Embedded System Design: From Electronics to Microkernel Development

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Workshop schedule

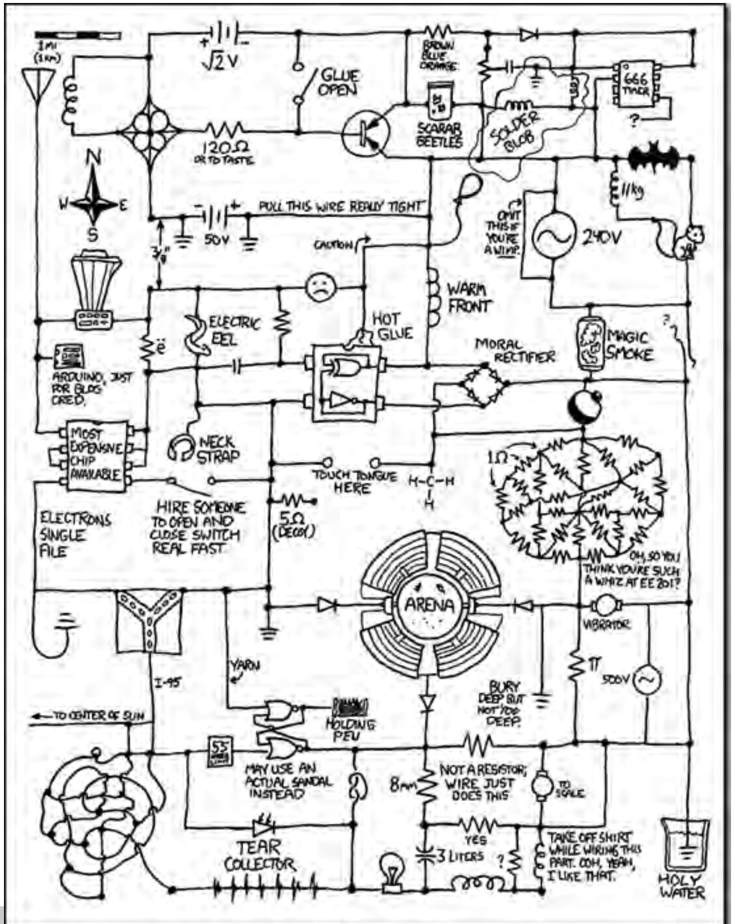
- Hardware
  - Electronics introduction
  - Board development
- Firmware
  - Embedded programming
  - Peripheral access
- Kernel
  - Timing requirements
  - Device drivers

Hardware

Hardware concepts

- Electronics introduction
  - Schematics
  - Datasheets
  - Protoboard/breadboard
  - LED
  - Potentiometer
  - LCD
  - Microcontroller
- System design
  - Basic steps

