

5TC option AUD

Embedded Programming Basics : embedded peripherals

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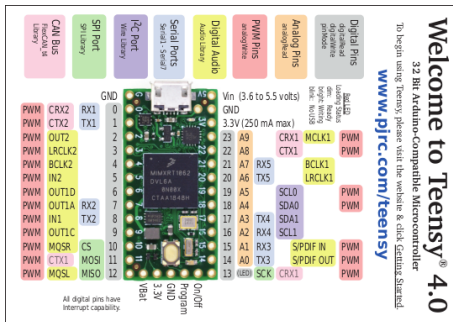
Embedded Peripherals Programming

Interrupt in Embedded Programming

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 : LED Blink in Teensy

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 triggering 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) {  
    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 timers....

- `delay(100)` is called *busy wait*
- Blinking leds on timer interrupts free the CPU from busy 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 :
 - 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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Embedded Peripherals Programming

Interrupt in Embedded Programming

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.

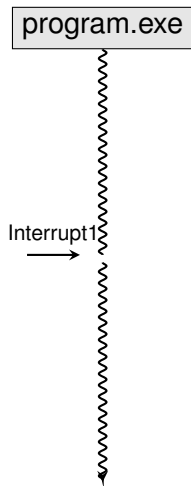
Processing an Interrupt

- 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

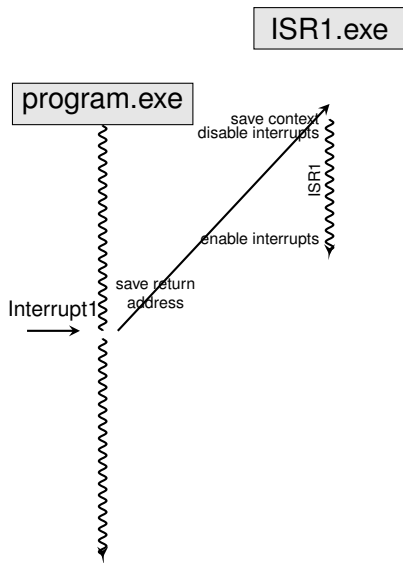
Interrupt Service Routine (ISR)

