SISTEMI EMBEDDED

The C Pre-processor
Fixed-size integer types
Bit Manipulation

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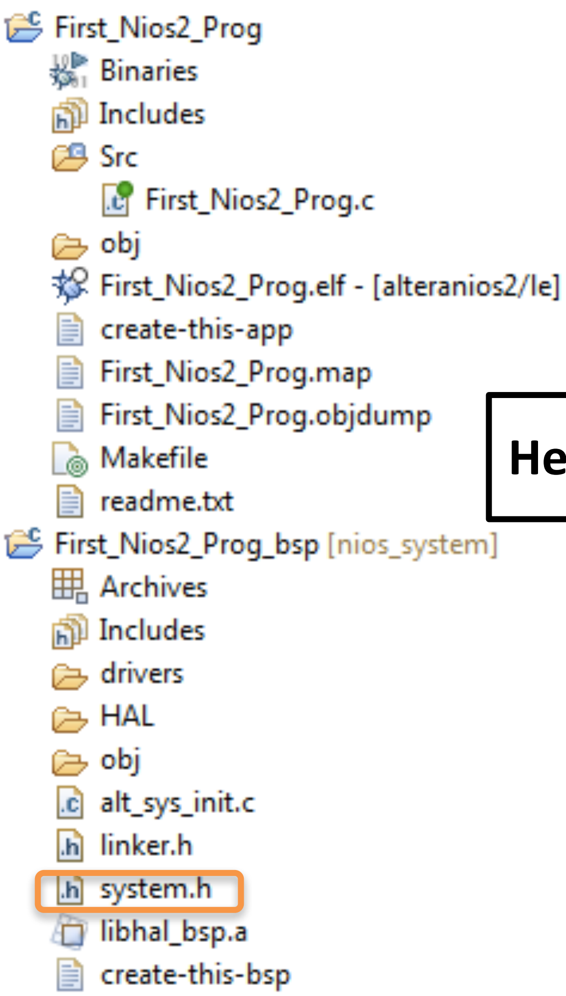
The **C** **P**re**P**rocessor CPP (1)

- **CPP** is a program called by the compiler that processes the **text** of the program before its actual translation
- It basically does the following operations:
  - Includes the content of other files (usually *header* files)
  - Expands the SYMBOLS with their related definitions
  - Includes/Excludes part of the code to the text that will be actually compiled
- These actions are controlled by **directives**
  - A directive is a single code line that starts with #
  - You can use the character \ to go to a new line within the same directive

The C PreProcessor (2)

- **Inclusion of header files** (files with .h extension that contains only declarations). E.g.
  #include <stdint.h>
  #include "my_header.h"
- The file stdint.h is searched in a standard directory list; my_header.h is searched in the same directory as the including source file
- The list of directories searched for header files can be changed with a compiler option

The C PreProcessor (3)



First_Nios2_Prog.c

```
/* … */
#include "../FirstNios2_Prog_bsp/system.h"
/* … */
```

Compiling First_Nios2_Prog.c (other compiler options omitted)

nios2-elf-gcc -c –o First_Nios2_Prog.o First_Nios2_Prog.c

Header path can be omitted by using *-Idir* compiler option

First_Nios2_Prog.c

```
/* … */
#include "system.h"
/* … */
```

Compiling First_Nios2_Prog.c (other compiler options omitted)

nios2-elf-gcc **–I../FirstNios2_Prog_bsp/** -c –o First_Nios2_Prog.o First_Nios2_Prog.c

The C PreProcessor (4)

- **Macro** is a symbol that is replaced with its definition before compilation (it can be followed by one or or more arguments). E.g. of macro def.

```
#define MASK 0xF
#define MAX(A,B) ((A) > (B) ? (A) : (B))
```

- The instructions:

```
b = a & MASK;
y = 1 + MAX(10,x);
```

- are expanded by the preprocessor to:

```
b = a & 0xF;
y = 1 + ((10) > (x) ? (10) : (x));
```

The C PreProcessor (5)

- **Macro** are largely used in C programming of embedded systems to access peripheral registers.
  E.g. of definition:

```
#include "system.h"
#define RED_LEDS_DATA_REG    \
        (*(volatile unsigned int*) RED_LEDS_BASE)
#define SLIDER_DATA_REG      \
        (*(volatile unsigned int*) SLIDER_SWITCHES_BASE)
```

- E.g. of use:

```
RED_LEDS_DATA_REG = SLIDER_DATA_REG;
/* Show the status of the slider switches on the red leds */
```

The C PreProcessor (6)

- **The macro** *name_of_the_macro* exists from its definition to the end of the file or when it is undefined using the directive:
  #undef *name_of_the_macro*
- A macro can also be defined with an option passed to the compiler:
  -D *name_of_the_macro=def*
- Do a large use of parenthesis to avoid unintended behaviors when the MACRO is expanded
- **Write macro SYMBOLS with all CAPITAL letters**