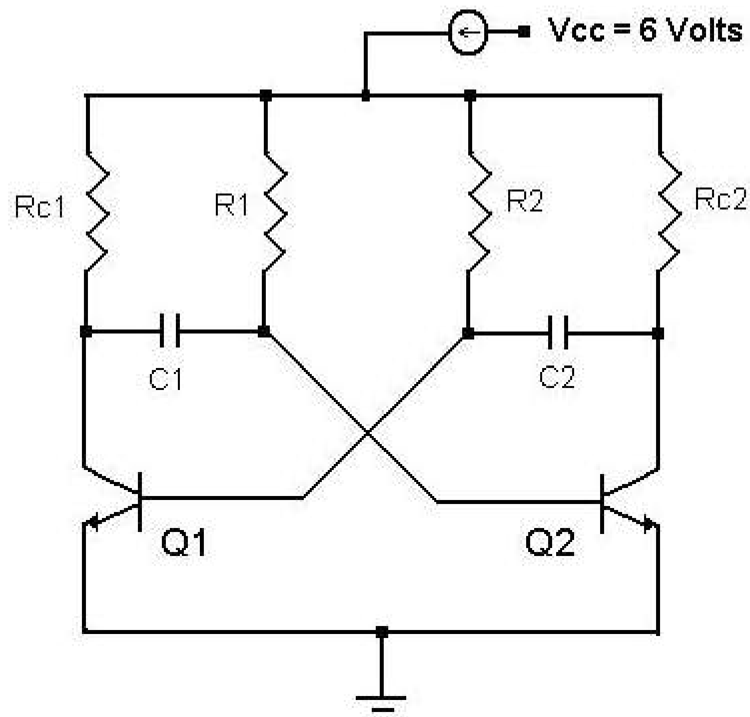
Electronics introduction



- http://xkcd.com/730/

Schematics

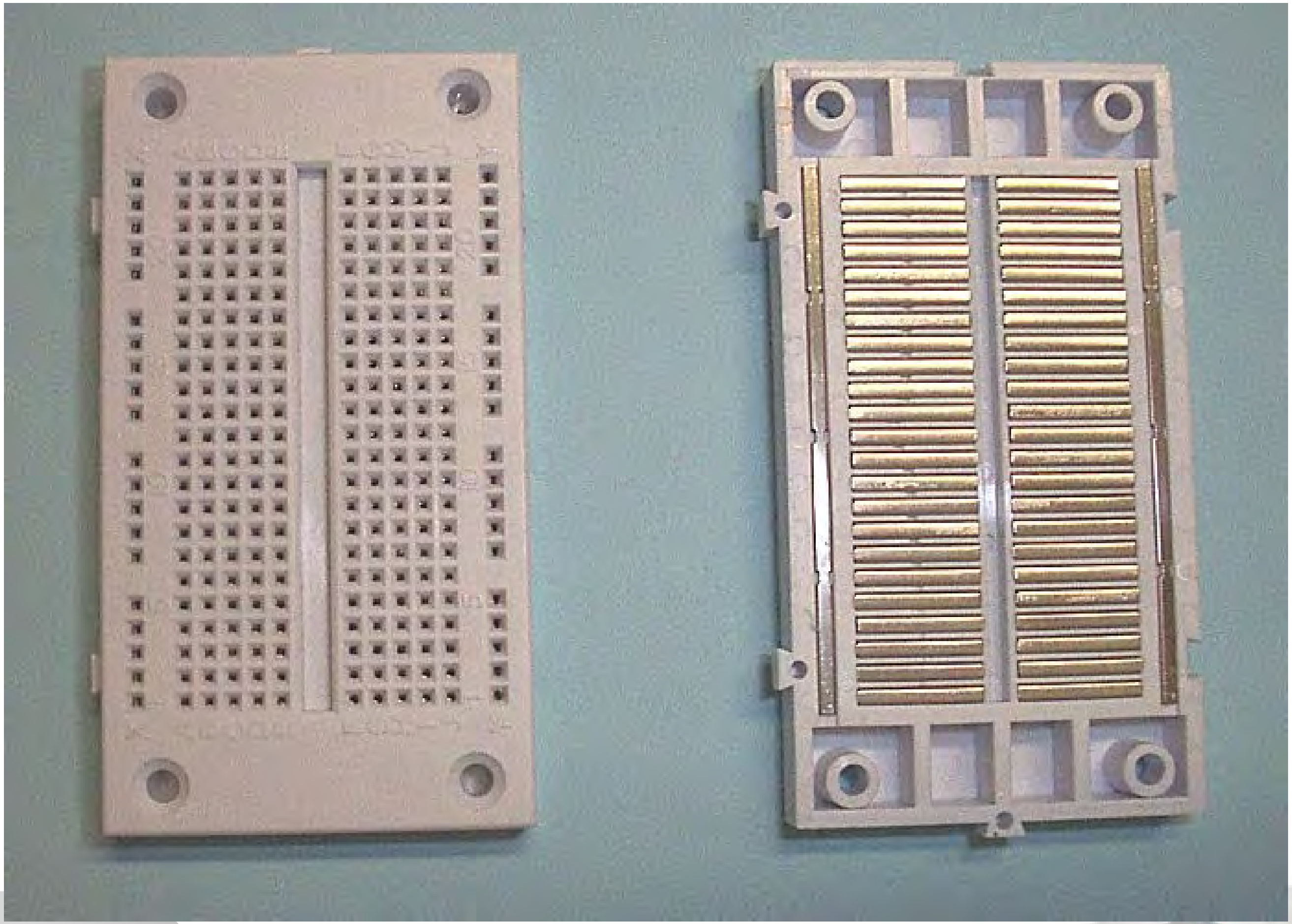
- Way to represent the components and its connections
- Each component has its own symbol
- Crossing wires only are connected if joined with a dot



