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TivaC Lab 8 - MPU

CPE 403

Checklist for Lab 8

- ☑ *A text/word document of the initial code with comments*
- ☑ *In the document, for each task submit the modified or included code (only) with highlights and justifications of the modifications. Also include the comments.*
- ☑ *Provide a permanent link to all main and dependent source code files only (name them as LabXX-TYY, XX-Lab# and YY-task#)Screenshots of debugging process along with pictures of actual circuit*
- ☑ *Video link of demonstration.*

Code for Experiment

Task 1:

```
#include <stdint.h>
#include <stdbool.h>
#include "inc/hw_types.h"
#include "inc/hw_memmap.h"
#include "driverlib/sysctl.h"
#include "driverlib/pin_map.h"
#include "driverlib/debug.h"
#include "driverlib/gpio.h"
#include "driverlib/flash.h"     // support for Flash APIs
#include "driverlib/eeprom.h"    // support for EEPROM APIs

int main()
{
        // Buffer for read and write data and to initialize the write data.
        uint32_t pui32Data[2]; // For writing to memory.
        uint32_t pui32Read[2]; // For reading from memory.
        pui32Data[0] = 0x12345678;
        pui32Data[1] = 0x56789abc;

        // Set clock to 40 MHz
        SysCtlClockSet(SYSCTL_SYSDIV_5|SYSCTL_USE_PLL|SYSCTL_XTAL_16MHZ|SYSCTL_OSC_MAIN);

        // Enable GPIO at port F with all pins with value of 0.
        SysCtlPeripheralEnable(SYSCTL_PERIPH_GPIOF);
        GPIOPinTypeGPIOOutput(GPIO_PORTF_BASE, GPIO_PIN_1|GPIO_PIN_2|GPIO_PIN_3);
        GPIOPinWrite(GPIO_PORTF_BASE,GPIO_PIN_1|GPIO_PIN_2|GPIO_PIN_3, 0x00);

        SysCtlDelay(20000000); // Delay

        FlashErase(0x10000); // erase the block of flash starting at 0x10000
        FlashProgram(pui32Data, 0x10000, sizeof(pui32Data)); // Program pui32Data to the start of the
block of length of pui32Data
        GPIOPinWrite(GPIO_PORTF_BASE,GPIO_PIN_1|GPIO_PIN_2|GPIO_PIN_3, 0x02); // Light green LED
        SysCtlDelay(20000000); // Delay

        SysCtlPeripheralEnable(SYSCTL_PERIPH_EEPROM0); // Enable EEPROM peripheral
        EEPROMInit(); // Init EEPROM. Performs revocery if power failed during previous write op.
        EEPROMMassErase(); // unecessary. Erase entire EEPROM.
        EEPROMRead(pui32Read, 0x0, sizeof(pui32Read)); // Read EEPROM from 0 into pui32Read.
        EEPROMProgram(pui32Data, 0x0, sizeof(pui32Data));  // Write pui32Data values to beginning of
EEPROM.
        EEPROMRead(pui32Read, 0x0, sizeof(pui32Read)); // Read values that were just written.
        // Turn off red LED, turn on blue LED
        GPIOPinWrite(GPIO_PORTF_BASE,GPIO_PIN_1|GPIO_PIN_2|GPIO_PIN_3, 0x04);

        while(1);

}
```