- 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

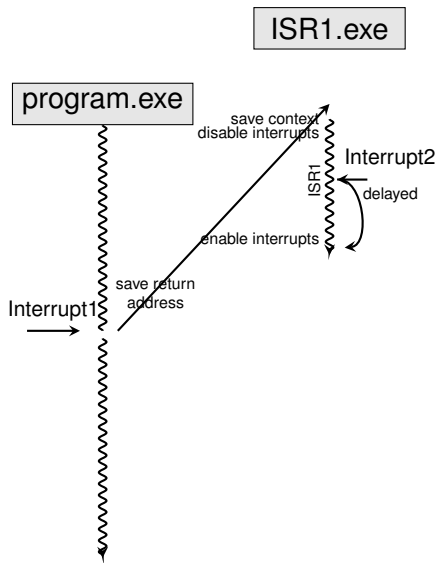
Interrupt mechanism



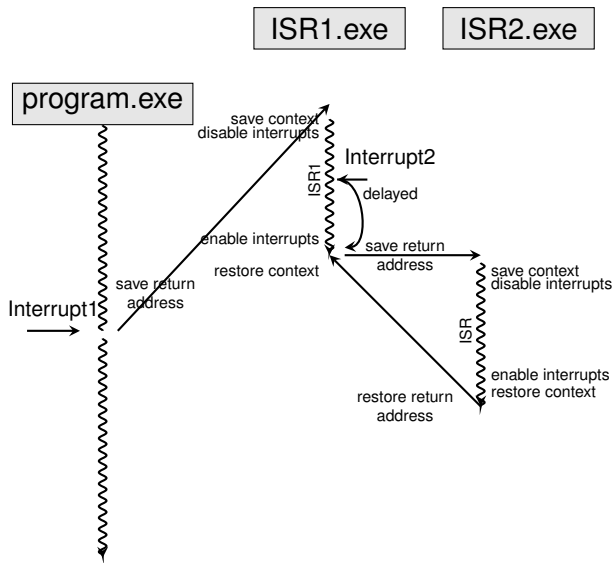
Interrupt mechanism



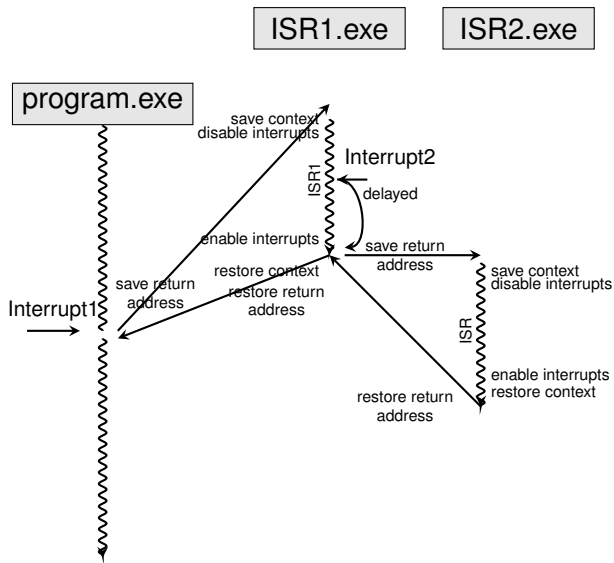
Interrupt mechanism



Interrupt mechanism

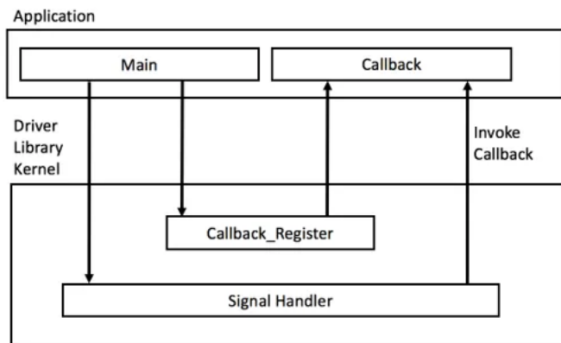


Interrupt mechanism



Callback mechanism

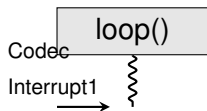
The Callback mechanism allows to define ISR behaviour as a regular function.



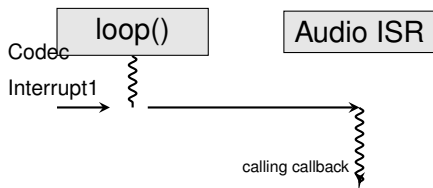
Interrupt Callback principle

(Image Source : Reusable Firmware Development book)

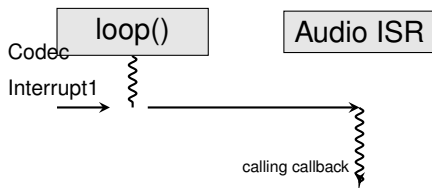
Audio Callback



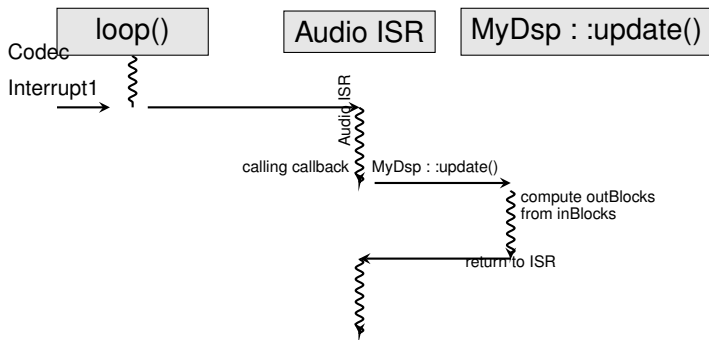
Audio Callback



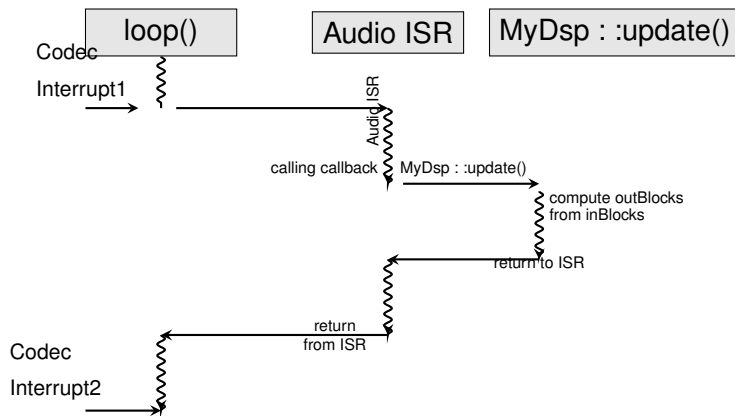
Audio Callback



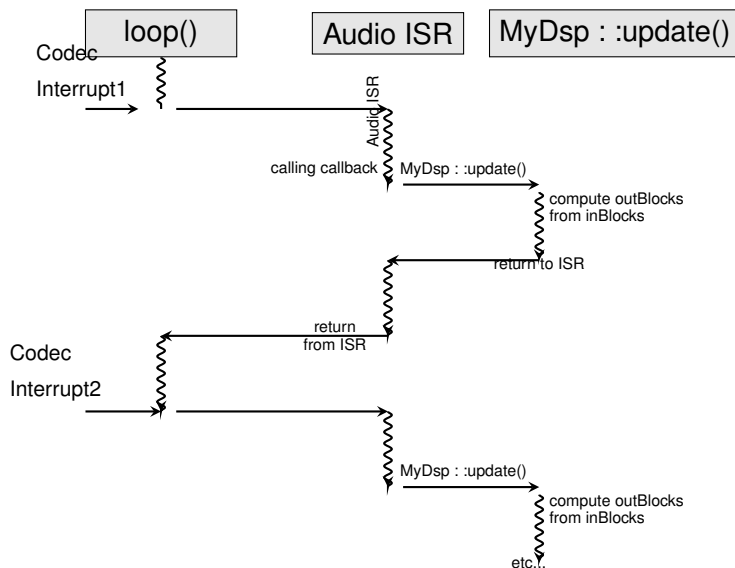
Audio Callback



Audio Callback



Audio Callback



Callback mechanism

- A callback mechanism 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 mechanism is used to *register* a user function 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 course web site, 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 occurred since the beginning.
 - download the `teensy_audio` from the `embaudio` web site, run it and make it *click* by adding a `delay(10)` in the timer callback