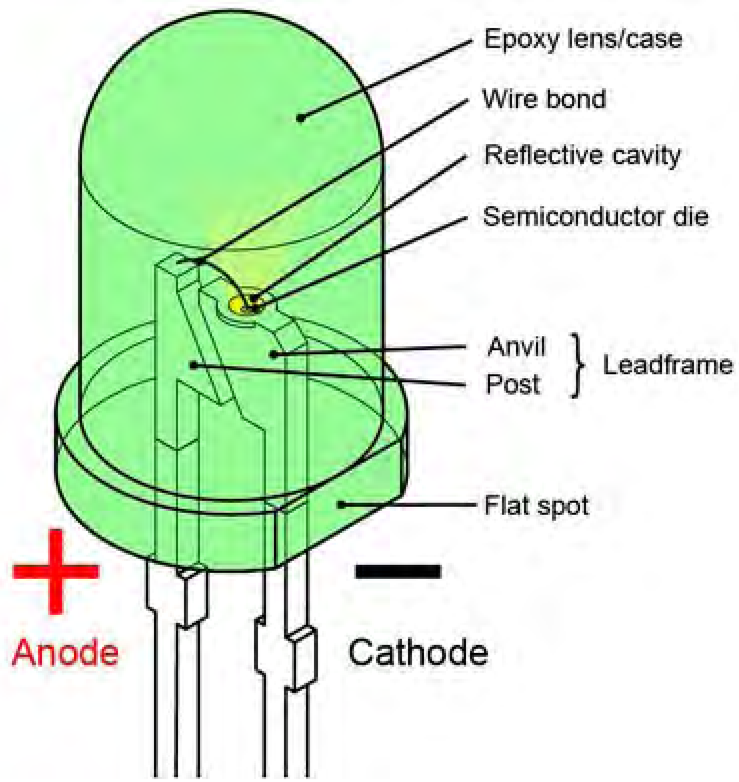
Datasheets

- The main source of information concerning electronics
- Presents
  - Electrical characteristics
  - Simplified schematics
  - Use example
  - Opcodes/API