Bitband example

```
#include <stdint.h>
#include <stdbool.h>
#include "inc/hw_memmap.h"
#include "inc/hw_types.h"
#include "driverlib/debug.h"
#include "driverlib/gpio.h"
#include "driverlib/fpu.h"
#include "driverlib/pin_map.h"
#include "driverlib/sysctl.h"
#include "driverlib/systick.h"
#include "driverlib/rom.h"
#include "driverlib/uart.h"
#include "utils/uartstdio.h"

//*****************************************************************************
//
//! \addtogroup example_list
//! <h1>Bit-Banding (bitband)</h1>
//!
//! This example application demonstrates the use of the bit-banding
//! capabilities of the Cortex-M4F microprocessor.  All of SRAM and all of the
//! peripherals reside within bit-band regions, meaning that bit-banding
//! operations can be applied to any of them.  In this example, a variable in
//! SRAM is set to a particular value one bit at a time using bit-banding
//! operations (it would be more efficient to do a single non-bit-banded write;
//! this simply demonstrates the operation of bit-banding).
//*****************************************************************************


//*****************************************************************************
// The value that is to be modified via bit-banding.
//*****************************************************************************
static volatile uint32_t g_ui32Value;

//*****************************************************************************
// The error routine that is called if the driver library encounters an error.
//*****************************************************************************
#ifdef DEBUG
void
__error__(char *pcFilename, uint32_t ui32Line)
{
    while(1); // Hang on runtime error.
}
#endif

//*****************************************************************************
// Delay for the specified number of seconds.  Depending upon the current
// SysTick value, the delay will be between N-1 and N seconds (i.e. N-1 full
// seconds are guaranteed, along with the remainder of the current second).
//*****************************************************************************
void
Delay(uint32_t ui32Seconds)
{
    // Loop while there are more seconds to wait.
    while(ui32Seconds--)
    {
        // Wait until the SysTick value is less than 1000.
        while(ROM_SysTickValueGet() > 1000);
        // Wait until the SysTick value is greater than 1000.
        while(ROM_SysTickValueGet() < 1000);
    }
}

//*****************************************************************************
// Configure the UART and its pins.  This must be called before UARTprintf().
//*****************************************************************************
void
ConfigureUART(void)
{
    // Enable the GPIO Peripheral used by the UART.
    ROM_SysCtlPeripheralEnable(SYSCTL_PERIPH_GPIOA);

    // Enable UART0
    ROM_SysCtlPeripheralEnable(SYSCTL_PERIPH_UART0);

    // Configure GPIO Pins for UART mode.
    ROM_GPIOPinConfigure(GPIO_PA0_U0RX);
    ROM_GPIOPinConfigure(GPIO_PA1_U0TX);
    ROM_GPIOPinTypeUART(GPIO_PORTA_BASE, GPIO_PIN_0 | GPIO_PIN_1);

    // Use the internal 16MHz oscillator as the UART clock source.
    UARTClockSourceSet(UART0_BASE, UART_CLOCK_PIOSC);

    // Initialize the UART for console I/O.
    UARTStdioConfig(0, 115200, 16000000);
}

//*****************************************************************************
// This example demonstrates the use of bit-banding to set individual bits
// within a word of SRAM.
//*****************************************************************************
int
main(void)
{
    uint32_t ui32Errors, ui32Idx;

    // Enable lazy stacking for interrupt handlers.  This allows floating-point
    // instructions to be used within interrupt handlers, but at the expense of
    // extra stack usage.
    ROM_FPULazyStackingEnable();

    // Set the clocking to run directly from the crystal.
    ROM_SysCtlClockSet(SYSCTL_SYSDIV_1 | SYSCTL_USE_OSC | SYSCTL_OSC_MAIN |
                       SYSCTL_XTAL_16MHZ);

    // Initialize the UART interface.
    ConfigureUART();

    UARTprintf("\033[2JBit banding...\n");

    // Set up and enable the SysTick timer.  It will be used as a reference
    // for delay loops.  The SysTick timer period will be set up for one
    // second.
    ROM_SysTickPeriodSet(ROM_SysCtlClockGet());
    ROM_SysTickEnable();

    // Set the value and error count to zero.
    g_ui32Value = 0;
    ui32Errors = 0;

    // Print the initial value to the UART.
    UARTprintf("\r%08x", g_ui32Value);

    // Delay for 1 second.
    Delay(1);

    // Set the value to 0xdecafbad using bit band accesses to each individual bit.
    for(ui32Idx = 0; ui32Idx < 32; ui32Idx++)
    {
        // Set this bit.
        HWREGBITW(&g_ui32Value, 31 - ui32Idx) = (0xdecafbad >>
                                                 (31 - ui32Idx)) & 1;

        // Print the current value to the UART.
        UARTprintf("\r%08x", g_ui32Value);

        // Delay for 1 second.
        Delay(1);
    }

    // Make sure that the value is 0xdecafbad.
    if(g_ui32Value != 0xdecafbad)
    {
        ui32Errors++;
    }

    // Make sure that the individual bits read back correctly.
    for(ui32Idx = 0; ui32Idx < 32; ui32Idx++)
    {
        if(HWREGBITW(&g_ui32Value, ui32Idx) != ((0xdecafbad >> ui32Idx) & 1))
        {
            ui32Errors++;
        }
    }

    // Print out the result.
    if(ui32Errors)
    {
        UARTprintf("\nErrors!\n");
    }
    else
    {
        UARTprintf("\nSuccess!\n");
    }

    while(1);
}
```

