Embedded System Design: From Electronics to Microkernel Development

Rodrigo Maximiano Antunes de Almeida
rmaalmeida@gmail.com
@rmaalmeida
Universidade Federal de Itajubá
Portal embarcados

MPLABX – SDCC - GPUTILS
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Workshop schedule

• Hardware
  ▪ Electronics introduction
  ▪ Board development

• Firmware
  ▪ Embedded programming
  ▪ Peripheral access

• Kernel
  ▪ Timing requirements
  ▪ Device drivers
Last time disclaimer.

- It would probably work.
  - I tested it
- If it don’t...
  - Blame TSA
Hardware
Hardware concepts

• Electronics introduction
  ▪ Schematics
  ▪ Datasheets
  ▪ Protoboard/breadboard
  ▪ LED
  ▪ Potentiometer
  ▪ LCD
  ▪ Microcontroller

• System design
  ▪ Basic steps
Electronics introduction

• http://xkcd.com/730/
Schematics

• Way to represent the components and its connections
• Each component has its own symbol
• Crossing wires only are connected if joined with a dot
Datasheets

• The main source of information concerning electronics

• Presents
  ▪ Electrical characteristics
  ▪ Simplified schematics
  ▪ Use example
  ▪ Opcodes/API
Protoboard/Breadboard
LED

- Epoxy lens/case
- Wire bond
- Reflective cavity
- Semiconductor die
- Anvil Post
- Leadframe
- Flat spot
- Anode
- Cathode
LED

- 6V battery
- LED
- Resistor: 470 Ω (yellow, violet, brown)
- LED color: any
Potentiometer

- Linear/Log
- Used as voltage divisor
- Need an analog input
- Filter
Potentiometer

Connection Leads

Rotating Dial
Resistive Element

R1 10K

V_in

Z_1

Z_2

V_out

A0
LCD Display

19 DEFC0N

Embd-Workshop
LCD Display

- Complete interface solution
  - Screen + Video card + Protocol + Data cable
- "Standard" HD44780
  - 4/8 bits communication
  - 3 control bits
LCD Display

• Backlight
• Data connection
• Current consumption
• Power on time/routine
Microcontroller

• System-on-a-chip
  ▪ Processor
  ▪ Memory
  ▪ Input/Output peripherals
  ▪ Communication
  ▪ Safety components
Microcontroller

- Xtal configuration
- Reset pin
- DC needs
- Many peripherals on the same pin
System designing
System design

• Steps on a generic electronic system design
  ▪ Define the objective(s)
  ▪ Choose the main components needed to achieve the objective
  ▪ Get the use example and recommendations from component datasheet
  ▪ Build the schematics
  ▪ Simulation of HW elements
  ▪ Board layout
System design

• Free CAD tools for electronics
  ▪ Fritzing (fritzing.org)
  ▪ Kicad
  ▪ LTSpice
  ▪ https://www.circuitlab.com/
System design

• Ultra fast workshop
  ▪ Power source development

• Online circuit simulation + fritzing for layout
  ▪ From concept to ready to manufacture in 10 min
System design

- Minimum circuit components
  - Microcontroller
  - Voltage source
  - Input/Output as needed
  - Clock source
  - Programmer connection
Firmware development
Firmware development

• Programmer
• IDE
• Basic concepts
  ▪ CPU Architecture
  ▪ HW configuration
  ▪ Memory access
• First program (Led blinking)
• Second program (ADC read)
• Third program (LCD access)
Firmware tools

- Programmer
  - PICkit3
  - Can use ICSP
  - Can program a lot of Microchip products
  - Also a debugger
  - Jtag equivalent
Firmware tools

PICKIT™ 3 PROGRAMMER CONNECTOR PINOUT

Pin 1 Indicator

Pin Description*
1 = VPP/MCLR
2 = VDD Target
3 = VSS (ground)
4 = ICSPDAT/PGD
5 = ICSPCLK/PGC
6 = LVP

* The 6-pin header (0.100" spacing) accepts 0.025" square pins.
Firmware tools

• IDE
  - MPLABX
    • Based on Netbeans

• Compiler
  - SDCC
    • Based on GCC
  - GPUtils
Embedded programming concepts

Because while(a==a); is not an infinite loop!
Embedded programming concepts

![Diagram of PICmicro® MCU Processor with Indexed addressing]
Embedded programming concepts

• Memory segmentation

<table>
<thead>
<tr>
<th>Stack 1</th>
<th>GPR1</th>
<th>0x0000 0x0FF</th>
</tr>
</thead>
<tbody>
<tr>
<td>...</td>
<td>GPR2</td>
<td>0x100 0x1FF</td>
</tr>
<tr>
<td>Stack 31</td>
<td>GPR3</td>
<td>0x200 0x2FF</td>
</tr>
<tr>
<td></td>
<td>GPR4</td>
<td>0x300 0x3FF</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Não implementado</td>
<td>0xF60 0xFFF</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Embedded programming concepts