Protoboard/Breadboard

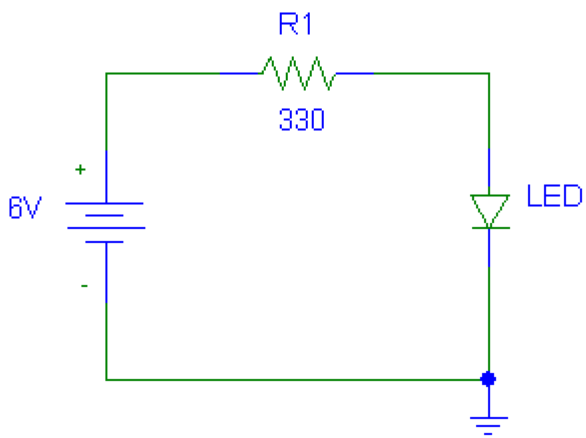


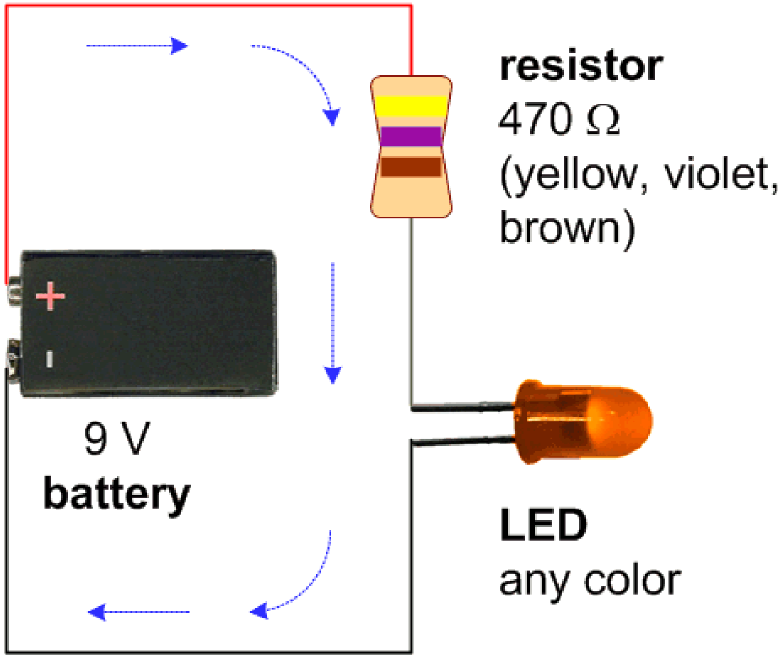
LED



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

LED

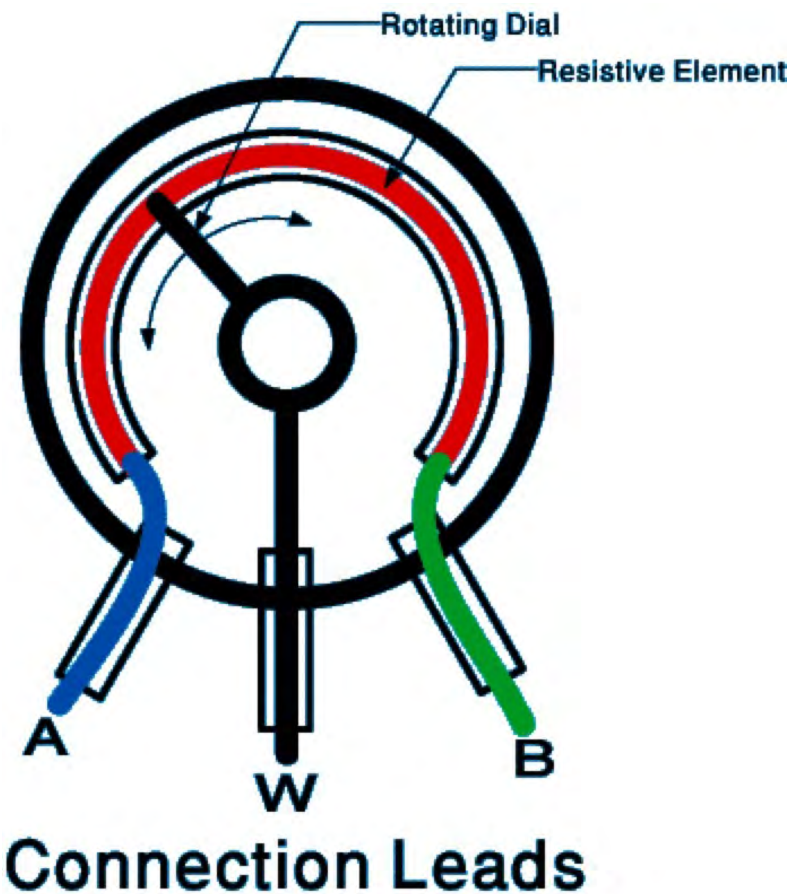

R1
330
6V
+
-
LED

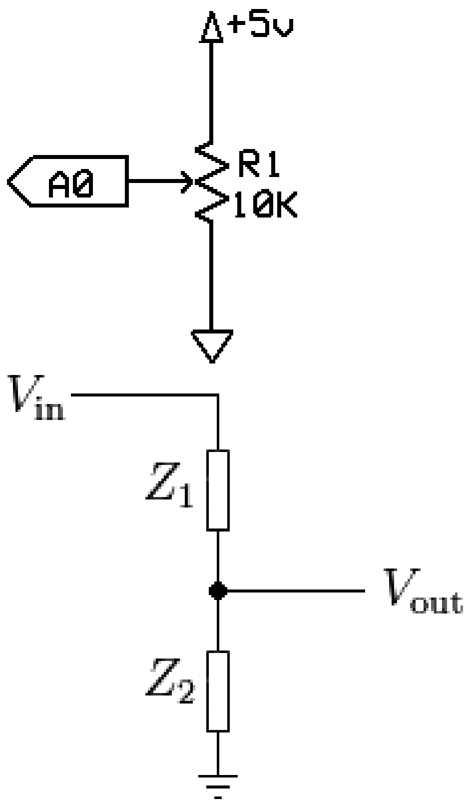

resistor
470 Ω
(yellow, violet, brown)
+
-
9 V
battery
LED
any color

Potentiometer

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