MPU Fault Ex:

```
#include <stdbool.h>
#include <stdint.h>
#include "inc/hw_ints.h"
#include "inc/hw_memmap.h"
#include "inc/hw_nvic.h"
#include "inc/hw_types.h"
#include "driverlib/debug.h"
#include "driverlib/fpu.h"
#include "driverlib/gpio.h"
#include "driverlib/interrupt.h"
#include "driverlib/mpu.h"
#include "driverlib/pin_map.h"
#include "driverlib/rom.h"
#include "driverlib/sysctl.h"
#include "driverlib/uart.h"
#include "utils/uartstdio.h"

//*****************************************************************************
//
//! \addtogroup example_list
//! <h1>MPU (mpu_fault)</h1>
//!
//! This example application demonstrates the use of the MPU to protect a
//! region of memory from access, and to generate a memory management fault
//! when there is an access violation.
//!
//! UART0, connected to the virtual serial port and running at 115,200, 8-N-1,
//! is used to display messages from this application.
//
//*****************************************************************************


//*****************************************************************************
// Variables to hold the state of the fault status when the fault occurs and
// the faulting address.
//*****************************************************************************
static volatile uint32_t g_ui32MMAR;
static volatile uint32_t g_ui32FaultStatus;

//*****************************************************************************
// A counter to track the number of times the fault handler has been entered.
//*****************************************************************************
static volatile uint32_t g_ui32MPUFaultCount;

//*****************************************************************************
// A location for storing data read from various addresses.  Volatile forces
// the compiler to use it and not optimize the access away.
//*****************************************************************************
static volatile uint32_t g_ui32Value;

//*****************************************************************************
// The error routine that is called if the driver library encounters an error.
//*****************************************************************************
#ifdef DEBUG
void
__error__(char *pcFilename, uint32_t ui32Line)
{
}
#endif
```

```
//*****************************************************************************
//
// The exception handler for memory management faults, which are caused by MPU
// access violations.  This handler will verify the cause of the fault and
// clear the NVIC fault status register.
//
//*****************************************************************************
void
MPUFaultHandler(void)
{
    // Preserve the value of the MMAR (the address causing the fault).
    // Preserve the fault status register value, then clear it.
    g_ui32MMAR = HWREG(NVIC_MM_ADDR);
    g_ui32FaultStatus = HWREG(NVIC_FAULT_STAT);
    HWREG(NVIC_FAULT_STAT) = g_ui32FaultStatus;

    // Increment a counter to indicate the fault occurred.
    g_ui32MPUFaultCount++;

    // Disable the MPU so that this handler can return and cause no more
    // faults.  The actual instruction that faulted will be re-executed.
    ROM_MPUDisable();
}

//*****************************************************************************
//
// Configure the UART and its pins.  This must be called before UARTprintf().
//
//*****************************************************************************
void
ConfigureUART(void)
{
    // Enable the GPIO Peripheral used by the UART.
    ROM_SysCtlPeripheralEnable(SYSCTL_PERIPH_GPIOA);

    // Enable UART0
    ROM_SysCtlPeripheralEnable(SYSCTL_PERIPH_UART0);

    // Configure GPIO Pins for UART mode.
    ROM_GPIOPinConfigure(GPIO_PA0_U0RX);
    ROM_GPIOPinConfigure(GPIO_PA1_U0TX);
    ROM_GPIOPinTypeUART(GPIO_PORTA_BASE, GPIO_PIN_0 | GPIO_PIN_1);

