Computer Hardware Engineering (IS1200)
Computer Organization and Components (IS1500)

Spring 2018

Lecture 6: I/O Systems, part II

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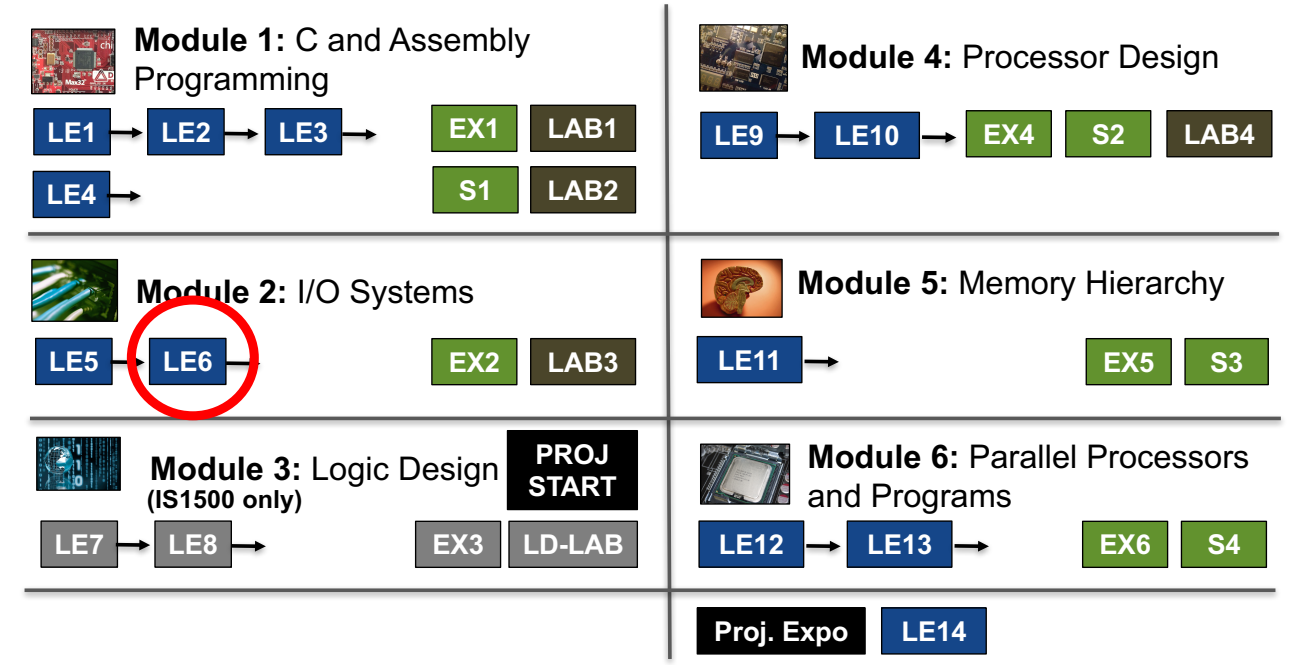
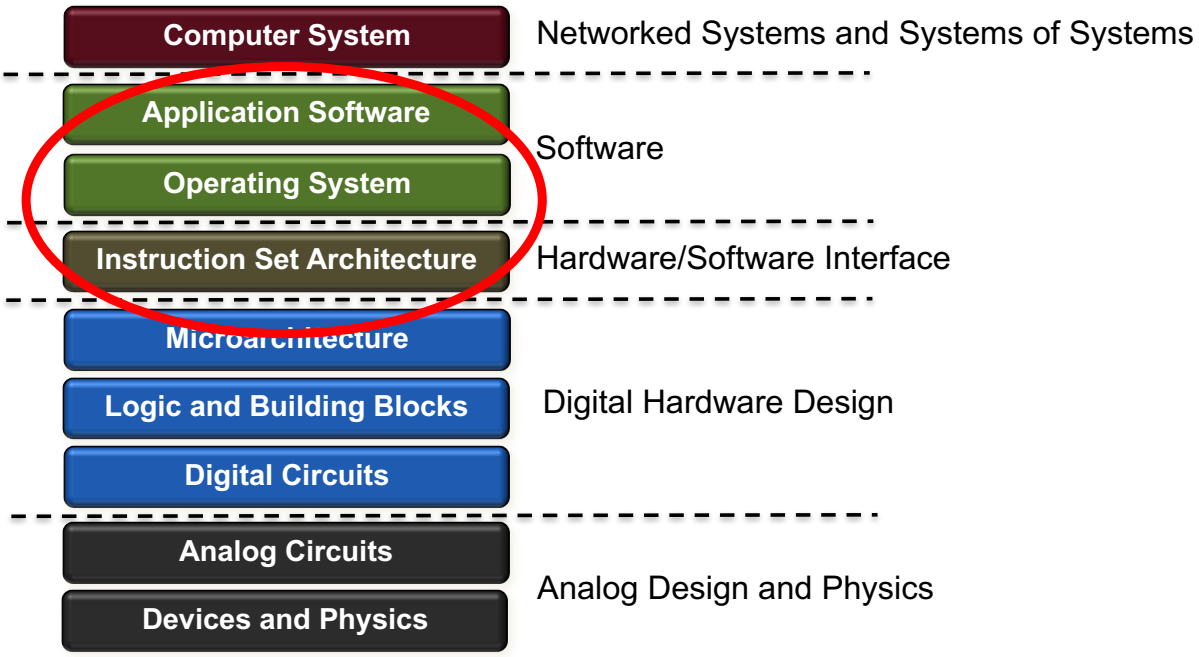
Slides version 1.1