Potentiometer

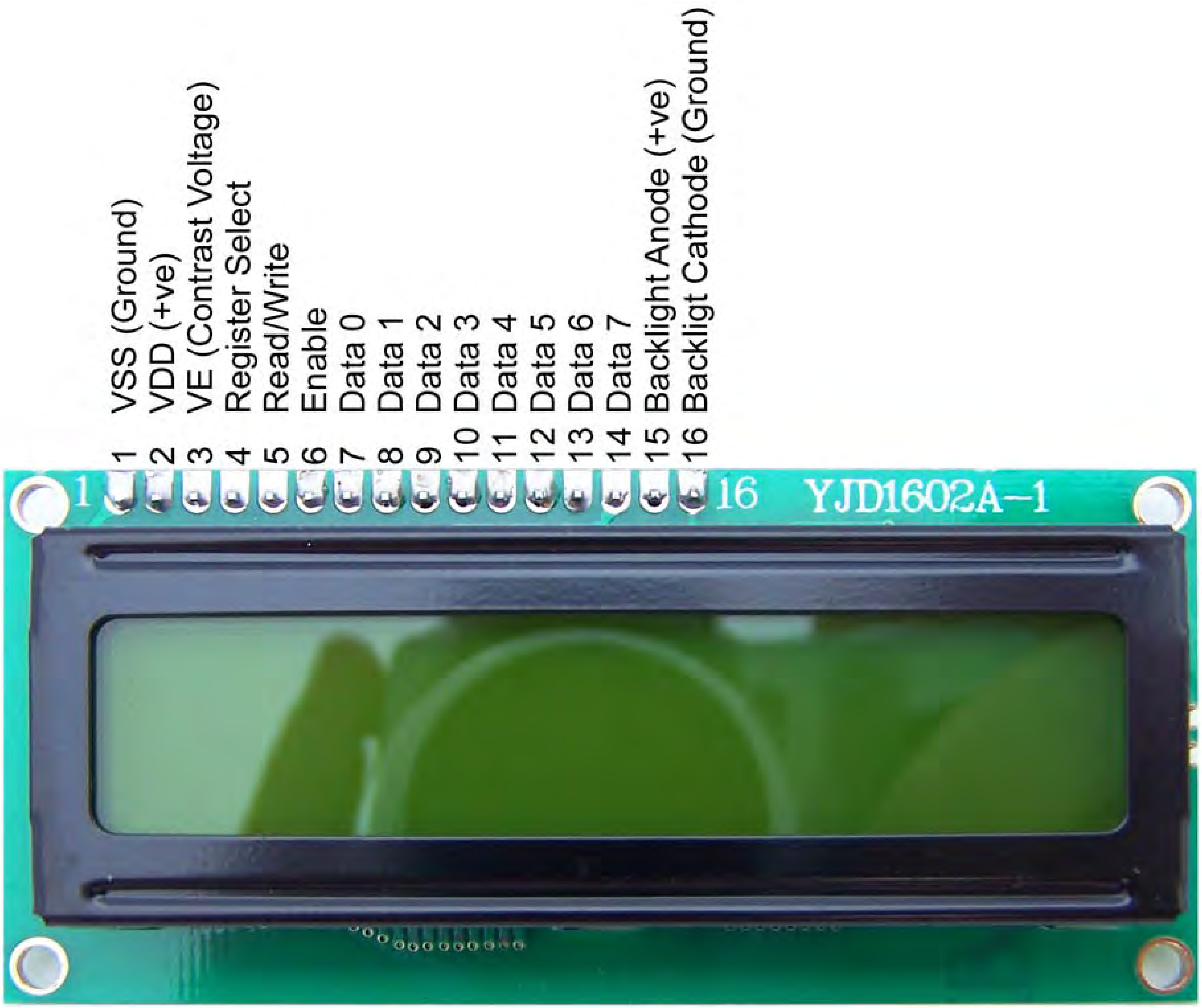




LCD Display

LCD Display

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


1 VSS (Ground)
2 VDD (+ve)
3 VE (Contrast Voltage)
4 Register Select
5 Read/Write
6 Enable
7 Data 0
8 Data 1
9 Data 2
10 Data 3
11 Data 4
12 Data 5
13 Data 6
14 Data 7
15 Backlight Anode (+ve)
16 Backligt Cathode (Ground)
1
16
YJD1602A-1

