31)
% A n	The Address register X, Y, or Z
% %	The % symbol when needed
\\	The \ symbol when needed
\\N	A newline to separate multiple asm commands
\\T	A tab used in generated asm



## EEL 4744

# Inline Assembly


asm volatile ( asm-template : output-operand-list :  
list-input-operand : clobber list )

- The *output-operand-list* and *list-input-operand* uses various modifiers as needed for the operands given

Modifier	Meaning
=	Output operand
&	Not used as input but only an output
+	Input and Output Operand

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
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



## EEL 4744

# Examples

- Vector Add Mixed
  - > **.s** File Compilation Example
  - > Requires both .c and .s file
- Later
  - > Vector Add
    - Inline Assembly version
  - > Input Port
    - Inline Assembly version

  
 VectorAdd\_Mixed.c  
 VectorAdd\_Mixed.s


  
 VectorAdd\_Casm.c

  
 Input\_Port\_C.c

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## Mixed C/Assembly

- The slides that follow are **NOT** covered this semester, i.e., you will not write mixed C/Assembly code, nor will you be responsible to know this for labs or exams

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## C Projects and .s Assembly Files

- When creating a C project in Microchip/Atmel Studio, a simple **.c** file is created with a template structure
  - > C code should be restricted to **.c** files
- When adding Assembly to a C project, a **.s** file is used to hold all Assembly code (**not** a **.asm** file)
- A **.s** file will resemble a standard assembly file, however, there are some considerations that must be made when in C projects
  - > Registers are used differently since C also uses them
  - > Assembly preprocessor directives have different formats

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## EEL 4744 “.s” File Compilation Registers

- When writing assembly in a C project, registers have different rules

Register	Description	Assembly code called from C	Assembly code that calls C code
r0	Temporary	Save and restore	Save and restore
r1	Always Zero	Must clear before returning	Must clear before returning
r2-r17 r28 r29	“call-saved”	Save and restore	Can freely use
r18-r27 r30 r31	“call-used”	Can freely use	Save and restore

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## EEL 4744 “.s” File Compilation Registers

- r0**: defined as a temporary register which may be used by compiler generated code
- r1**: assumed to always be zero by the compiler, so any assembly code that uses this should clear the register before calling compiler generated code
- r2 – r31**: defined as “call-saved” or “call-used”
  - > **call-saved**: registers that a called C function may leave unaltered, however, assembly functions called from C should save and restore the contents of the register (using stack)
  - > **call-used**: registers available for any code to use, but if calling a C function, these registers should be saved since compiler generated code will not attempt to save them

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## EEL 4744 “.s” File Compilation Syntax

- When writing assembly in a C project, some syntax is different

Path for the equivalent file to the ATxmega128A1Udef.inc is:  
 C:\Program Files (x86)\Atmel\Atmel Toolchain\AVR8  
 GCC\Native\3.4.2.1002\avr8-gnu-  
 toolchain\avr\include\avr\iox128a1u.h

Atmel AVR	AVR-GCC
.include “ATxmega128A1Udef.inc”	#include <avr/io.h>
.dseg	.section .data
.cseg	.section .text
.db 1,2,3,4	.byte 1,2,3,4
.db “message”	.ascii “message”
.db “message”, 0x00	.asciz “message”
.byte 37 ;save space for bytes	.ds.b 37
.dw	.word
HIGH(), LOW()	hi8(), lo8()

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## EEL 4744 “.s” File Compilation .dseg and Data Memory

- Data memory defaults to start at 0x2000
- .section .data** replaces the use of **.dseg** to access the Data Memory space

>Example:

```
.section .data // old way .dseg
Var1: .ds.b 7 // save 7 bytes
Var2: .ds.w 3 // save 3 words
Var3: .byte 0x37 // Var3 = 0x37
// Previously, .byte saved space; now value
Text: .asciz "hello world"

.global __do_copy_data // needed for Var3
// and Text
```

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## EEL 4744 “.s” File Compilation .dseg and Data Memory

- **.section .data** is necessary to begin the Data Memory (i.e., volatile memory = RAM) segment
- The **.asciz** command is used to define a **specific** null terminated string, a constant
  - > **.ascii** is like **.asciz**, but with no null termination
- The **ds.b** and **ds.w** commands are used to define **storage** of varying sizes (like **.byte** in **.asm** files)
- The **.byte** command is used to define a **specific** byte, i.e., a constant (like **.db** in **.asm** files)

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## EEL 4744 “.s” File Compilation .dseg and Data Memory

- Data memory is typically used to create storage of variables like **Var1** and **Var2**
- It is occasionally desired to create memory **and store an initial value** in that memory space, as we did for **Var3** and **Text**
  - > The initial value is stored in program memory
  - > The **.global \_\_do\_copy\_data** special command handles copying the data from program memory to data memory

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## EEL 4744 .s File Program Memory & Watch Window

- In a .s file, we do **NOT** have to do the shifting that we did in .asm files for reading Program Memory Section (.dseg in .asm and .section .text in .s)

> Example for a .s file

```
ldi ZL, lo8(VA) // Load the address of program
ldi ZH, hi8(VA) // memory for VA
```

VectorAdd\_Mixed.s

- The watch window can **NOT** display XL, XH, YL, YH, ZL, or ZH in .s files, nor most other things (other than registers, Rx)

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## EEL 4744 “.s” File Compilation Functions Example

- One of the main aspects of using Assembly in a C project is to benefit from using Assembly functions
- Functions must be declared in both C files and Assembly files
  - > Function prototypes should be defined in C code for any function called from Assembly
    - `extern int funct();`
  - > Functions defined in Assembly code that will be called from C code should be declared global
    - `.global funct`

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## EEL 4744 “.s” File Compilation Functions in C/Assembly

> .c file syntax:

```
extern int funct();

int main(void)
{
    funct();
}

> .s file syntax:
.global funct

funct:
    ldi    R18, 0x47
    ...
    ret
```

> .c file example:

```
extern void MAIN_ASM();
int main(void)
{
    MAIN_ASM();
}

VectorAdd_Mixed.c
```

---


> .s file example:

```
.global MAIN_ASM
MAIN_ASM:
    ldi    R18, N
    ...
    ret

VectorAdd_Mixed.s
```

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## EEL 4744

# The End!

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