- HW configuration
  - Some options must be set before the program start
  - This can only be accomplished by special instructions
  - Compiler datasheet
### Embedded programming concepts

#### TABLE 25-1: CONFIGURATION BITS AND DEVICE IDS

<table>
<thead>
<tr>
<th>File Name</th>
<th>Bit 7</th>
<th>Bit 6</th>
<th>Bit 5</th>
<th>Bit 4</th>
<th>Bit 3</th>
<th>Bit 2</th>
<th>Bit 1</th>
<th>Bit 0</th>
<th>Default/ Unprogrammed Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>300000h</td>
<td>CONFIG1L</td>
<td>—</td>
<td>—</td>
<td>USBDIV</td>
<td>CPUDIV1</td>
<td>CPUDIV0</td>
<td>PLLDIV2</td>
<td>PLLDIV1</td>
<td>PLLDIV0</td>
</tr>
<tr>
<td>300001h</td>
<td>CONFIG1H</td>
<td>IESO</td>
<td>FCMEN</td>
<td>—</td>
<td>—</td>
<td>FOSC3</td>
<td>FOSC2</td>
<td>FOSC1</td>
<td>FOSC0</td>
</tr>
<tr>
<td>300002h</td>
<td>CONFIG2L</td>
<td>—</td>
<td>—</td>
<td>VREGEN</td>
<td>BORV1</td>
<td>BORV0</td>
<td>BOREN1</td>
<td>BOREN0</td>
<td>PWRTEN</td>
</tr>
<tr>
<td>300003h</td>
<td>CONFIG2H</td>
<td>—</td>
<td>—</td>
<td>—</td>
<td>WDTPS3</td>
<td>WDTPS2</td>
<td>WDTPS1</td>
<td>WDTPS0</td>
<td>WDTEN</td>
</tr>
<tr>
<td>300005h</td>
<td>CONFIG3H</td>
<td>MCLRE</td>
<td>—</td>
<td>—</td>
<td>—</td>
<td>—</td>
<td>LPT1OSC</td>
<td>PBADEN</td>
<td>CCP2MX</td>
</tr>
<tr>
<td>300006h</td>
<td>CONFIG4L</td>
<td>DEBUG</td>
<td>XINST</td>
<td>ICPRT(3)</td>
<td>—</td>
<td>—</td>
<td>LVP</td>
<td>—</td>
<td>STVREN</td>
</tr>
<tr>
<td>300007h</td>
<td>CONFIG5L</td>
<td>—</td>
<td>—</td>
<td>—</td>
<td>—</td>
<td>CP3(1)</td>
<td>CP2</td>
<td>CP1</td>
<td>CP0</td>
</tr>
<tr>
<td>300009h</td>
<td>CONFIG5H</td>
<td>CPD</td>
<td>CPB</td>
<td>—</td>
<td>—</td>
<td>—</td>
<td>—</td>
<td>—</td>
<td>—</td>
</tr>
<tr>
<td>30000Ah</td>
<td>CONFIG6L</td>
<td>—</td>
<td>—</td>
<td>—</td>
<td>—</td>
<td>WRT3(1)</td>
<td>WRT2</td>
<td>WRT1</td>
<td>WRT0</td>
</tr>
<tr>
<td>30000Bh</td>
<td>CONFIG6H</td>
<td>WRTD</td>
<td>WRTB</td>
<td>WRTC</td>
<td>—</td>
<td>—</td>
<td>—</td>
<td>—</td>
<td>—</td>
</tr>
<tr>
<td>30000Ch</td>
<td>CONFIG7L</td>
<td>—</td>
<td>—</td>
<td>—</td>
<td>—</td>
<td>EBTR3(1)</td>
<td>EBTR2</td>
<td>EBTR1</td>
<td>EBTR0</td>
</tr>
<tr>
<td>30000Dh</td>
<td>CONFIG7H</td>
<td>—</td>
<td>EBTRB</td>
<td>—</td>
<td>—</td>
<td>—</td>
<td>—</td>
<td>—</td>
<td>—</td>
</tr>
<tr>
<td>3FFFFEh</td>
<td>DEVID1</td>
<td>DEV2</td>
<td>DEV1</td>
<td>DEV0</td>
<td>REV4</td>
<td>REV3</td>
<td>REV2</td>
<td>REV1</td>
<td>REV0</td>
</tr>
<tr>
<td>3FFFFFh</td>
<td>DEVID2</td>
<td>DEV10</td>
<td>DEV9</td>
<td>DEV8</td>
<td>DEV7</td>
<td>DEV6</td>
<td>DEV5</td>
<td>DEV4</td>
<td>DEV3</td>
</tr>
</tbody>
</table>

**Legend:**  
- $\times$ = unknown,  
- $\sim$ = unchanged,  
- - = unimplemented. Shaded cells are unimplemented, read as ‘0’.

