5TC option AUD

Embedded Programming Basics : embedded peripherals

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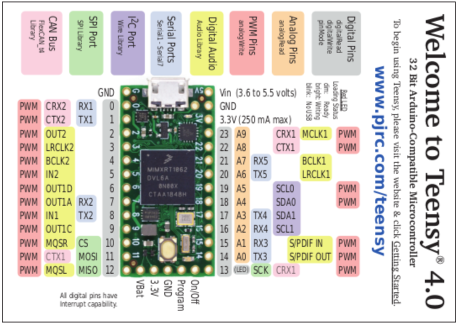
Peripheral programming

- Peripherals are (nowadays) all programmed with *memory map*
  - Each peripheral contains configuration registers
  - These registers are *mapped* to special addresses in the memory
- Example : TODO (LED Blink)

Most basic peripheral : GPIO



- Teensy 4.0 has 40 physical I/O pad
- Some of them can be used for analog input or PWM output
- Digital I/O pins can be configured :
  - as GPIO or for trigerring a peripheral
  - GPIO can be configured
    - As input or output
    - Pulled up, pulled down, or not
    - Interrupt enable

Could you write the “blink” example ?

- The LED is connected to a teensy GPIO
- Blinking the LED is done using the following code :

```
// Pin 13 has an LED connected on most Arduino boards.
int led = 13;

void setup() {
  pinMode(led, OUTPUT);
}

void loop() {
  digitalWrite(led, HIGH);
  delay(1000);
  digitalWrite(led, LOW);
  delay(1000);
}
```

How to blink the LED on teensy

- Identify IO port connected to LED : teensy schematics (end of page `https://www.pjrc.com/store/teensy40.html`)

→ I/O pin number 13

- Configure I/O 13 in output mode : `pinMode()` function (see `https://www.pjrc.com/teensy/td_digital.html`)
- Write 1 or 0 at IO 13 port address : `digitalWrite()` function (see also `https://www.pjrc.com/teensy/td_digital.html`)

```
const int ledPin = 13;
  pinMode(ledPin, OUTPUT);
  while (1) {
    digitalWrite(ledPin, 1);
    delay(100);
    digitalWrite(ledPin, 0);
    delay(100);
  }
```

Better with macros...

```
const int ledPin = LED_BUILTIN;
  pinMode(ledPin, OUTPUT);
  while (1) {
    digitalWrite(ledPin, HIGH);
    delay(100);
    digitalWrite(ledPin, LOW);
    delay(100);
  }
```

in `$ARDUINOPATH/hardware/teensy/avr/cores/teensy4/pins_arduino.h`

```
#define LED_BUILTIN   (13)
```

in `$ARDUINOPATH/hardware/teensy/avr/cores/core_pins.h`

```
#define HIGH 0x1
#define LOW  0x0
```

Better with macros...

```
const int ledPin = LED_BUILTIN;
  pinMode(ledPin, OUTPUT);
  while (1) {
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#define LED_BUILTIN   (13)
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in `$ARDUINOPATH/hardware/teensy/avr/cores/core_pins.h`

```
#define HIGH 0x1
#define LOW  0x0
```

Better with timers....

- `delay(100)` is called *buzy wait*
- Blinking leds on timer interrupts free the CPU from buzy waiting.

```
void blinkLED() {
   //timer call back: blink the led
   [...]
}

void setup(void)
{
   //set led pin to output direction
   pinMode(ledPin, OUTPUT);
   // Initialize timer callback (called  every 300 milliseconds)
   myTimer.begin(blinkLED, 300000);
}