Course Structure



Abstractions in Computer Systems



Agenda

Part I

Timers

Part II

Parallel and Serial Communication

Part III

Exceptions and Interrupts

Part IV

Mini Project

Part I

Timers

Acknowledgement: The structure and several of the good examples are derived from the book "Digital Design and Computer Architecture" (2013) by D. M. Harris and S. L. Harris.

Timers

Timers are I/O devices that are used to measure elapsed time.

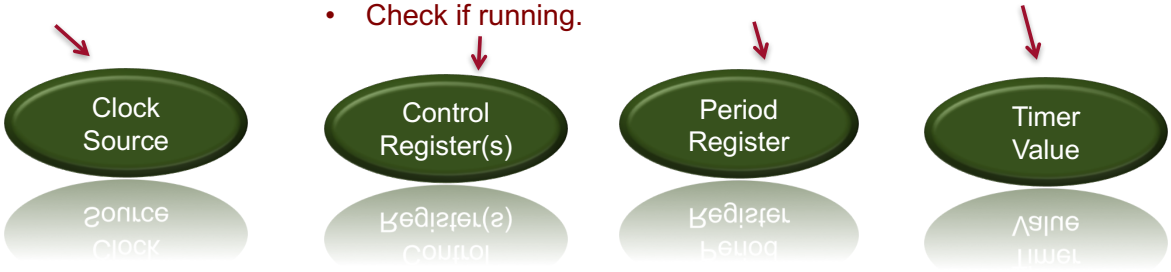
Timers can be configured in different ways, but have basically the following components.

A timer is driven by a **clock source**. Example, 50Mhz external clock.

- Tells if time-out is reached.
- Stop/start counting
- Check if running.

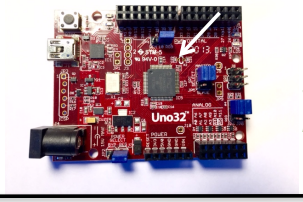
Write registers, states the period

Read/write register. A "snap-shot" of the timer value.



PIC32 Timers – Searching for information

On the ChipKIT Uno32 board, we have a **PIC32MX320F128H** processor.



How can we find this information?

See the ***chipKIT Uno32 Board reference manual***. Here called [UNO32 ref].

This processor has five 16-bit timers.

How can we find this information?

See the **PIC32MX3XX/4XX Family Data Sheet**. Here called [PIC32MX ref].

The PIC32 processor has two types of timers:

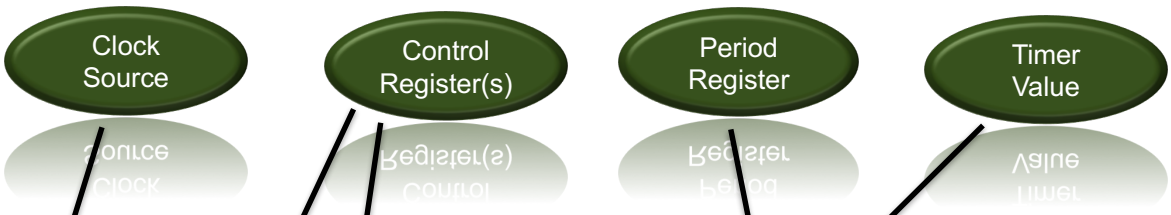
- **Type A timers (Timer 1):**
  Can operate on an external clock
- **Type B timers (Timers #2-5):**
  Can be combined to form 32-bit timers.
  Runs with the peripheral clock.