**Note 1:** Unimplemented in PIC18FX455 devices; maintain this bit set.

**Note 2:** See Register 25-13 and Register 25-14 for DEVID values. DEVID registers are read-only and cannot be programmed by the user.

**Note 3:** Available only on PIC18F4455/4550 devices in 44-pin TQFP packages. Always leave this bit clear in all other devices.
Embedded programming concepts

```c
#pragma config MCLRE=ON
// Master Clear desabilitado
#pragma config FOSC=INTOSC_XT
// Oscilador c/ cristal externo HS
#pragma config WDT=OFF
// Watchdog controlado por software
#pragma config LVP=OFF
// Sem programação em baixa tensão
#pragma config DEBUG=OFF
// Desabilita debug
#pragma config XINST=OFF
```
Embedded programming concepts
Embedded programming concepts

• Build a pointer to a specific memory address:

```c
void main (void){
    char *ptr;
    //pointing to the port D
    ptr = 0xF83;
    //changing all outputs to high
    *ptr = 0xFF;
}
```
Embedded programming concepts

• Building a header with all definitions
  ▪ __near = sfr region
  ▪ volatile = can change without program acknowledge

#define PORTD   (*(volatile __near unsigned char*)0xF83)
#define TRISC   (*(volatile __near unsigned char*)0xF94)

//this is not an infinite loop!
while( PORTD == PORTD);
Embedded programming concepts

• Bitwise operations

```c
char mask;
mask = 1 << 2;
arg = arg | mask;

//one line
arg = arg | (1<<bit);

//using define
#define BitSet(arg,bit) ((arg) |= (1<<bit))
#define BitClr(arg,bit) ((arg) &= ~(1<<bit))
#define BitFlp(arg,bit) ((arg) ^= (1<<bit))
#define BitTst(arg,bit) ((arg) & (1<<bit))
```
Hands on
First lab

• Assemble the first circuit
• Install ide, compiler and linker
• Open MPLABX IDE
  ▪ configure SDCC and PICkit
• Create a project to
  ▪ blink a led. -> “Hello ‘mbed’ world”
  ▪ No includes! No includes!!! HEADERLESS
First lab
#define PORTD (*(volatile __near unsigned char*)0xF83)
#define TRISD (*(volatile __near unsigned char*)0xF95)

void main(void) {
    TRISD = 0x00;
    for(;;){
        PORTD ^= 0xFF;
        //delay();
    }
}
Second lab

• Using ADC potentiometer as input
Peripherals setup

- Analog to digital converter
#define TRISA (*(volatile __near unsigned char*)0xF92)
#define ADCON2 (*(volatile __near unsigned char*)0xFC0)
#define ADCON1 (*(volatile __near unsigned char*)0xFC1)
#define ADCON0 (*(volatile __near unsigned char*)0xFC2)
#define ADRESL (*(volatile __near unsigned char*)0xFC3)
#define ADRESH (*(volatile __near unsigned char*)0xFC4)

void adInit(void) {
    BitSet(TRISA, 0);  //pin setup
    ADCON0 = 0b00000001;  //channel select
    ADCON1 = 0b00001110;  //ref = source
    ADCON2 = 0b10101010;  //t_conv = 12 TAD
}

ADC setup
unsigned int adRead(void){
    unsigned int ADvalue;
    BitSet(ADCON0,1);   //start conversion
    while(BitTst(ADCON0,1));  //wait
    ADvalue = ADRESH;  //read result
    ADvalue <<= 8;
    ADvalue += ADRESL;
    return ADvalor;
}

ADC setup
Second lab
void main(void) {
    unsigned int i;
    unsigned int ad;
    TRISD = 0x00;
    adInit();
    for (;;) {
        ad = adRead();
        PORTD = 0xff;
        for (i = 0; i < ad; i++);
        PORTD = 0x00;
        for (i = ad; i < 1024; i++);
    }
}
Third example

• Using a LCD as information output peripheral
LCD communication

• The data is always an 8 bit information
  ▪ It may be split in two 4 bit data transfer

• The data may represent a character or a command
  ▪ They are distinguished by RS pin

