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Embedded System Design

Chapter 3: C Programming for ARM Microcontroller

1. C Program Basics
2. ARM Cortex-M C Compiler
3. ARM software library

1. Basic Programming for Embedded C

- Simple structure for embedded C program

```
#include <...> ; // Library declaration

int x, y, z; // Global variables

void function1 () {  }   // Function declaration
void funtction2() {  }

void main()  // main program
{
    int i, j, k;  // Local variable
    ...
    // Initialization

    while (1) // main process, loop forever
    {
    }
}
```

Example program

```
#include "inc/lm4f120h5qr.h“
//*************** Blinky LED ***********************
int main(void) {
    volatile unsigned long ulLoop;
    SYSCTL_RCGC2_R = SYSC TL_RCGC2_GPIOF; // Enable the GPIO port
    ulLoop = SYSCTL_RCGC2_R; // Do a dummy read to insert a few cycles
    GPIO_PORTF_DIR_R = 0x08; // Set the direction as output
    GPIO_PORTF_DEN_R = 0x08; // Enable the GPIO pin for digital function.
     while(1) // Loop forever
     { GPIO_PORTF_DATA_R |= 0x08; // Turn on the LED.
       for(ulLoop = 0; ulLoop < 200000; ulLoop++)     { }
       GPIO_PORTF_DATA_R &= ~(0x08); // Turn off the LED
       for(ulLoop = 0; ulLoop < 200000; ulLoop++)     {  }
     }
}
```

Data Types

Type	Size (bits)	Range
unsigned char	8	0 ÷ 255
unsigned short int	8	0 ÷ 255
unsigned int	16	0 ÷ 65535
unsigned long int	32	0 ÷ 4294967295
signed char	8	-128 ÷ 127
signed short int	8	-128 ÷ 127
signed int	16	-32768 ÷ 32767
signed long int	32	-2147483648 ÷ 2147483647
float	32	±1.17549435082E-38 ÷ ±6.80564774407E38
double	32	±1.17549435082E-38 ÷ ±6.80564774407E38
long double	32	±1.17549435082E-38 ÷ ±6.80564774407E38

Keywords for Embedded C (1)

No.	Keyword	Meaning
1	asm	Insert assembly code
2	auto	Specifies a variable as automatic (created on the stack)
3	break	Causes the program control structure to finish
4	case	One possibility within a switch statement
5	char	8 bit integer
6	const	Defines parameter as constant in ROM
7	continue	Causes the program to go to beginning of loop
8	default	Used in switch statement for all other cases
9	do	Used for creating program loops
10	double	Specifies variable as double precision floating point

Keywords for Embedded C (2)

No.	Keyword	Meaning
11	else	Alternative part of a conditional
12	extern	Defined in another module
13	float	Specifies variable as single precision floating point
14	for	Used for creating program loops
15	goto	Causes program to jump to specified location
16	if	Conditional control structure
17	int	16 bit integer (same as short on the 6811 and 6812)
18	long	32 bit integer
19	register	Specifies how to implement a local
20	return	Leave function

Keywords for Embedded C (3)

No.	Keyword	Meaning
21	short	16 bit integer
22	signed	Specifies variable as signed (default)
23	sizeof	Built-in function returns the size of an object
24	static	Stored permanently in memory, accessed locally
25	struct	Used for creating data structures
26	switch	Complex conditional control structure
27	typedef	Used to create new data types
28	unsigned	Always greater than or equal to zero
29	void	Used in parameter list to mean no parameter
30	volatile	Can change implicitly

Scope

- The ***scope*** of a variable is the portion of the program from which it can be referenced.
- If we declare a local variable with the **same name** as a global object or another local in a superior block, the new variable temporarily supersedes the higher level declarations.

```
unsigned char x;   /* a regular global variable*/
void sub(void){
    x=1;
    {   unsigned char x;   /* a local variable*/
        x=2;
        {   unsigned char x;  /* a local variable*/
            x=3;
            PORTA=x;}
        PORTA=x;}
    PORTA=x;}
}
```

Static Variables

- **Static variables** are defined in RAM permanently.
  - **Static global**: can only be accessed within the file where it is defined.
  - **Static local:** can only be accessed within the function where it is defined

```
static short TheGlobal;   /* a static global variable*/
void main(void){
    TheGlobal=1000;
}
```

```
void main(void){
    static stort TheLocal;   /* a static local variable*/
    TheLocal=1000;
}
```