void loop(void) {
  //nothing to do here
}
```

What are "Peripherals" ?

- All peripherals (Timers, ADC, USB, ETH, etc.) are **dedicated circuits.**
- These circuits can be configured by a set of **registers**
- Each register has its own **address** (i.e. address within the peripheral) specified in peripheral datasheet.
- Two ways of writing these registers :
  - Memory map : the register corresponds to an address in Memory (see previous MSP430 multiplier example)
  - Use a serial protocol (I2C, SPI, ...) to access the registers of the Peripheral
- Peripherals can send **interrupts** to the CPU :
  - The CPU will execute a particular **callback function** in order to perform specific task asked by the peripheral.
  - eg : `blinkLED()` (timer callback). `MyDSP.update()` (audio callback)

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Interrupt mechanism principle

- By default, the program `main` is executed infinitely, it generally contains an infinite loop that never ends.
- The processor can receive *interrupts* at any time (*hardware interrupts*).
- An interrupt can be sent by a peripheral of the micro-controller (timer, radio chip, serial port, etc...), or received from outside (on a GPIO) like the `reset` for example.
- It is the programmer who configures the peripherals (for example the timer) to send an interrupt on certain events
- It is a common naming habit to say that Interrupts arrive on a *port* of the micro-controller.
- An interrupt is processed by a dedicated *interrupt service routine* (ISR).
- Each interrupt has its own ISR. it is a function written by the programmer which has some special properties.

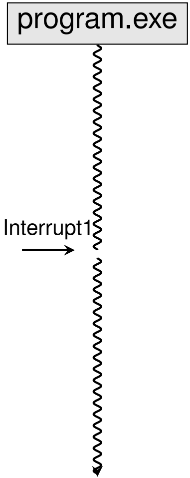
Processing an Interrupt

- Interrupts (i.e. “hardware interrupts”) are essential for the operation of any computer.