• The data must be stable for "some time"
  ▪ In this period the EN pin must be set
#define RS 6
#define EN 7

```c
void delayMicroseconds(int ms) {
    int i;
    for (; ms > 0; ms--) {
        for (i = 0; i < 30; i++);
    }
}
```

```c
void pulseEnablePin() {
    BitClr(PORTC, EN);
    delayMicroseconds(1);
    // send a pulse to enable
    BitSet(PORTC, EN);
    delayMicroseconds(1);
    BitClr(PORTC, EN);
}
```
void pushNibble(int value, int rs) {
    PORTD = value;
    if (rs) {
        BitSet(PORTC, RS);
    } else {
        BitClr(PORTC, RS);
    }
    pulseEnablePin();
}

void pushByte(int value, int rs) {
    int val_lower = value & 0x0F;
    int val_upper = value >> 4;
    pushNibble(val_upper, rs);
    pushNibble(val_lower, rs);
}
void lcdCommand(int value) {
    pushByte(value, 0);
    delayMicroseconds(40);
}

void lcdChar(int value) {
    pushByte(value, 1);
    delayMicroseconds(2);
}
void lcdInit() {
    BitClr(TRISC, EN);
    BitClr(TRISC, RS);
    TRISD = 0x0f;
    delayMicroseconds(50);

    commandWriteNibble(0x03);
    delayMicroseconds(5);
    commandWriteNibble(0x03);
    delayMicroseconds(100);
    commandWriteNibble(0x03);
    delayMicroseconds(5);
    commandWriteNibble(0x02);
    delayMicroseconds(10);
    //display config
    lcdCommand(0x28); //4bits, 2 linhas, 5x8
    lcdCommand(0x06); //incremental mode
    lcdCommand(0x0c); //display on, cursor and blink off
    lcdCommand(0x03); //clean internal variables
    lcdCommand(0x80); //initial position
    lcdCommand(0x01); //clear display
    delayMicroseconds(2);
}
LCD communication

- The LCD can hold up to 8 custom characters
- Each character is a 5*8 matrix
- Translating: 40*64 b/w drawing area
### LCD Communication

<table>
<thead>
<tr>
<th>Custom Pattern</th>
<th>Decimal</th>
<th>Hex</th>
</tr>
</thead>
<tbody>
<tr>
<td>Row 1</td>
<td>4</td>
<td>0x04</td>
</tr>
<tr>
<td>Row 2</td>
<td>14</td>
<td>0x0E</td>
</tr>
<tr>
<td>Row 3</td>
<td>14</td>
<td>0x0E</td>
</tr>
<tr>
<td>Row 4</td>
<td>14</td>
<td>0x0E</td>
</tr>
<tr>
<td>Row 5</td>
<td>31</td>
<td>0x1F</td>
</tr>
<tr>
<td>Row 6</td>
<td>0</td>
<td>0x00</td>
</tr>
<tr>
<td>Row 7</td>
<td>4</td>
<td>0x04</td>
</tr>
</tbody>
</table>

Source: http://www.8051projects.net/lcd-interfacing/lcd-custom-character.php
void lcdDefconLogo(void) {
    int i;
    unsigned char defcon[] = {
        0x00, 0x01, 0x03, 0x03, 0x03, 0x03, 0x01, 0x04,
        0x0e, 0x1f, 0x04, 0x04, 0x1f, 0x0e, 0x11, 0x1f,
        0x00, 0x10, 0x18, 0x18, 0x18, 0x18, 0x10, 0x04,
        0x0c, 0x03, 0x00, 0x00, 0x00, 0x03, 0x0c, 0x04,
        0x00, 0x00, 0x1b, 0x04, 0x1b, 0x00, 0x00, 0x00,
        0x06, 0x18, 0x00, 0x00, 0x00, 0x18, 0x06, 0x02
    };
    lcdCommand(0x40);
    for (i = 0; i < 8 * 6; i++) {
        lcdChar(defcon[i]);
    }
}
Third Laboratory

- Read ADC value and present in LCD
Third Laboratory
Time to break;

Back @ 14:00
void main (void) {
    //variable declaration
    kernel_project(1);
    //initialization
    concepts(2);
    //hard-work
    microkernel(3);
    device_driver_controller(4);
}

//afternoon topics
void kernel_project (float i){
  what_is_a_kernel(1.1);
  alternatives(1.2);
  monolithic_vs_microkernel(1.3);
  kernel_design_decisions(1.4);
  this_course_decisions(1.5);
}
kernel_project(1);

what_is_a_kernel(1.1);
kernel_project(1);
• Kernel tasks:
  1. Manage and coordinate the processes execution using “some criteria”
  2. Manage the free memory and coordinate the processes access to it
  3. Intermediate the communication between the hardware drivers and the processes
kernel_project(1); 

Develop my own kernel? 

Why?
kernel_project(1);
kernel_project(1);

Develop my own kernel?