How can we find this information?

See the **PIC32 Family Reference Manual, Section 14. Timers**.
Here called [PIC32Family ref, Sec 14].

See the course web, page "Literature & Resources" for links.

PIC32 Timers



Timer 2 (that we will use) operates at 80 MHz.

TxCON (x is the timer number)

- 16-bit control register.
- Configures the prescaling
- Start/stops the timer

TMRx (x is the timer number)

- Holds the current 16-bit timer value
- May be written to.

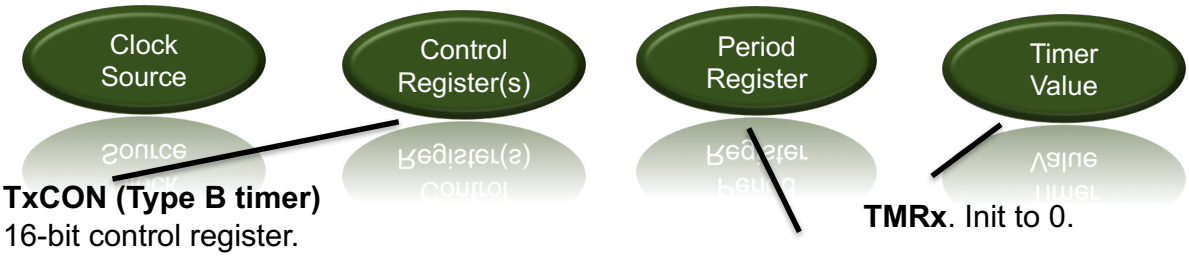
IFS0

- Interrupt register indicating when the counter has reached the period value.
- Note that the define in pic32mx.h is **IFS(0)** and not **IFS0**.

PRx (x is the timer number)

- The period register.
- TMRx counts upwards until reaching this value.

PIC32 Timers – Initialization (1/2)



TxCON (Type B timer)
16-bit control register.

- 3 bits called TCKPS configures the prescaling. Options: 1:256, 1:64, 1:32, 1:16, 1:8, 1:4, 1:2, 1:1
- 1 bit to start/stops the timer
- 1 bit for timer clock source select (TCS). Use 0 for internal peripheral clock
- 1 bit for timer mode (connect 2 timers to form a 32-bit timer). Use 0 for 16-bit timer.

For details on the bit layout, see
[PIC32Family ref, Sec 14, Page 14-9]

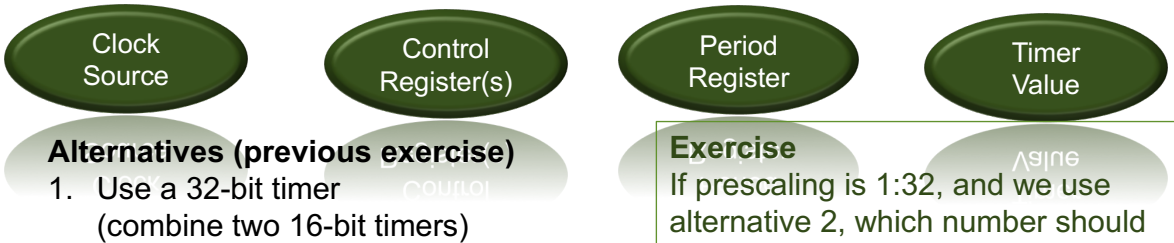
TMRx. Init to 0.

PRx The period register (16-bit)

Exercise
What should PR2 (timer 2) be initiated to, if we want the period to be 1 second and we assume that the clock is 80 MHz?

Solution: Not possible for a 16-bit timer.
80 000 000/256 = 312 500.
Cannot fit a 16-bit timer.

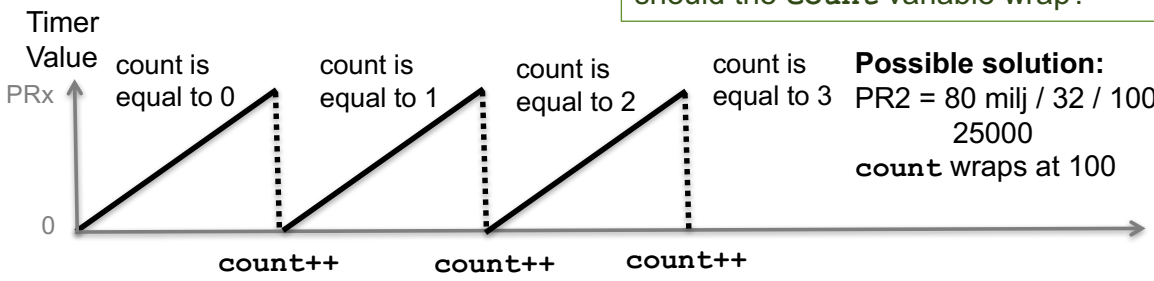
PIC32 Timers – Initialization (2/2)