LCD Display

- Backlight
- Data connection
- Current consumption
- Power on time/routine

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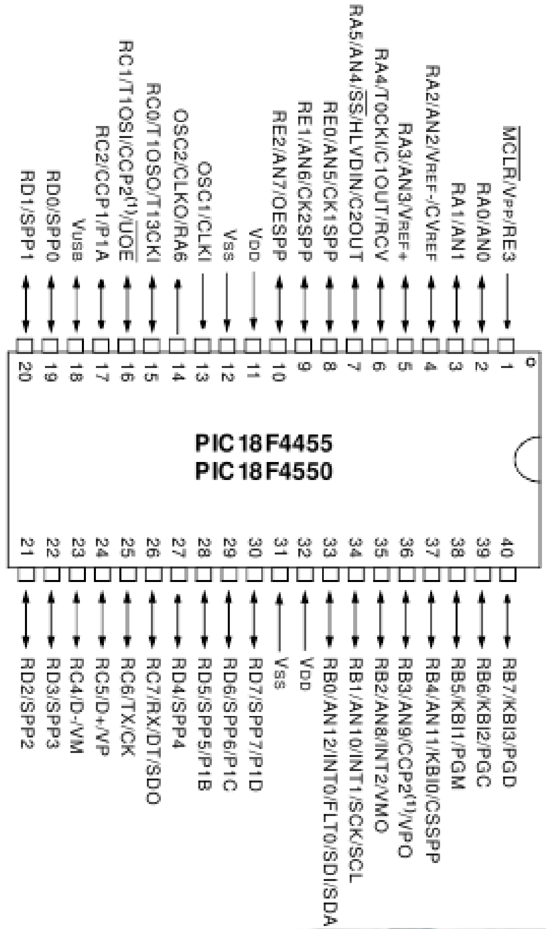
Microcontroller

- 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 desing

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

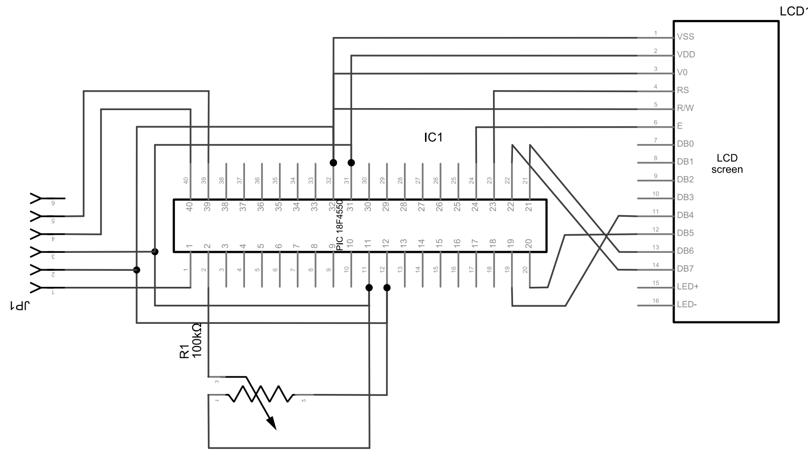
- Free CAD tools for electronics
  - Fritzing (fritzing.org)
  - Kicad
  - LTSpice
  - https://www.circuitlab.com/

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

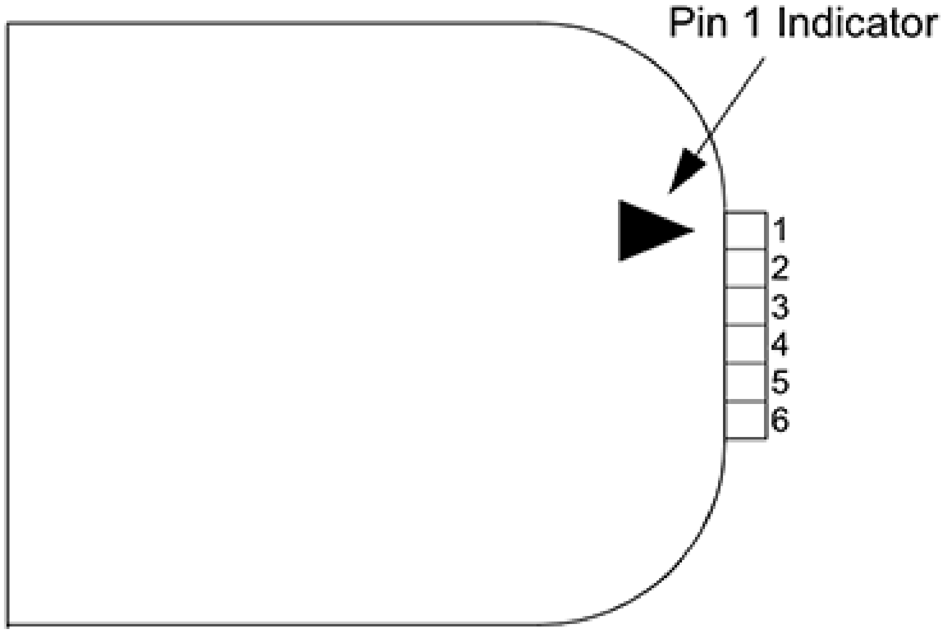
- Programmer
- IDE
- Basic concepts
  - CPU Architecture
  - HW configuration
  - Memory access
- First program (Led blinking)
- Second program (ADC read)
- Third program (LCD access)