Why not?
kernel_project(1);

- Kernel overhead (both in time and memory)
- Free and paid alternatives
- Time intensive project
- Continuous development
kernel_project(1);

• Alternatives
  ▪ Windows Embedded Compact®
  ▪ VxWorks®
  ▪ X RTOS®
  ▪ uClinux
  ▪ FreeRTOS
  ▪ BRTOS
Monolithic kernel versus microkernel
Linus Torvalds and Andrew Tanenbaum
kernel_project(1);

- Kernel design decisions
  - I/O devices management
  - Process management
  - System safety
Our decisions:

- Microkernel
- Non-preemptive
- Cooperative
- No memory management
- Process scheduled based on timer
- Isolate drivers using a controller
```c
void concepts (float i){
    function_pointers(2.1);
    structs(2.2);
    circular_buffers(2.3);
    temporal_conditions(2.4);
    void_pointers(2.5);
}
```
concepts(2);

function_pointers(2.1);
concepts (2);

• Necessity:
  ▪ Make an image editor that can choose the right function to call

• 1st Implementation
  ▪ Use a option parameter as a switch operator
concepts(2);

image Blur(image nImg) {}
image Sharpen(image nImg) {}

image imageEditorEngine(image nImg, int opt) {
    image temp;
    switch(opt) {
        case 1:
            temp = Sharpen(nImg);
            break;
        case 2:
            temp = Blur(nImg);
            break;
    }
    return temp;
}
• Function pointers
  - Work almost as a normal pointer
  - Hold the address of a function start point instead the address of a variable
  - The compiler need no known the function signature to pass the correct parameters and the return value.
  - Awkward declaration (it is best to use a typedef)
typedef void (*pointerTest)(void);

//Function to be called
void nop (void){ __asm NOP __endasm } 

//creating an pointerTest variable;
pointerTest foo;
foo = nop;
(*foo)(); //calling the function via pointer
Re-code the image editor engine using function pointers
concepts(2);

```c
image Blur(image nImg) {}  
image Sharpen(image nImg) {}  

typedef image (*ptrFunc)(image nImg);

//image editor engine
image imageEditorEngine(ptrFunc function, image nImg) {
    image temp;
    temp = (*function)(nImg);
    return temp;
}
```
• Good
  - New function additions do not alter the engine
  - The engine only needs to be tested once
  - Can change the function implementations dynamically

• Bad
  - More complex code (function pointers are not so easy to work with)
  - Not all compilers support function pointers
concepts(2);

structs(2.2);
concepts(2);

- Structs are composed variables.
- Group lots of information as if they were one single variable.
- A vector that each position stores a different type

```c
// struct declaration
typedef struct {
    unsigned short int age;
    char name[51];
    float weight;
} people;
```
```c
void main(void) {
    struct people myself = {26, "Rodrigo", 70.5};

    myself.age = 27;

    //using each variable from the struct
    printf("Age: %d\n", myself.age);
    printf("Name: %s\n", myself.name);
    printf("Weight: %f\n", myself.weight);

    return 0;
}
```
// struct declaration
typedef struct{
    unsigned short int *age;
    char *name[51];
    float *weight;
} people;

void main(void) {
    struct people myself = {26, "Rodrigo", 70.5};
    // using each variable from the struct
    printf("Age: %d\n", myself->age);
    printf("Name: %s\n", myself->name);
    printf("Weight: %f\n", myself->weight);
    return 0;
}

concepts(2);
concepts(2);

circular_buffers(2.3);
Circular Buffers
- “Endless” memory spaces
- Use FIFO approach
- Store temporary data
- Can implemented using vectors or linked-lists
• Vector implementation
  ▪ Uses less space
  ▪ Need special caution when cycling
  ▪ Problem to differentiate full from empty
#define CB_SIZE 10

int circular_buffer[CB_SIZE];

int index=0;

for(;;){
    //do anything with the buffer
    circular_buffer[index] = index;
    //increment the index
    index = (index+1)%CB_SIZE;
}

concepts(2);
```c
#define CB_SIZE 10
int circular_buffer[CB_SIZE];
int start=0, end=0;

char AddBuff(int newData)
{
    //check if there is space to add a number
    if ( ((end+1)%CB_SIZE) != start )
    {
        circular_buffer[end] = newData;
        end = (end+1)%CB_SIZE;
        return SUCCESS;
    }
    return FAIL;
}
```
concepts(2);

temporal_conditions(2.4);
In the majority part of embedded systems, we need to guarantee that a function will be executed in a certain frequency. Some systems may even fail if these deadlines are not met.
concepts (2);  

• To implement temporal conditions:
  1. There must be a tick event that occurs with a precise frequency
  2. The kernel must be informed of the execution frequency needed for each process.
  3. The sum of process duration must “fit” within the processor available time.
concepts (2);

• 1st condition:
  ▪ Needs an internal timer that can generate an interrupt.

• 2nd condition:
  ▪ Add the information for each process when creating it

• 3rd condition:
  ▪ Test, test and test.
  ▪ If fail, change chip first, optimize only on last case
• Scheduling processes:
  - Using a finite timer to schedule will result in overflow
  - Example: scheduling 2 processes for 10 and 50 seconds ahead.
• And if two processes are to be called in the same time?
• Question:
  - From the timeline above (only the timeline) is P2 late or it was scheduled to happen 55(s) from now?
• Solution:
  - Use a downtime counter for each process instead of setting a trigger time.