- When an interrupt occurs, the microprocessor saves the current state of its running program :
  - all general registers
  - the status register
  - the program counter
- It then executes a specific piece of code to process this interrupt (interrupt handler or ISR)
- when the handler is finished, it restores the state of the processor and resumes execution of the interrupted program

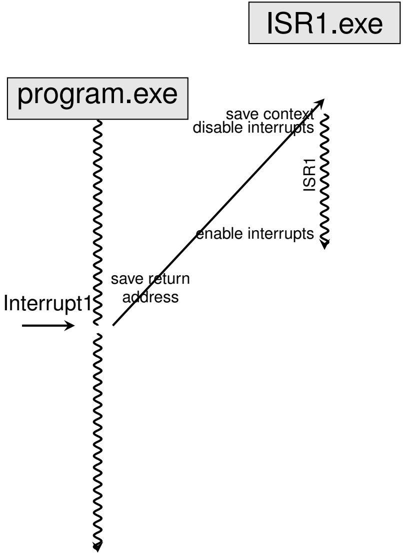
Interrupt Service Routine (ISR)

- The call to the interrupt handling routine is not exactly a function call like the others.
- It must be compiled a little differently, so it is usually identified by a *pragma* for the compiler. Example for `gcc` : `interrupt(PORT1_VECTOR)port1_irq_handler(void)`
- an interrupt handler can itself be interrupted or not by another interrupt (interrupt priority).
- User can write its own interrupt routines in C, the compilers provide facilities for this.
- On slightly more advanced systems, the ISR is provided by the programming environment which offers the user to write a function that will be called during the interruption : *callback* mechanism

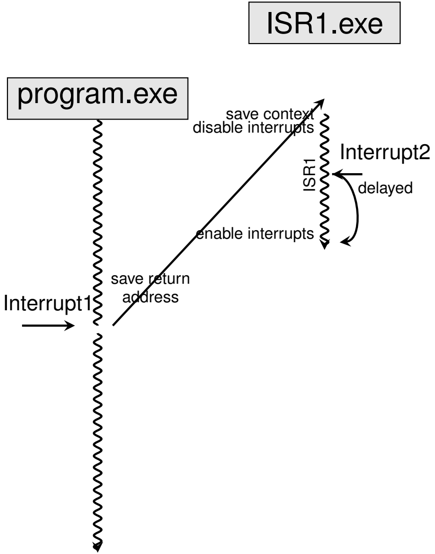
Interrupt mecanism



Interrupt mecanism



Interrupt mecanism



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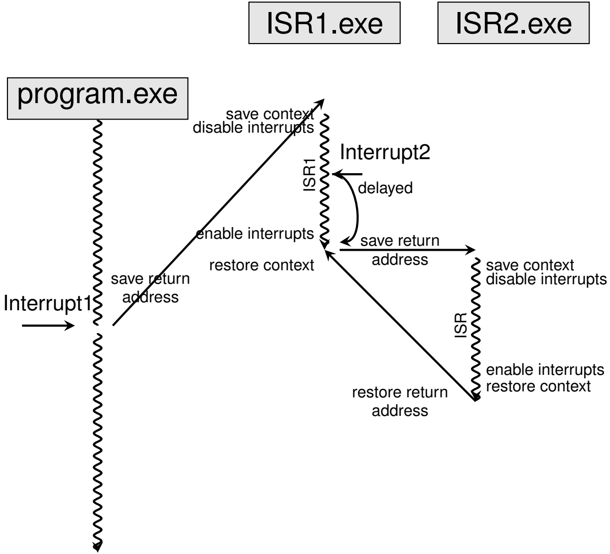

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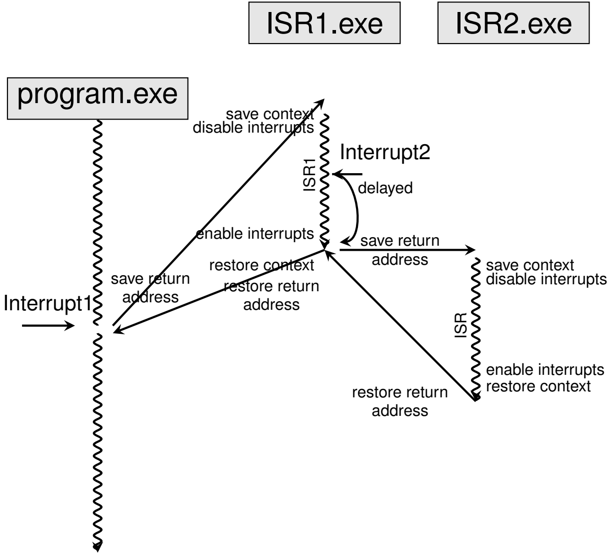
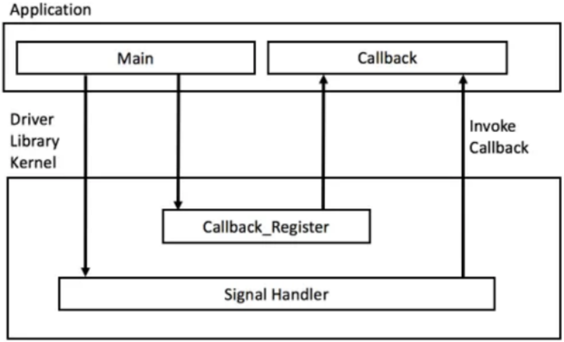


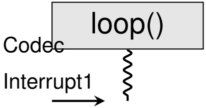
Callback mechanism

The Callback mechanism allows to define ISR behaviour is as a regular function.

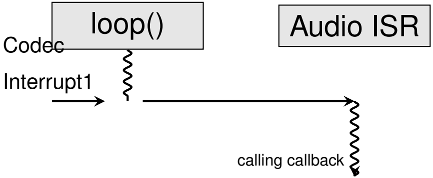


Interrupt Callback principle
(Image Source : Reusable Firmware Development book)

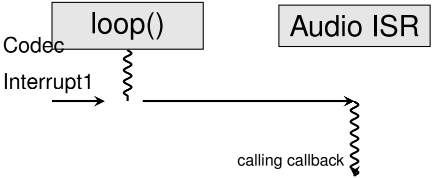
Audio Callback



Audio Callback



Audio Callback