Alternatives (previous exercise)

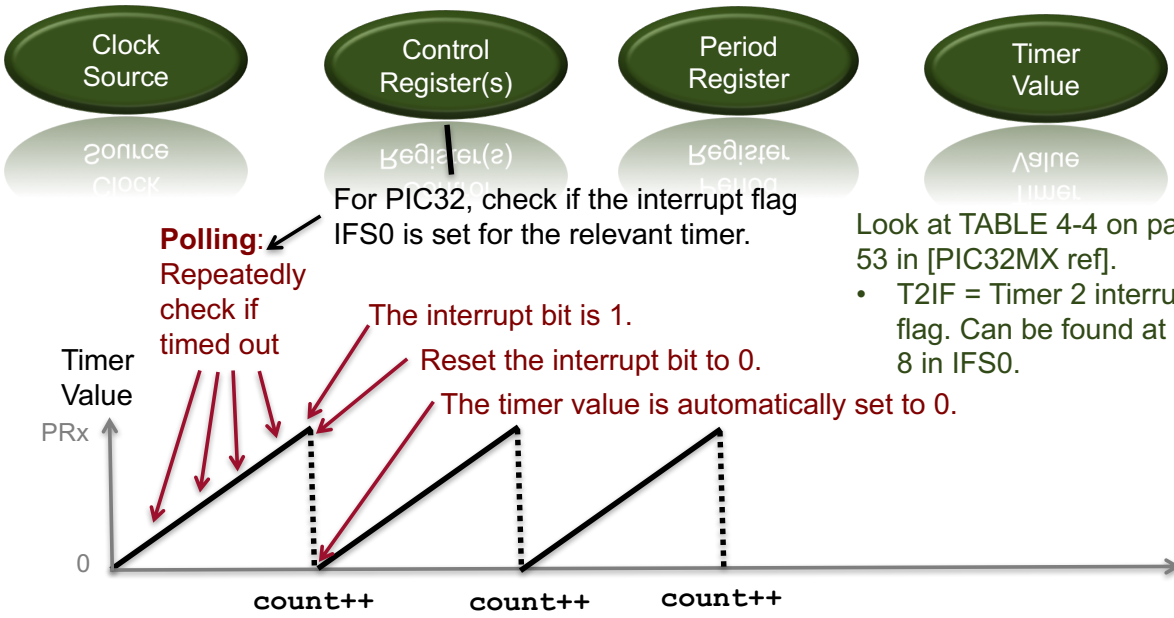
1. Use a 32-bit timer (combine two 16-bit timers)
2. or, add another counter in the program.
   `int count = 0;`

Exercise
If prescaling is 1:32, and we use alternative 2, which number should then PR2 have if we want the software counter to wrap after 1 second? When should the `count` variable wrap?



Possible solution:
PR2 = 80 milj / 32 / 100 = 25000
`count` wraps at 100

PIC32 Timers – Polling

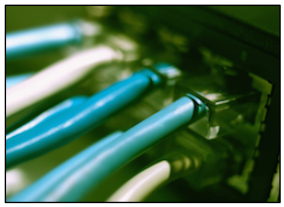


Look at TABLE 4-4 on page 53 in [PIC32MX ref].

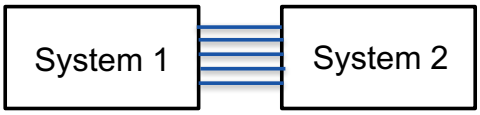
- T2IF = Timer 2 interrupt flag. Can be found at bit 8 in IFS0.

Part II

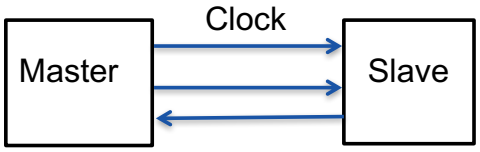
Parallel and Serial Communication



Parallel vs. Serial Communication



Parallel Communication
Several wires that transmits data in parallel.
Problem: Requires many cables



Synchronous Serial Communication
Examples:
Serial Peripheral Interface (SPI)
- Full duplex
- 4 wires, fast transfers, (10-100 MHz)

I²C (Inter-integrated circuit)
- Two lines: Serial Data Line (SDL) and Serial Clock Line (SCL)
- 7 or 10 bits addresses. (Fast mode 400kHz)

Asynchronous Serial Communication
Example: **UART (pronounced "you-art")**

PC I/O Systems

- Demand for very high **performance**.
- Must be easy to **add devices**.