• Problem:
  - Each counter must be decremented in the interrupt subroutine.
  - Is it a problem for your system?
concepts(2);

void_pointers(2.5);
• Void pointers
  ▪ Abstraction that permits to the programmer to pass parameters with different types to the same function.
  ▪ The function which is receiving the parameter must know how to deal with it
  ▪ It can not be used without proper casting!
concepts(2);

char *name = "Paulo";

double weight = 87.5;

unsigned int children = 3;

void main (void){
    //its not printf, yet.
    print(0, &name);
    print(1, &weight);
    print(2, &children);
}
void print(int option; void *parameter){
    switch(option){
    case 0:
        printf("%s",(char*)parameter);
        break;
    case 1:
        printf("%f",*((double*)parameter));
        break;
    case 2:
        printf("%d",*((unsigned int*)parameter));
        break;
    }
}
void microkernel (float i){
    init_kernel(3.0);
    for(int i=1; i<4; i++)
    {
        kernel_example(3+i/10);
    }
    running_the_kernel(3.4);
}
microkernel(3);

init_kernel(3.0);
microkernel(3);

• The examples will use a minimum of hardware or platform specific commands.
• Some actions (specifically the timer) needs hardware access.
microkernel(3);

//first implementation
kernel_example(3.1);
microkernel(3);

• In this first example we will build the main part of our kernel.
• It should have a way to store which functions are needed to be executed and in which order.
• This will be done by a static vector of pointers to function

```c
//pointer function declaration
typedef void(*ptrFunc)(void);
//process pool
static ptrFunc pool[4];
```
microkernel(3);

- Each process is a function with the same signature of ptrFunc

```c
void tst1(void) {
    printf("Process 1\n");
}

void tst2(void) {
    printf("Process 2\n");
}

void tst3(void) {
    printf("Process 3\n");
}
```
The kernel itself consists of three functions:

- One to initialize all the internal variables
- One to add a new process
- One to execute the main kernel loop

```c
//kernel internal variables
ptrFunc pool[4];
int end;
//kernel function's prototypes
void kernelInit(void);
void kernelAddProc(ptrFunc newFunc);
void kernelLoop(void);
```
microkernel(3);

//kernel function's implementation

void kernelInit(void) {
    end = 0;
}

void kernelAddProc(ptrFunc newFunc) {
    if (end < 4) {
        pool[end] = newFunc;
        end++;
    }
}
microkernel(3);

//kernel function's implementation

void kernelLoop(void)
{
    int i;
    for(;;)
    {
        //cycle through the processes
        for(i=0; i<end; i++)
        {
            (*pool[i])();
        }
    }
}
microkernel(3);

//main loop

void main(void) {
    kernelInit();
    kernelAddProc(tst1);
    kernelAddProc(tst2);
    kernelAddProc(tst3);
    kernelLoop();
}
microkernel(3);

Simple?
microkernel(3);

// second implementation
// circular buffer and struct added
kernel_example(3.2);
microkernel(3);

- The only struct field is the function pointer. Other fields will be added latter.
- The circular buffer open a new possibility:
  - A process now can state if it wants to be rescheduled or if it is a one-time run process
  - In order to implement this every process must return a code.
  - This code also says if there was any error in the process execution
// return code
#define SUCCESS 0
#define FAIL 1
#define REPEAT 2

// function pointer declaration
typedef char(*ptrFunc)(void);

// process struct
typedef struct {
    ptrFunc function;
} process;

process pool[POOL_SIZE];
microkernel(3);

char kernelInit(void) {
    start = 0;
    end = 0;
    return SUCCESS;
}

char kernelAddProc(process newProc) {
    // checking for free space
    if ( ((end+1)%POOL_SIZE) != start ) {
        pool[end] = newProc;
        end = (end+1)%POOL_SIZE;
        return SUCCESS;
    }
    return FAIL;
}
microkernel(3);

```c
void kernelLoop(void){
    for(;;){
        //Do we have any process to execute?
        if (start != end){
            //check if there is need to reschedule
            if (pool[start]->Func() == REPEAT){
                kernelAddProc(pool[start]);
            }
        }
        //prepare to get the next process;
        start = (start+1)%POOL_SIZE;
    }
}
```
• Presenting the new processes

```c
void tst1(void) {
    printf("Process 1\n");
    return REPEAT;
}

void tst2(void) {
    printf("Process 2\n");
    return SUCCESS;
}

void tst3(void) {
    printf("Process 3\n");
    return REPEAT;
}
```
microkernel(3);

void main(void) {
    // declaring the processes
    process p1 = {tst1};
    process p2 = {tst2};
    process p3 = {tst3};
    kernelInit();
    // Test if the process were added
    if (kernelAddProc(p1) == SUCCESS) {
        printf("1st process added\n");
    }
    if (kernelAddProc(p2) == SUCCESS) {
        printf("2nd process added\n");
    }
    if (kernelAddProc(p3) == SUCCESS) {
        printf("3rd process added\n");
    }
    kernelLoop();
}
microkernel(3);