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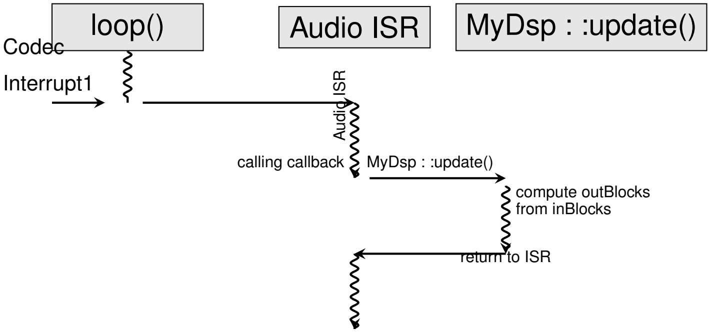
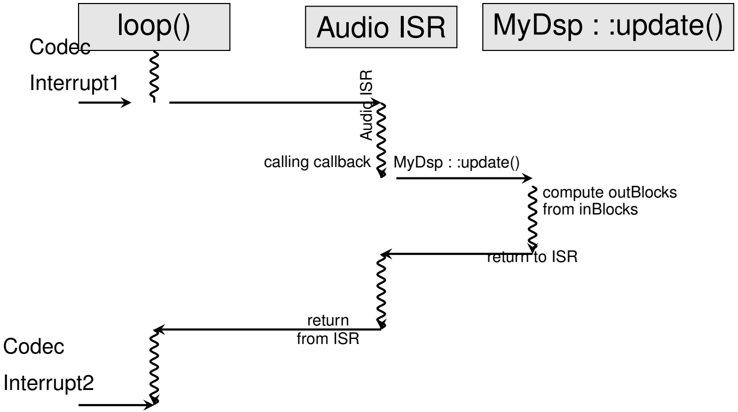


Audio Callback



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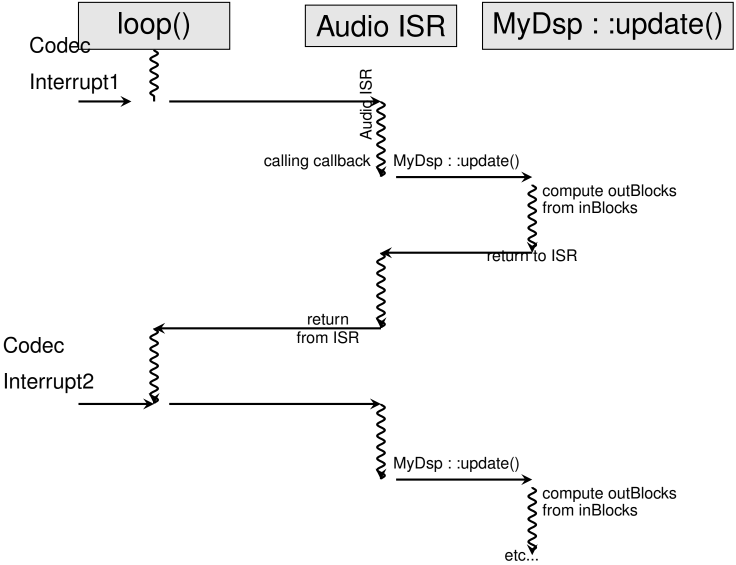

Callback mecanism

- A callback mecanism is used to allow the user to write its own ISR function
- In primitive systems (bare metal) :
  - The compiler uses pragmas to distinguish between regular function and ISR.
  - Each interrupt has a dedicated number corresponding to its entry in the *interrupt vector table*
- In more elaborate systems :
  - A function pointer mecanism is used to *register* a user fonction as callback for a given interrupt
  - Examples on the teensy : intervalTimer
  - Examples on the teensy : the audio callback (`void MyDsp::update(void)`

Timer example

- Teensy provide the `intervalTimer` object (`https://www.pjrc.com/teensy/td_timing_IntervalTimer.html`) dedicated to provide *regular interrupts*.

```
// Create an IntervalTimer object
IntervalTimer myTimer;
```

- At timer initialization :
  - Set the frequency of interrupts (e.g. every 150 ms)
  - Register the callback function (e.g. `blinkLED`)

```
myTimer.begin(blinkLED, 150000)
```

- callback function (i.e. `blinkedLED`) must have fixed type : `void blinkedLED(void):`

Hands on

- As explained on Embaudio web site (lecture9), from the `teensy_example`
  - Create a `teensy_led` example that blinks the led with the `delay()` function.
  - Create a `teensy_timer` example that blinks the led with a timer.
  - Create a `teensy_serial` example that blinks the led with a timer and prints out on UART port every seconds, the number of blinks occured since the beguinning.
  - download the `teensy_audio` from the embaudio web site, run it and make it *click* by adding a `delay(10)` in the timer callback