The C PreProcessor (7)

- **Conditional compilation** makes it possible to include/exclude code segments if certain expressions evaluated by the preprocessor are true or false. E.g.

```
#ifdef DEBUG
    printf("Debug mode enabled\n");
   /* or any other code that we want to include
      for debug purposes */
#endif
```

- #define DEBUG 1
  includes the debug code

The C PreProcessor (8)

- A common use of **conditional compilation** is to avoid multiple inclusions of a header file. To this end, start the header file, say config.h, with:
  #ifndef CONFIG_H_
  #define CONFIG_H_
- and end it with:
  #endif /* CONFIG_H_ */
- After the first inclusion of my_header.h, the symbol MY_HEADER_H is defined. Thus, further inclusions are filtered out by the **conditional compilation directives**

Integer types

- 2 basic integer types: ***char, int***
- and some type-specifiers:
  - sign: *signed*, *unsigned*
  - size: *short*, *long*
- The actual size of an integer type depends on the compiler implementation
  - *sizeof*(*type*) returns the size (in number of bytes) used to represent the *type* argument
  - *sizeof*(*char*) ≤ *sizeof*(*short*) ≤ *sizeof*(*int*) ≤ *sizeof*(*long*)... ≤ *sizeof*(*long long*)

Fixed-size integers (1)

- In embedded system programming **integer size is important**
  - Controlling minimum and maximum values that can be stored in a variable
  - Increasing efficiency in memory utilization
  - Managing peripheral registers
- To increase software portability, fixed-size integer types can be defined in a header file using the *typedef* keyword

Fixed-size integers (2)

- **C99** update of the **ISO C standard** defines a set of standard names for signed and unsigned fixed-size integer types
  - 8-bit: int8_t, uint8_t
  - 16-bit: int16_t, uint16_t
  - 32-bit: int32_t, uint32_t
  - 64-bit: int64_t, uint64_t
- These types are defined in the standard-library header file **stdint.h**

Fixed-size integers (3)

- Altera HAL (Hardware Abstraction Layer) also provides the header file **alt_types.h** (<*project_name*_bsp>/HAL/inc/) with definition of fixed-size integer types:

typedef signed char	**alt_8**;
typedef unsigned char	**alt_u8**;
typedef signed short	**alt_16**;
typedef unsigned short	**alt_u16**;
typedef signed long	**alt_32**;
typedef unsigned long	**alt_u32**;
typedef long long	**alt_64**;
typedef unsigned long long	**alt_u64**;

- These type definitions are used in Altera HAL source files.
- **To increase portability, you'd better code using C99 fixed-size integer types (including the header file stdint.h)**

Logical operators

- Integer data can be interpreted as **logical values** in conditions (if, while, ...) or in logical expressions:

  = 0, FALSE

  ANY OTHER VALUE, TRUE

- **Logical operators:**

AND	**&&**
OR	**||**
NOT	**!**

- Integer data can store the result of a logical expressions: 1 (**TRUE**), 0 (**FALSE**)

Bitwise operators (1)

- Operate on the bits of the operand/s

AND	**&**
OR	**|**
XOR	**^**
NOT	**~**
SHIFT LEFT	**<<**
SHIFT RIGHT	**>>**

Shift operators

- ***A << n***
  - The result is the bits of *A* moved to the left by *n* positions and padded on the right with 0
  - It is equivalent to multiply *A* by 2^n if the result can be represented
- ***A >> n***
  - The result is the bits of *A* moved to the right by *n* positions and padded on the left with 0 if type of *A* is unsigned or with the MSB of *A* if type is signed
  - It is equivalent to divide *A* by 2^n

Bit manipulation (1)

- **<<** and **|** operands can be used to create <u>expressive binary constants</u> by specifying the positions of the bits equal to 1
  - E.g. (1**<<**7) | (1**<<**5) | (1**<<**0) = 0xA1 (10100001)
  - Better not to use "magic numbers" as 7, 5 and 0. Use instead symbolic names to specify bit positions
    - For instance, the symbolic names can reflect the function of the bit within a peripheral register
  - (1<<x) can be encapsulated into a macro:
    - `#define BIT(x)    (1<<(x))`

Bit manipulations (2)

- Altering only the bits in given positions
  - E.g. bits: 7, 5, 0
  - *#define* MSK = BIT(7) | BIT(5) | BIT(0)
- Clearing bits
  - *A* &= ~MSK;
- Setting bits
  - *A* |= MSK;
- Toggling bits
  - *A* ^= MSK;

Bit manipulations (3)