// third implementation
// time conditions added
kernel_example(3.3);
microkernel(3);

• The first modification is to add one counter to each process

```c
//process struct
typedef struct {
    ptrFunc function;
    int period;
    int start;
} process;
```
We must create an function that will run on each timer interrupt updating the counters

```c
void isr(void) __interrupt 1{
    unsigned char i;
    i = ini;
    while(i!=fim){
        if((pool[i].start)>(MIN_INT)){
            pool[i].start--;
        }
        i = (i+1)%SLOT_SIZE;
    }
}
```
The add process function will be the responsible to initialize correctly the fields

```c
char AddProc(process newProc) {
    // checking for free space
    if ( ((end+1)%SLOT_SIZE) != start ){
        pool[end] = newProc;
        // increment start timer with period
        pool[end].start += newProc.period;
        end = (end+1)%SLOT_SIZE;
        return SUCCESS;
    }
    return FAIL;
}
```
if (start != end){
    //Finding the process with the smallest start
    j = (start+1)%SLOT_SIZE;
    next = start;
    while(j!=end){
        if (pool[j].start < pool[next].start){
            next = j;
        }
        j = (j+1)%SLOT_SIZE;
    }
    //exchanging positions in the pool
    tempProc = pool[next];
    pool[next] = pool[start];
    pool[start] = tempProc;
    while(pool[start].start>0){
    } //great place to use low power mode
    if ( (*pool[ini].function))() == REPEAT ){
        AddProc(&(vetProc[ini]));
    }
    ini = (ini+1)%SLOT_SIZE;
}
microkernel(3);

running_the_kernel(3.4);
“My board's programming” also works =)
void dd_controller (float i){
    device_driver_pattern(5.1);
    controller_engine(5.2);
    isr_abstract_layer(5.3);
    driver_callback(5.4);
}
device_driver_controller(4); 

device_driver_pattern(5.1);
device_driver_controller(4);

• What is a driver?
  ▪ An interface layer that translate hardware to software

• Device driver standardization
  ▪ Fundamental for dynamic drivers load
device_driver_controller(4);

- **Parameters problem**
  - The kernel must be able to communicate in the same way with all drivers
  - Each function in each driver have different types and quantities of parameters

- **Solution**
  - Pointer to void
device_driver_controller(4);

Generic Device Driver

drvGeneric

- thisDriver: driver
- this_functions: ptrFuncDrv
- callbackProcess: process*
+ availableFunctions: enum = {GEN_FUNC_1, GEN_FUNC_2 }
- init(parameters: void*): char
- genericDrvFunction(parameters: void*): char
- genericIsrSetup(parameters: void*): char
+ getDriver(): driver*

driver

+ drv_id: char
+ functions: ptrFuncDrv
+ drv_init: ptrFuncDrv
device_driver_controller(4);

controller_engine(5.2);
device_driver_controller(4);

- Device Driver Controller
  - Used as an interface layer between the kernel and the drivers
  - Can “discover” all available drivers (statically or dynamically)
  - Store information about all loaded drivers
  - Responsible to interpret the messages received from the kernel
device_driver_controller(4);

char initDriver(char newDriver) {
    char resp = FAIL;

    if(dLoaded < QNTD_DRV) {
        //get driver struct
        drivers[dLoaded] = drvInitVect[newDriver]();

        //should test if driver was loaded correctly
        resp = drivers[dLoaded]->drv_init(&newDriver);
        dLoaded++;
    }

    return resp;
}
device_driver_controller(4);

char callDriver(char drv_id, char func_id, void *p) {
    char i;
    for (i = 0; i < dLoaded; i++) {
        //find the right driver
        if (drv_id == drivers[i]->drv_id) {
            return drivers[i]->func[func_id].func_ptr(p);
        }
    }
    return DRVFUNC_NOT_FOUND;
}
device_driver_controller(4);

```c
void main(void) {
    // system initialization
    kernelInitialization();
    initDriver(DRV_LCD);
    callDriver(DRV_LCD, LCD_CHAR, 'D');
    callDriver(DRV_LCD, LCD_CHAR, 'E');
    callDriver(DRV_LCD, LCD_CHAR, 'F');
    callDriver(DRV_LCD, LCD_CHAR, 'C');
    callDriver(DRV_LCD, LCD_CHAR, '0');
    callDriver(DRV_LCD, LCD_CHAR, 'N');
    callDriver(DRV_LCD, LCD_CHAR, '@');
    callDriver(DRV_LCD, LCD_CHAR, 'L');
    callDriver(DRV_LCD, LCD_CHAR, 'A');
    callDriver(DRV_LCD, LCD_CHAR, 'S');
}
```
device_driver_controller(4);