Consequence: complex I/O protocols

Peripheral Component Interconnect (PCI)
- Used for adding expansion cards (from 1994)
- For example, Ethernet directly on the motherboard.

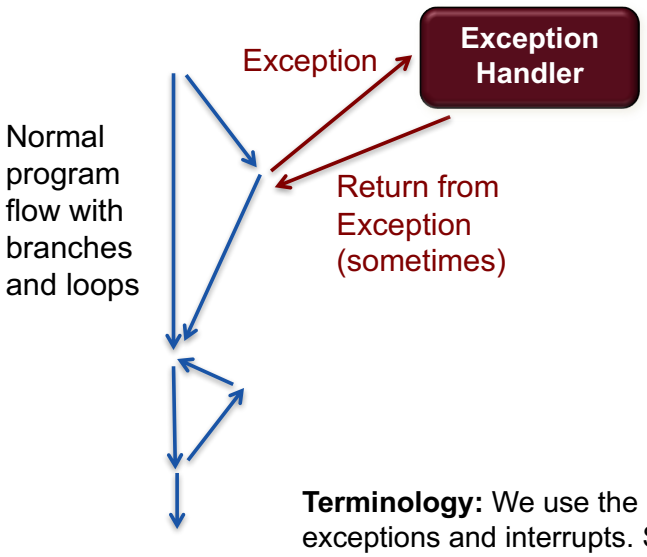
Universal Serial Bus (USB)
- Taking over. High speed serial communication.
- Versions 1.0 to 3.0. Up to 5Gb/s.
- Simple for users, complex hardware and software.

Other Devices
- Ethernet (Wired networking)
- Wi-Fi (Wireless communication)
- SATA (Serial interface to hard disks)

Part III

Exceptions and Interrupts

Exceptions and Interrupts



Causes of Exceptions

- **Error conditions.** For instance division by zero, unknown instruction etc.
- **Interrupts.** External interrupt, e.g., keyboard event.
- **Software Interrupts (also called traps).** For instance system calls (from user to supervisory mode).

Terminology: We use the MIPS terminology to differentiate between exceptions and interrupts. Some authors use the term interrupts for everything (e.g. used in x86 terminology).

Exception Handling in MIPS (general description)

In MIPS, the exception handler is located at address 0x80000180.

Exception handling step-by-step procedure

1. The processor stores the current PC in a register called **EPC**.
2. The processor stores the cause of the exception in register called **Cause**.
3. The processor jumps to address 0x80000180 where the exception handler is stored.
4. The exception handler saves registers on the stack.
5. The exception handler inspects the cause of the exception and handles the exception. EPC and Cause are not normal register. They are accessed using instruction **mfc0** (move from coprocessor 0).
6. The exception handler restores saved registers, copies the return program pointer EPC to $k0, and jumps back using `jr $k0`. Alternatively, for MIPS32, use the **eret** instruction.

Exception Vectors and the ARM ISA

In ARM, the cause of the exception is shown by jumping to different exception handlers, depending on the cause. This is called an **exception vector.**

The vector will normally contain jumps to where the actual handler is stored.

Exception	Vector address
Reset	0x0000 0000
Undefined instruction	0x0000 0004
Software Interrupt (SWI)	0x0000 0008
Prefetch abort	0x0000 000C
Data abort	0x0000 0010
IRQ (normal interrupt)	0x0000 0018
FIQ (fast interrupt)	0x0000 001C

PIC32 can be configured to use either single vector (with cause register) or multi-vector mode.

Maskable Interrupts and Priorities

External interrupts may be enabled (allowed) or disabled. This is typically configured by using an interrupt flag status register.

Interrupts can be given different **priorities.** An interrupt with higher priority will **preempt** a lower priority interrupt.

For instance, a timer might have higher priority than the UART and will preempt the UART handling routine.

Non-maskable interrupts are interrupts that cannot be masked (disabled). Typically involved non-recoverable hardware errors.