    // Use the internal 16MHz oscillator as the UART clock source.
    UARTClockSourceSet(UART0_BASE, UART_CLOCK_PIOSC);

    // Initialize the UART for console I/O.
    UARTStdioConfig(0, 115200, 16000000);
}

//*****************************************************************************
//
// This example demonstrates how to configure MPU regions for different levels
// of memory protection.  The following memory map is set up:
//
// 0000.0000 - 0000.1C00 - rgn 0: executable read-only, flash
// 0000.1C00 - 0000.2000 - rgn 0: no access, flash (disabled sub-region 7)
// 2000.0000 - 2000.4000 - rgn 1: read-write, RAM
// 2000.4000 - 2000.6000 - rgn 2: read-only, RAM (disabled sub-rgn 4 of rgn 1)
// 2000.6000 - 2000.7FFF - rgn 1: read-write, RAM
// 4000.0000 - 4001.0000 - rgn 3: read-write, peripherals
// 4001.0000 - 4002.0000 - rgn 3: no access (disabled sub-region 1)
// 4002.0000 - 4006.0000 - rgn 3: read-write, peripherals
// 4006.0000 - 4008.0000 - rgn 3: no access (disabled sub-region 6, 7)
// E000.E000 - E000.F000 - rgn 4: read-write, NVIC
// 0100.0000 - 0100.FFFF - rgn 5: executable read-only, ROM
//
// The example code will attempt to perform the following operations and check
// the faulting behavior:
//
// - write to flash                         (should fault)
// - read from the disabled area of flash   (should fault)
// - read from the read-only area of RAM    (should not fault)
// - write to the read-only section of RAM  (should fault)
//
//*****************************************************************************
int
main(void)
{
    unsigned int bFail = 0;

    // Enable lazy stacking for interrupt handlers.  This allows floating-point
    // instructions to be used within interrupt handlers, but at the expense of
    // extra stack usage.
    ROM_FPULazyStackingEnable();

    // Set the clocking to run directly from the crystal.
    ROM_SysCtlClockSet(SYSCTL_SYSDIV_1 | SYSCTL_USE_OSC | SYSCTL_OSC_MAIN |
                       SYSCTL_XTAL_16MHZ);

    // Initialize the UART and write status.
    ConfigureUART();

    UARTprintf("\033[2JMPU example\n");

    // Configure an executable, read-only MPU region for flash.  It is a 16 KB
    // region with the last 2 KB disabled to result in a 14 KB executable
    // region.  This region is needed so that the program can execute from
    // flash.
    ROM_MPURegionSet(0, FLASH_BASE,
                     MPU_RGN_SIZE_16K | MPU_RGN_PERM_EXEC |
                     MPU_RGN_PERM_PRV_RO_USR_RO | MPU_SUB_RGN_DISABLE_7 |
                     MPU_RGN_ENABLE);

    // Configure a read-write MPU region for RAM.  It is a 32 KB region.  There
    // is a 4 KB sub-region in the middle that is disabled in order to open up
    // a hole in which different permissions can be applied.
    ROM_MPURegionSet(1, SRAM_BASE,
                     MPU_RGN_SIZE_32K | MPU_RGN_PERM_NOEXEC |
                     MPU_RGN_PERM_PRV_RW_USR_RW | MPU_SUB_RGN_DISABLE_4 |
                     MPU_RGN_ENABLE);

    // Configure a read-only MPU region for the 4 KB of RAM that is disabled in
    // the previous region.  This region is used for demonstrating read-only
    // permissions.
    ROM_MPURegionSet(2, SRAM_BASE + 0x4000,
                     MPU_RGN_SIZE_2K | MPU_RGN_PERM_NOEXEC |
                     MPU_RGN_PERM_PRV_RO_USR_RO | MPU_RGN_ENABLE);

    // Configure a read-write MPU region for peripherals.  The region is 512 KB
    // total size, with several sub-regions disabled to prevent access to areas
    // where there are no peripherals.  This region is needed because the
    // program needs access to some peripherals.
    ROM_MPURegionSet(3, 0x40000000,
                     MPU_RGN_SIZE_512K | MPU_RGN_PERM_NOEXEC |
                     MPU_RGN_PERM_PRV_RW_USR_RW | MPU_SUB_RGN_DISABLE_1 |
                     MPU_SUB_RGN_DISABLE_6 | MPU_SUB_RGN_DISABLE_7 |
                     MPU_RGN_ENABLE);