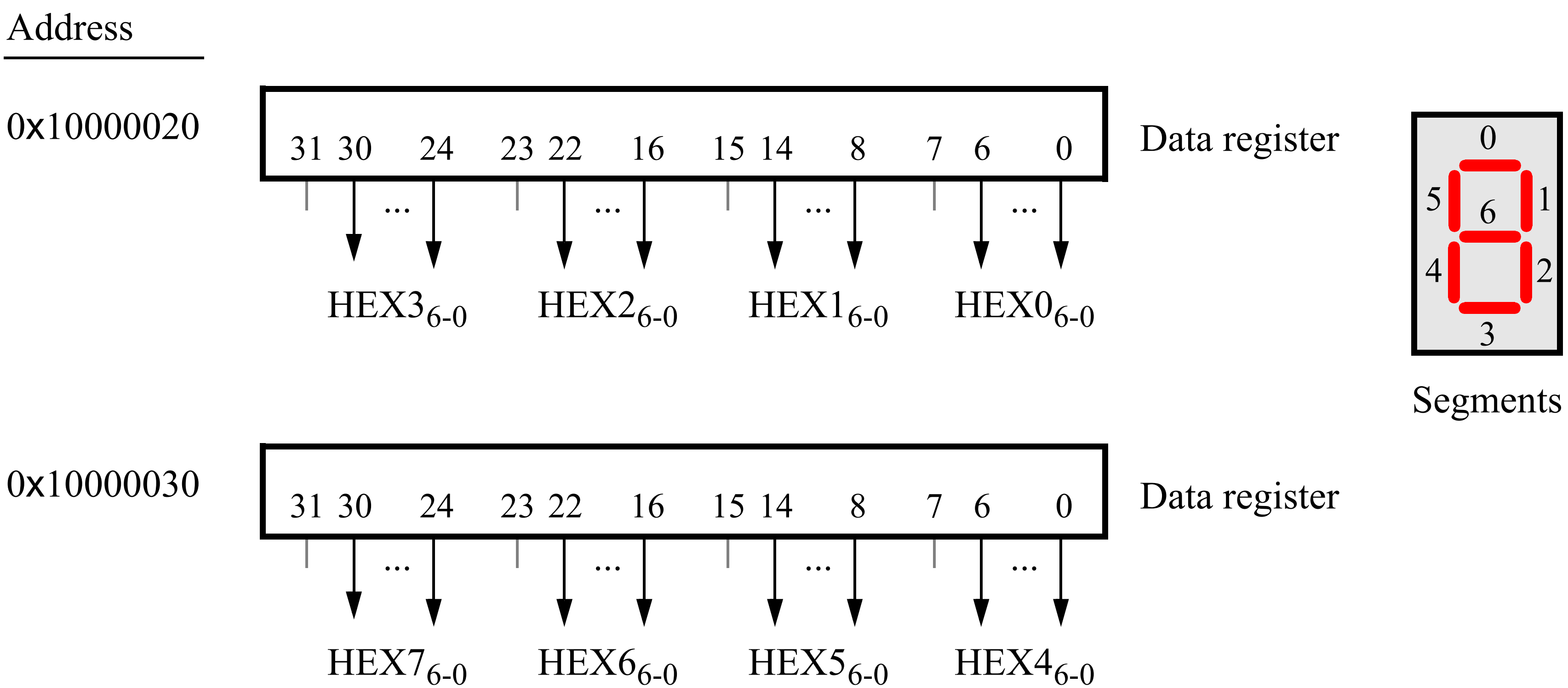
- Testing bits
  - E.g. do something if bit 0 (LSB) of *A* is set, regardeless of the other bits of *A*
  - *if* (A & BIT(0)) {
    /* some code here */
    }

Putting into practice (1)

- Write a program that shows on the 7-seg display HEX3-HEX0 the sizes in number of bytes of *long long*, *long*, *short* and *char* integer data types
- Do they match with the definitions of fixed-size integer types in alt_types.h?

Putting into practice (2)

- 7-seg display **Parallel Ports**



Putting into practice (3)

- To go on:
  1. Show on the **4x 7-Seg HEX3_HEX0 display** the 4 hexadecimal digits of the 16-bit unsigned number (Sw_{15}-Sw_0)
  2. Show on the **4x 7-Seg HEX3_HEX0 display** the 4 decimal digits of the 16-bit unsigned number (Sw_{15}-Sw_0) if the number can be represented; **E** otherwise
  3. Allow the user to choice the representation between hexadecimal and decimal by the slider Sw_{17}

Putting into practice (4)

- To go on:
  4. Show on the **4x 7-Seg HEX3_HEX0 display** the module of the 16-bit signed number (Sw_{15}-Sw_0) and on $LEDG_8$ the sign of the number ($LEDG_8$ is ON if and only if the number is negative). Show the module using hexadecimal and decimal digits as before
  5. Allow the user to choice if (Sw_{15}-Sw_0) code an unsigned or signed number by the slider Sw_{16}
  6. Combine all the features in a single program

References

- Altera “Basic Computer System for the Altera DE2 Board”
- Altera “Parallel Port for Altera DE-Series Boards”