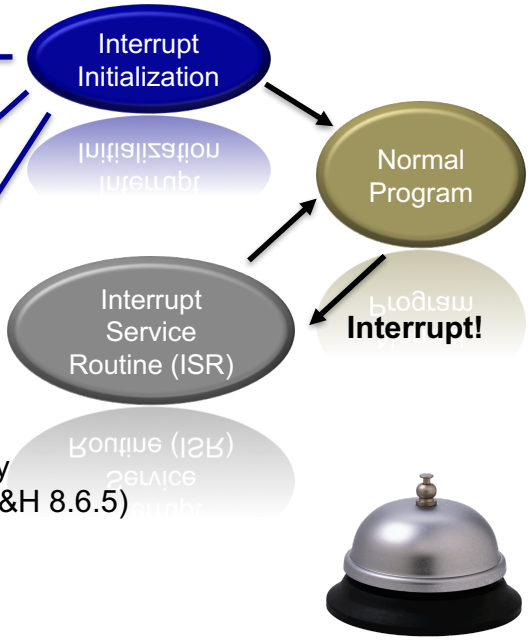
PIC32 Interrupts - Initialization

IECx (Interrupt Enable Control)
- The initialization procedure should set the bit for the interrupt that should be enabled.

IPCx (Interrupt Priority Control)
- Configure the priority (0-7, where 7 is highest) and the sub-priority (0-3 where 3 is highest).

Enable Interrupts
You need to enable interrupts by executing instruction `ei` (See H&H 8.6.5)

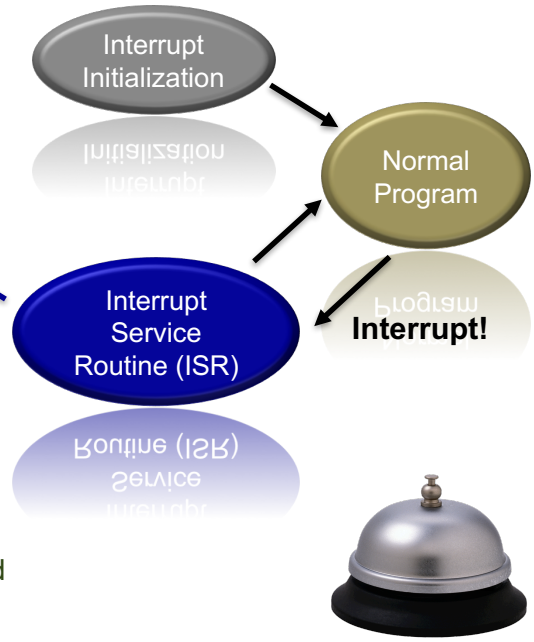
The x means that there exist several registers, e.g. IPC0, IPC1, etc. Note that for pic32mx.h, the syntax is e.g., IPC(1).



PIC32 Interrupts – Interrupt Execution

IFSx (Interrupt Flag Status Register)

- The interrupt request sets the bit (e.g. for a timer at timeout).
- The ISR must clear the flag before returning from the ISR.

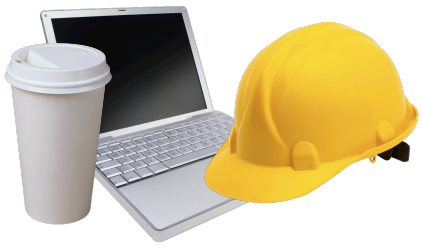


The relevant bits for IECx, IPCx, and IFSx can be found in TABLE 4-4 on page 53 in [PIC32MX ref] or on page 90 (table).

Advice for lab 3. Use the above and find: i) T2IF (for timer 2 interrupt flag), ii) T2IE (for timer 2 interrupt enable), iii) T2IP for priority, and iv) T2IS for sub priority. Set highest priorities.

Part IV

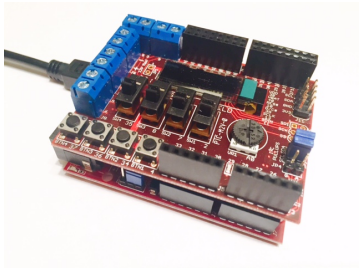
Mini Project



Mini Project

Groups

- Preferably, you work in the same group as you do with the labs (1-2 students).
- Student groups may communicate, e.g., connect hardware using UART.



Equipment

- You must use the PIC32 platform supplied by the course.
- You may extend this platform in any way you want (Arduino shields, custom electronics, communication with computer...)
- You may use the MCB32 tool chain **or** the MPLAB X IDE, but **not** the MPIDE (a ported Arduino IDE)
- Use a version handling system, such as SVN or Git (recommended).