Volatile variables

- **Volatile** is a variable that can change value outside the scope of the function
- Applications:
  - memory-mapped peripheral
  - Global variables which can be changed by interrupts
  - Global variables which are access by many tasks

```
void main(void)
{
		volatile unsigned char *p = (char *) 0x8000;
		while (*p == 0);
}
```

Externals

- Objects that are defined outside of the present source module have the external storage class.
- The compiler knows an external variable by the keyword **extern** that must precede its declaration.
- Only global declarations can be designated extern

```
extern short ExtGlobal;   /* an external global variable*/
void main(void){
   ExtGlobal=1000;
}
```

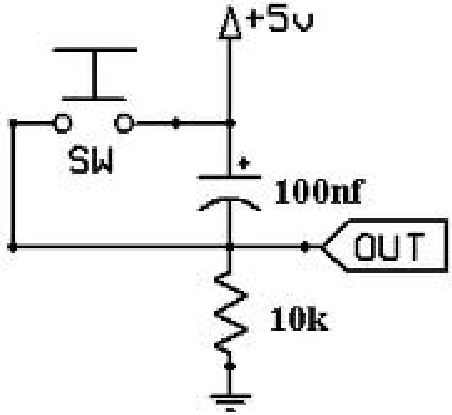
Delay in C programming

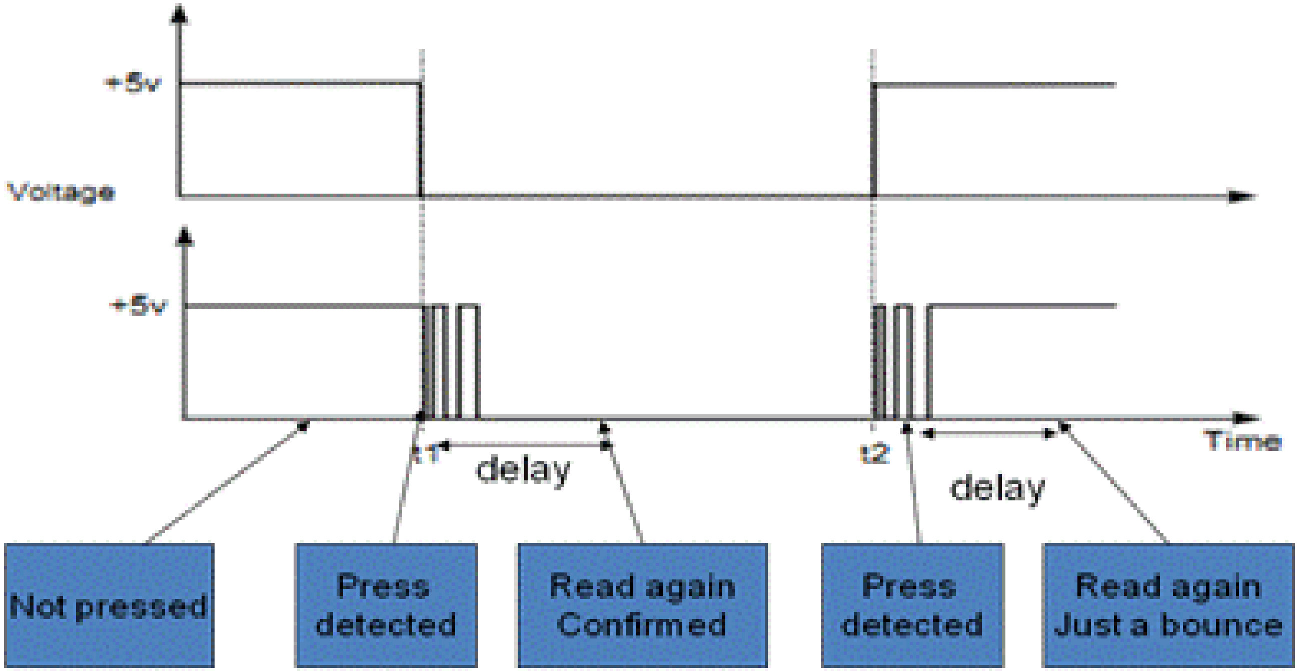
- Delay techniques:
  - Loop
    - Simple, not precise
  - Timer / Interrupt
    - Complex, precise

```
void loop_delay()
{
    unsigned int i;
    for(i=0;i<1000;i++);
}
```