Where are the defines?
In order to simplify the design, each driver builds its function define enum.

```c
enum {
    LCD_COMMAND, LCD_CHAR, LCD_INTEGER, LCD_END
};
```

The controller builds a driver define enum

```c
enum {
    DRV_INTERRUPT, DRV_TIMER, DRV_LCD, DRV_END
};
```
device_driver_controller(4);  

isr_abstract_layer(5.3);
device_driver_controller(4);

- Interrupts are closely related to hardware
- Each architecture AND compiler pose a different programming approach

//SDCC compiler way
void isr(void) interrupt 1{
    thisInterrupt();
}

//C18 compiler way
void isr(void){
    thisInterrupt();
}

#pragma code highvector=0x08
void highvector(void){
    _asm goto isr _endasm
}

#pragma code

- How to hide this from programmer?
device_driver_controller(4);

//Inside drvInterrupt.c

//defining the pointer to use in ISR callback
typedef void (*intFunc)(void);

//store the pointer to ISR here
static intFunc thisInterrupt;

//Set interrupt function to be called
char setInterruptFunc(void *parameters) {
    thisInterrupt = (intFunc) parameters;
    return SUCESS;
}
device_driver_controller(4);

//Interrupt function set without knowing hard/compiler issues
void timerISR(void) {
    callDriver(DRV_TIMER, TMR_RESET, 1000);
    kernelClock();
}

void main (void){
    kernelInit();

    initDriver(DRV_TIMER);
    initDriver(DRV_INTERRUPT);

    callDriver(DRV_TIMER, TMR_START, 0);
    callDriver(DRV_TIMER, TMR_INT_EN, 0);
    callDriver(DRV_INTERRUPT, INT_TIMER_SET, (void*)timerISR);
    callDriver(DRV_INTERRUPT, INT_ENABLE, 0);

    kernelLoop();
device_driver_controller(4);

driver_callback(5.4);
device_driver_controller(4);

How to make efficient use of CPU peripherals without using pooling or hard-coding the interrupts?
device_driver_controller(4);

Callback functions
device_driver_controller(4);

- Callback functions resemble events in high level programming
  - e.g.: When the mouse clicks in the button X, please call function Y.
- The desired hardware must be able to rise an interrupt
- Part of the work is done under interrupt context, preferable the faster part
device_driver_controller(4);
//********** Excerpt from drvAdc.c **********
// called from setup time to enable ADC interrupt
// and setup ADC ISR callback
char enableAdcInterrup(void* parameters) {
    callDriver(DRV_INTERRUPT, INT_ADC_SET, (void*)adcISR);
    BitClr(PIR1, 6);
    return FIM_OK;
}

//********** Excerpt from drvInterrupt.c **********
// store the pointer to the interrupt function
typedef void (*intFunc)(void);
static intFunc adcInterrupt;

// function to set ADC ISR callback for latter use
char setAdcInt(void *parameters) {
    adcInterrupt = (intFunc)parameters;
    return FIM_OK;
}
//********** Excerpt from main.c **********
//  Process called by the kernel
char adc_func(void) {
    //creating callback process
    static process proc_adc_callback = {adc_callback, 0, 0};
callDriver(DRV_ADC,ADC_START,&proc_adc_callback);
    return REPEAT;
}

//********** Excerpt from drvAdc.c **********
//function called by the process adc_func (via drv controller)
char startConversion(void* parameters){
    callBack = parameters;
    ADCON0 |= 0b00000010; //start conversion
    return SUCCESS;
}
device_driver_controller(4);

/************** Excerpt from drvInterrupt.c *************/
//interrupt function
void isr(void) interrupt 1 {
    if (BitTst(INTCON, 2)) { //Timer overflow
    }
    if (BitTst(PIR1, 6)) { //ADC conversion finished
        //calling ISR callback stored
        adcInterrupt();
    }
}

/************** Excerpt from drvAdc.c ***************/
//ADC ISR callback function
void adcISR(void) {
    value = ADRESH;
    value <<= 8;
    value += ADRESL;
    BitClr(PIR1, 6);
    kernelAddProc(callBack);
}
device_driver_controller(4);

//********** Excerpt from main.c **********
//callback function started from the kernel
char adc_callback(void) {
    unsigned int resp;
    //getting the converted value
    callDriver(DRV_ADC,ADC_LAST_VALUE,&resp);
    //changing line and printing on LCD
    callDriver(DRV_LCD,LCD_LINE,1);
    callDriver(DRV_LCD,LCD_INTEGER,resp);
    return SUCCESS;
}
“Don't Reinvent The Wheel, Unless You Plan on Learning More About Wheels”

Jeff Atwood
Thanks!

Rodrigo Maximiano Antunes de Almeida
rmaalmeida@gmail.com
@rmaalmeida
Universidade Federal de Itajubá
Portal embarcados