Mini Project

Shields and Electronics

You may (optionally) extend your project with electronics. Check out the following for inspiration:
http://www.instructables.com/id/Arduino-Projects/

KTH cannot supply more hardware than the boards. If you want to buy e.g. shields, check out:

- Kjell & Company: www.kjell.se
- ELFA: www.elfa.se
- Electrokit: www.electrokit.se
- Or international delivery, e.g. www.aliexpress.com or www.ebay.co.uk

Search for e.g., “arduino sensors” or “picKIT”

Mini Project

What kind of project?

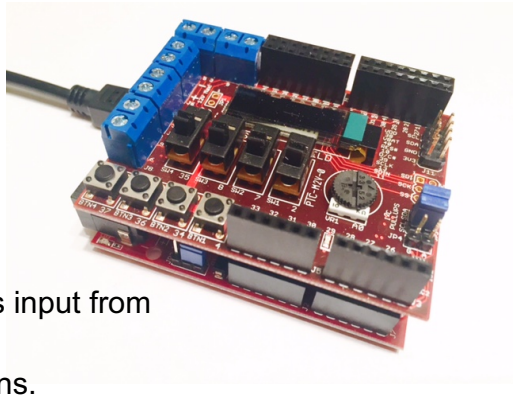
It is very flexible and it is up to you what you want to do. Examples:

- Make a game (snake, Tetris, ping/pong, Othello etc.)
- Use serial communication or WIFI. Solve a problem.
- Use sensors such as temperature sensor (available on the I/O board), accelerometer etc.
- Do something with sound (add microphone or speaker). Play with A/D (built in) and alternative ways for analog output (see H&H section 8.6.6)
- …

Mini Project – Requirements

Basic Project

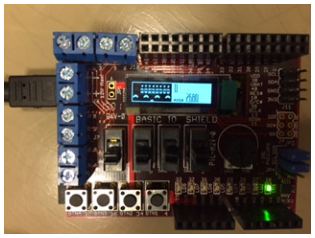
- Should use some other device/component besides the LEDs, switches, and push buttons on the board (e.g. display, temperature sensor etc.)
- Should be non-trivial and actual perform something. Should make use of timers and/or interrupts.

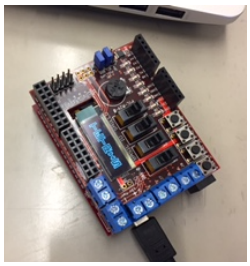
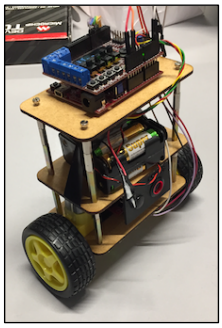


Not qualified as a project

- A program with very simple logic that just reads input from the buttons and displays some text.
- An implementation with a lot of code duplications.
  In general, if you start to copy and duplicate your own code, then you are doing something that is not very good.

Mini Project – Requirements



Advanced project

Requirements for getting a final grade A or B. The main categories:

1. Use external components in a complex manner by using specific protocols: SPI, I²C, or or another non-trivial protocol (please check with David). UART is not counted as advanced.
2. Sophisticated graphics on the screen (see examples on the next pages).
3. Advanced interaction with sound (see examples on the next pages).

Besides the above, the program logic must be rather complex. It must clearly show that the project required some substantial development effort.

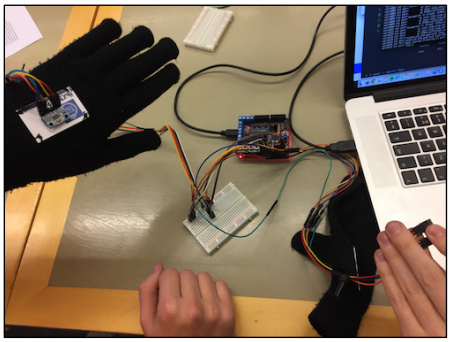
Examples – Advanced projects

Category 1 – Advanced protocols

Requirement: Make use of SPI, I2C or other advanced protocols.

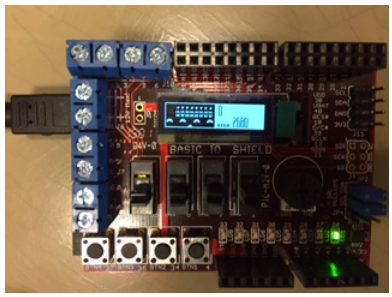
Example 1: A program that is using external accelerometers, which communicate using I2C. The application shows a non trivial C program (e.g., a simple snake game).