De-bouncing

- De-bouncing techniques
  - Hardware
    - Using a capacitor
  - Software
    - Check twice the status of the button





Timeout

- Timeout: solve the problem when it has to be waiting an event for long time.
- Solution
  - Counter loop
  - Timer

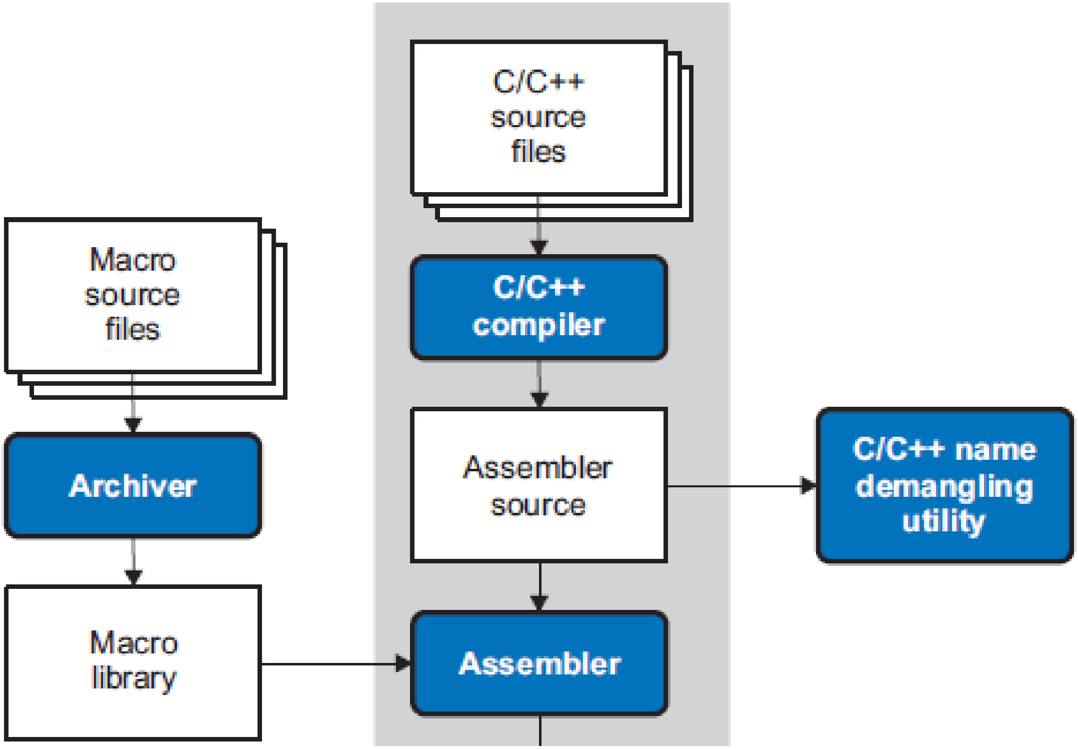
```
long timeout_loop = TIMEOUT_INIT;
…
while(++timeout_loop !=0);
```

2. ARM Cortex-M C Compiler

- Tool chains:
  - Keil™ RealView® Microcontroller Development Kit
  - MentorGraphics Sourcery CodeBench for ARM EABI
  - IAR Embedded Workbench®
  - Texas Instruments Code Composer Studio™
- References
  - Texas Instrument, “ARM Optimizing C/C++ Compiler”