    // Configure a read-write MPU region for access to the NVIC.  The region is
    // 4 KB in size.  This region is needed because NVIC registers are needed
    // in order to control the MPU.
    ROM_MPURegionSet(4, NVIC_BASE,
                     MPU_RGN_SIZE_4K | MPU_RGN_PERM_NOEXEC |
                     MPU_RGN_PERM_PRV_RW_USR_RW | MPU_RGN_ENABLE);

    // Configure an executable, read-only MPU region for ROM.  It is a 64 KB
    // region.  This region is needed so that ROM library calls work.
    ROM_MPURegionSet(5, (uint32_t)ROM_APITABLE & 0xFFFF0000,
                     MPU_RGN_SIZE_64K | MPU_RGN_PERM_EXEC |
                     MPU_RGN_PERM_PRV_RO_USR_RO | MPU_RGN_ENABLE);

    // Need to clear the NVIC fault status register to make sure there is no
    // status hanging around from a previous program.
    g_ui32FaultStatus = HWREG(NVIC_FAULT_STAT);
    HWREG(NVIC_FAULT_STAT) = g_ui32FaultStatus;

    // Enable the MPU fault.
    ROM_IntEnable(FAULT_MPU);

    // Enable the MPU.  This will begin to enforce the memory protection
    // regions.  The MPU is configured so that when in the hard fault or NMI
    // exceptions, a default map will be used.  Neither of these should occur
    // in this example program.
    ROM_MPUEnable(MPU_CONFIG_HARDFLT_NMI);

    // Attempt to write to the flash.  This should cause a protection fault due
    // to the fact that this region is read-only.
    UARTprintf("Flash write... ");
    g_ui32MPUFaultCount = 0;
    HWREG(0x100) = 0x12345678;

    // Verify that the fault occurred, at the expected address.
    if((g_ui32MPUFaultCount == 1) && (g_ui32FaultStatus == 0x82) &&
       (g_ui32MMAR == 0x100))
    {
        UARTprintf(" OK\n");
    }
    else
    {
        bFail = 1;
        UARTprintf("NOK\n");
    }

    // The MPU was disabled when the previous fault occurred, so it needs to be
    // re-enabled.
    ROM_MPUEnable(MPU_CONFIG_HARDFLT_NMI);

    // Attempt to read from the disabled section of flash, the upper 2 KB of
    // the 16 KB region.
    UARTprintf("Flash read... ");
    g_ui32MPUFaultCount = 0;
```

```
g_ui32Value = HWREG(0x3820);

// Verify that the fault occurred, at the expected address.
if((g_ui32MPUFaultCount == 1) && (g_ui32FaultStatus == 0x82) &&
   (g_ui32MMAR == 0x3820))
{
    UARTprintf(" OK\n");
}
else
{
    bFail = 1;
    UARTprintf("NOK\n");
}

// The MPU was disabled when the previous fault occurred, so it needs to be
// re-enabled.
ROM_MPUEnable(MPU_CONFIG_HARDFLT_NMI);

// Attempt to read from the read-only area of RAM, the middle 4 KB of the
// 32 KB region.
UARTprintf("RAM read... ");
g_ui32MPUFaultCount = 0;
g_ui32Value = HWREG(0x20004440);

// Verify that the RAM read did not cause a fault.
if(g_ui32MPUFaultCount == 0)
{
    UARTprintf(" OK\n");
}
else
{
    bFail = 1;
    UARTprintf("NOK\n");
}

// The MPU should not have been disabled since the last access was not
// supposed to cause a fault.  But if it did cause a fault, then the MPU
// will be disabled, so re-enable it here anyway, just in case.
ROM_MPUEnable(MPU_CONFIG_HARDFLT_NMI);

// Attempt to write to the read-only area of RAM, the middle 4 KB of the
// 32 KB region.
UARTprintf("RAM write... ");
g_ui32MPUFaultCount = 0;
HWREG(0x20004460) = 0xabcdef00;

//
// Verify that the RAM write caused a fault.
//
if((g_ui32MPUFaultCount == 1) && (g_ui32FaultStatus == 0x82) &&
   (g_ui32MMAR == 0x20004460))
{
    UARTprintf(" OK\n");
}
else
{
    bFail = 1;
    UARTprintf("NOK\n");
}

//
```

```
    // Display the results of the example program.
    //
    if(bFail)
    {
        UARTprintf("Failure!\n");
    }
    else
    {
        UARTprintf("Success!\n");
    }

    // Disable the MPU, so there are no lingering side effects if another
    // program is run.
    ROM_MPUDisable();

    // Loop forever.
    while(1);
}
```

<u>Video Link to Demo</u>

NONE