Example 2: A program that is using an external display, which is communicating over SPI. The program itself is non trivial, with different modes, menus, user interactions etc.



Examples – Advanced projects

Category 2 – Advanced graphics on the basic I/O shield's OLED display



Requirement: Pixel-by-pixel movements of objects that are larger than 2x2 pixels. The objects move smoothly 1 pixel at each frame update, both in X and Y directions.

Example 1: A pong game where the ball is 3x3 pixels, and moves according to the pixel-by-pixel requirement. The game supports several advanced features, such as 2 player mode, 1 player mode (simple AI for the computer player), different difficulty levels, high score, and more.

Note that simple games like Pong, Snake, Tetris etc. need to fulfil the pixel-by-pixel requirement above **and** support advanced features such as different player modes (1 and 2 player) and difficulty levels.

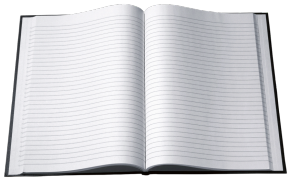
Examples – Advanced projects

Category 3 – Advanced interaction with sound

Example 1: A music player that reads sampled music files (e.g. wav files) from the flash and outputs the sound to the speaker. The user can select songs, move forward and backwards within the song, etc.

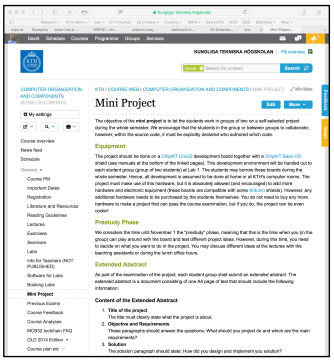
Example 2: Reading MIDI signals directly on the ChipKIT, and then generate sounds, including polyphony (e.g., at least 8 notes can be played simultaneously). The user can select different sounds, and instruments, adjust volume etc. The music is output to a real speaker.

Extended Abstract (1 page) - Contents



- **Title of the project**
  The title must clearly state what the project is about.
- **Objective and Requirements**
  These paragraphs should answer the question: What should your project do and which are the main requirements?
- **Solution**
  The solution paragraph should state: How did you design and implement you solution?
- **Verification**
  The verification paragraph should answer: How did you test or verify that you solution is correct?
- **Contributions**
  This section should explain who did what of the two project members.
- **Reflections**
  The last paragraph should include a few lines of reflections about the project.

Extended Abstract - Submission

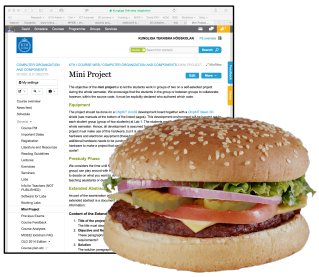


- **A DRAFT** of the extended abstract is submitted Canvas.
- The draft should include 1. the title, 2. the objective and requirements, 3. the solution (preliminary idea of how it will be done), and 4. verification (preliminary idea of how the verification is done).
- In the draft: **State if you aim for an advanced project!**

- **The final version** of the extended abstract should be submitted using Canvas.

Project Expo

- **Everyone shows their projects!**
  Monday March 5.
- **Nominations and Awards** for best projects.



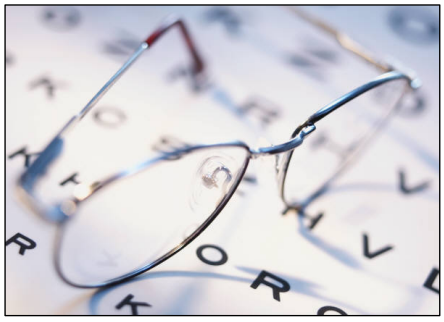
Getting Help

- Post questions on Canvas discussion forum!
- Come to the lunch office hours.

Yeah, you may leave this room soon…

(please do not fumble with the bags)

Reading Guidelines



Module 2 (I/O Systems)

H&H Chapters 8.5-8.7

For the labs, focus on 8.6.2-8.6.5
(GPIO, Timers, and Interrupts)

Also, look carefully at the solutions of exercise 2.

Reading Guidelines
See the course webpage
for more information.

Summary

Some key take away points:

- **A Timer** is used for keeping track of time and timing.
- **Exceptions** cause the processor to switch context and jump to an exception handling routine.
- **Interrupts** are special kinds of exceptions that are typically triggered by an external hardware event.
- **Good luck with the project!**

Thanks for listening!