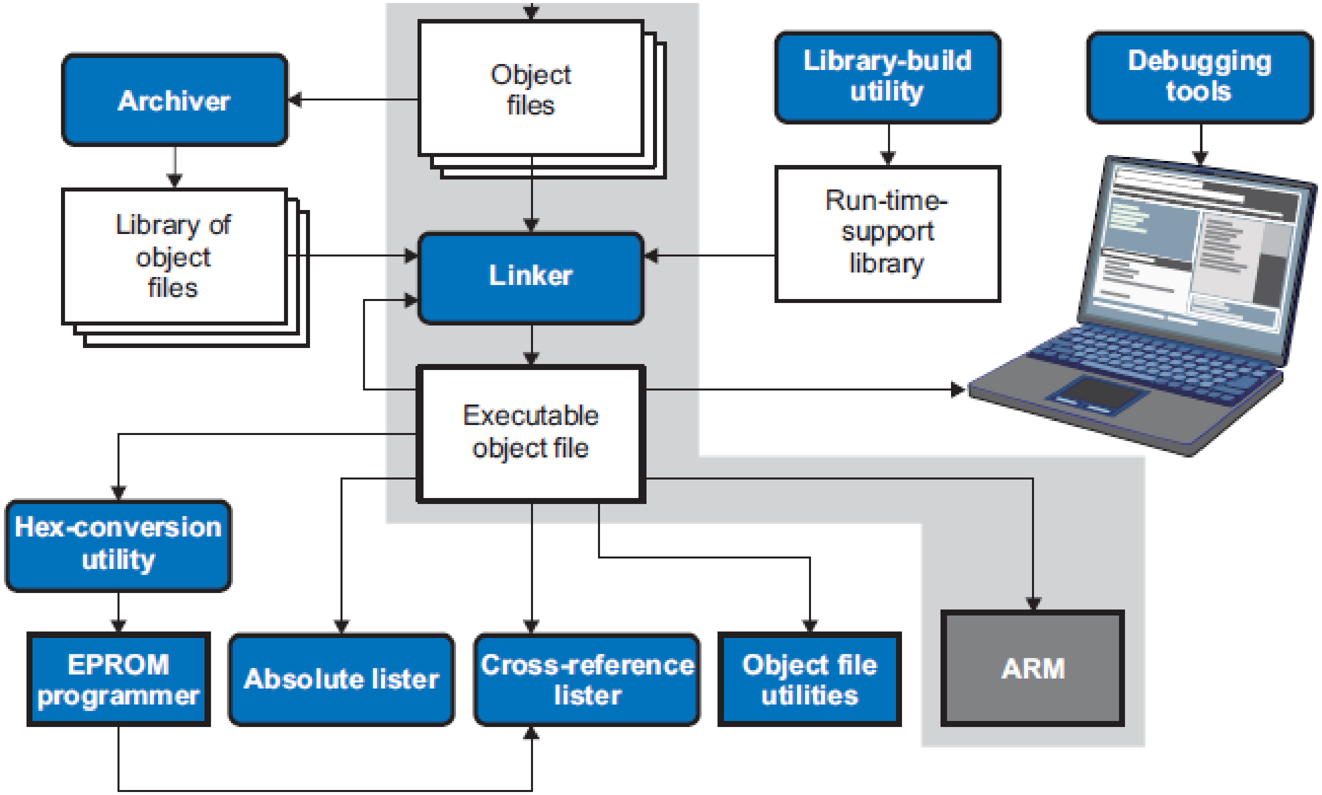
2. ARM Cortex-M C Compiler

- Software development flow for ARM Cortex-M
  - The **compiler** accepts C/C++ source code and produces ARM assembly language source code
  - The **assembler** translates assembly language source files into machine language



2. ARM Cortex-M C Compiler

- The **linker** combines relocatable object files into a single absolute executable object file.
- The **archiver** allows you to collect a group of files into a single archive file, called a library



2. ARM Cortex-M C Compiler

- armcl [options] [filenames] [--run_linker [link_options] object files]]
  - **Armcl:** Command that runs the compiler and the assembler.
  - **Options:** Options that affect the way the compiler processes input files.
  - **Filenames:** One or more C/C++ source files, assembly language source files, or object files.
  - **--run_linker:** Option that invokes the linker. The --run_linker option's short form is -z.
  - **link_options:** Options that control the linking process.
  - **object files:** Name of the additional object files for the linking process.

- Example:
  - armcl symtab.c file.c seek.asm --run_linker --library=lnk.cmd --output_file=myprogram.out

2. ARM Cortex-M C Compiler

- Examples:

armcl *c ; compiles and links

armcl --compile_only *.c ; only compiles

armcl *.c --run_linker lnk.cmd ; compiles and links using a command file

armcl --compile_only *.c --run_linker lnk.cmd

; only compiles (--compile_only overrides --run_linker)

2. ARM Cortex-M C Compiler

- Invoking the Linker Separately

armcl --run_linker {--rom_model | --ram_model} ***filenames***

[*options*] ***[--output_file= name.out] --library= library [lnk.cmd]***

Example:

- armcl --run_linker --rom_model prog1 prog2 prog3 --output_file=prog.out --library=rtsv4_A_be_eabi.lib

3. ARM Software Library

- TI’s ARM Cortex-M microcontroller
  - StellarisWare
  - TivaWare
- ST’s ARM Cortex-M microcontroller
  - ST8 firmware
  - STM32 firmware
- Documents
  - Texas Instruments, “StellarisWare Peripheral Driver Library”, 2013, www.ti.com/stellarisware
  - Texas Instruments, “TivaWare Peripheral Driver Library”, 2013, www.ti.com/tiva-c
  - ST Electronics, “STM32 MCUs Software”, 2013, http://www.st.com/web/en/catalog/tools/FM147/CL1794/SC961

StellarisWare

- an **extensive suite of software** designed to simplify and speed development of Stellaris-based microcontroller applications
- operates with **all LM3S and LM4F series Stellaris MCUs**
- StellarisWare software includes:
  - Stellaris Peripheral Driver Library
  - Stellaris Graphics Library
  - Stellaris USB Library
  - Stellaris Code Examples

TivaWare

- On 15 Apr. 2012, TI recommends that new design should use TivaWare and Tiva family MCUs
- TivaWare for C Series library includes:
  - TivaWare Peripheral Driver Library
  - TivaWare Graphics Library
  - TivaWare USB Library
  - TivaWare IQMath Library

TivaWare™
Software

GPIO

- **GPIO driver:**
  - Driverlib/gpio.c
  - Driverlib/gpio.h
- **Most useful functions:**
  - long **GPIOPinRead**(unsigned long ulPort, unsigned char ucPins)
  - void **GPIOPinWrite**(unsigned long ulPort, unsigned char ucPins, unsigned char ucVal)
- Examples:
  - X = GPIOPINRead(GPIO_PORTF_BASE, GPIO_PIN_0);
  - GPIOPinWrite(GPIO_PORTF_BASE, GPIO_PIN_3| GPIO_PIN_2, 7);

GPIO

- void **GPIODirModeSet**(unsigned long ulPort, unsigned char ucPins, unsigned long ulPinIO)
  - Description: Sets the direction and mode of the specified pin(s).
  - **ulPort** is the base address of the GPIO port
  - **ucPins** is the bit-packed representation of the pin(s).
  - **ulPinIO** is the pin direction and/or mode.
    - GPIO_DIR_MODE_IN: software controlled input
    - GPIO_DIR_MODE_OUT: software controlled output
    - GPIO_DIR_MODE_HW: under hardware control

System Clock

- void **SysCtlClockSet** (unsigned long ulConfig)
  - This function configures the clocking of the device
- ulConfig:
  - **Clock divider:** SYSCTL_SYSDIV_1, SYSCTL_SYSDIV_2, ... SYSCTL_SYSDIV_64
  - **Use of PLL:** SYSCTL_USE_PLL, SYSCTL_USE_OSC
  - **External crystal frequency:** SYSCTL_XTAL_1MHZ, SYSCTL_XTAL_4MHZ, SYSCTL_XTAL_8MHZ,
  - **Oscillator source:** SYSCTL_OSC_MAIN, SYSCTL_OSC_INT
- Examples:
  - SysCtlClockSet(SYSCTL_SYSDIV_4 | SYSCTL_USE_PLL | SYSCTL_XTAL_16MHZ | SYSCTL_OSC_MAIN);

System Clock

- unsigned long **SysCtlClockGet**(void)
  - return the processor clock rate
- void **SysCtlDelay**(unsigned long ulCount)
  - Provides a small delay.
  - **ulCount** is the number of delay loop
  - The loop takes 3 cycles/loop
- Example:
  - SysCtlDelay(SysCtlClockGet() / 10 / 3);

Class Assignment

The following assignments are applied for MCU LM4F120H5QR

1. Write a program to generate a clock signal 0.5Hz at PD0
2. Write a function to read the status of a button with de-bounced capability.
3. Write a program to control 8 single LEDs at port PB. Each LED is ON alternately from LSB LED to MSB LED.
4. Write a program to control 7-segment LED with the control signal A,B,C,D,E,F,G at port PB0 to PB6. The 7-segment LED shows the counted number form 0 to 9 for every 0.5s.
5. Write a function to read a 4x4 matrix keyboard with 16 buttons using key-scanning method.

STM32F4 Library - GPIO

- **GPIO configuration**

GPIO_InitTypeDef GPIO_InitStructure;//Declare a variable **GPIO_InitStructure**

Example 1:

```
GPIO_InitStructure.GPIO_Pin = GPIO_Pin_12 | GPIO_Pin_13| GPIO_Pin_14| GPIO_Pin_15;
GPIO_InitStructure.GPIO_Mode = GPIO_Mode_OUT;
GPIO_InitStructure.GPIO_OType = GPIO_OType_PP;
GPIO_InitStructure.GPIO_Speed = GPIO_Speed_100MHz;
GPIO_InitStructure.GPIO_PuPd = GPIO_PuPd_NOPULL;
GPIO_Init(GPIOD, &GPIO_InitStructure);
```

Example 2:

```
GPIO_InitStructure.GPIO_Pin = GPIO_Pin_All;
GPIO_InitStructure.GPIO_Mode = GPIO_Mode_IN;
GPIO_InitStructure.GPIO_OType = GPIO_OType_PP;
GPIO_InitStructure.GPIO_Speed = GPIO_Speed_50MHz;
GPIO_InitStructure.GPIO_PuPd = GPIO_PuPd_NOPULL;
GPIO_Init(GPIOD, &GPIO_InitStructure);
```

STM32F4 Library - GPIO

- uint8_t **GPIO_ReadInputDataBit**(GPIO_TypeDef* GPIOx, uint16_t GPIO_Pin)
  - GPIO_ReadInputDataBit(GPIOD, GPIO_Pin_12);
- uint16_t **GPIO_ReadInputData**(GPIO_TypeDef* GPIOx)
  - uint16_t D = GPIO_ReadInputData(GPIOD);
- uint8_t **GPIO_ReadOutputDataBit**(GPIO_TypeDef* GPIOx, uint16_t GPIO_Pin)
  - GPIO_ReadOutputDataBit(GPIOD, GPIO_Pin_12);
- uint16_t **GPIO_ReadOutputData**(GPIO_TypeDef* GPIOx)
  - unint16 X = GPIO_ReadOutputData(GPIOD);

STM32F4 Library - GPIO

- void **GPIO_SetBits**(GPIO_TypeDef* GPIOx, uint16_t GPIO_Pin)
  - GPIO_SetBits(GPIOD, GPIO_Pin_12);
  - GPIO_SetBits(GPIOB, GPIO_Pin_13);

- void **GPIO_ResetBits**(GPIO_TypeDef* GPIOx, uint16_t GPIO_Pin)
  - GPIO_ResetBits(GPIOD, GPIO_Pin_12|GPIO_Pin_13);

- void **GPIO_Write**(GPIO_TypeDef* GPIOx, uint16_t PortVal)
  - GPIO_Write(GPIOB, 0x000F);

- void **GPIO_ToggleBits**(GPIO_TypeDef* GPIOx, uint16_t GPIO_Pin)
  - GPIO_ToggleBits(GPIOC, GPIO_Pin_1);

STM32F4 Library - Systick

- uint32_t **SysTickConfig** (uint32_t ticks)
  - SysTick_Config(SystemCoreClock / 1000);
  - Delay(100); //delay 100 ms

```
void Delay(__IO uint32_t nTime)
{   TimingDelay = nTime;
     while(TimingDelay != 0);
}
```

```
void TimingDelay_Decrement(void)
{
  if (TimingDelay != 0x00)
                TimingDelay--;
}
```

```
void SysTick_Handler(void)
{  TimingDelay_Decrement();
}
```

Assignments

The following assignments are applied for MCU STM32F407VGT6

1. Write a program to generate a clock signal 5Hz at PB0, and a clock signal 10Hz at PB1.
2. Write a program to count a 8bit number and display on 8 single LEDs at port PB[7:0].
3. Write a program described as followings:
    1. There are 3 buttons: START, STOP, MODE
    2. 8 single LEDs are controlled by Port B [7:0]
    3. START: display LEDs according to the MODE
    4. STOP: turn off all the LEDS
    5. MODE: change the Mode for LED display
        1. Mode 1: each LED turns ON from LED0 to LED7
        2. Mode 2: each LED turns ON from LED7 to LED0