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 Description*

1 = $V_{PP}/\overline{MCLR}$

2 = V_{DD} Target

3 = V_{SS} (ground)

4 = ICSPDAT/PGD

5 = ICSPCLK/PGC

6 = LVP

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

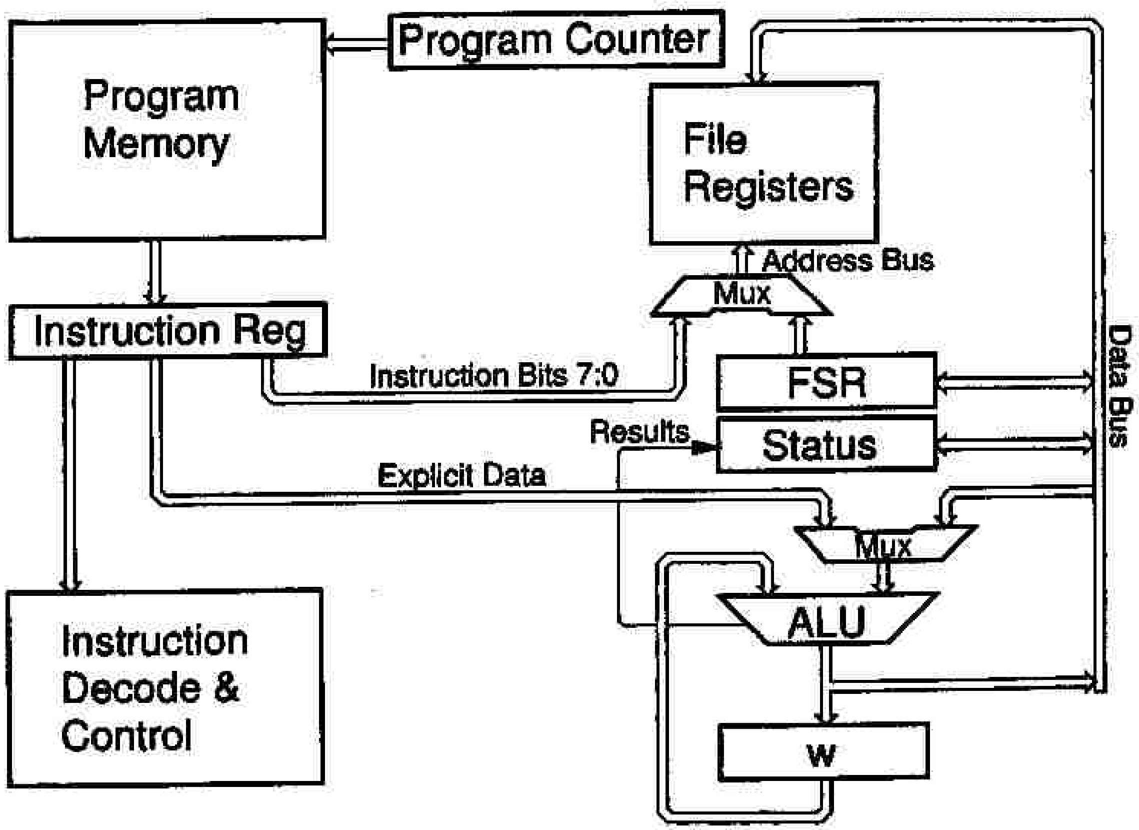
Firmware tools

- IDE
  - MPLABX
    - Based on Netbeans
- Compiler
  - SDCC
    - Based on GCC
  - GPUtils

Embedded programming concepts

Becouse while(a==a); is not an infinite loop!

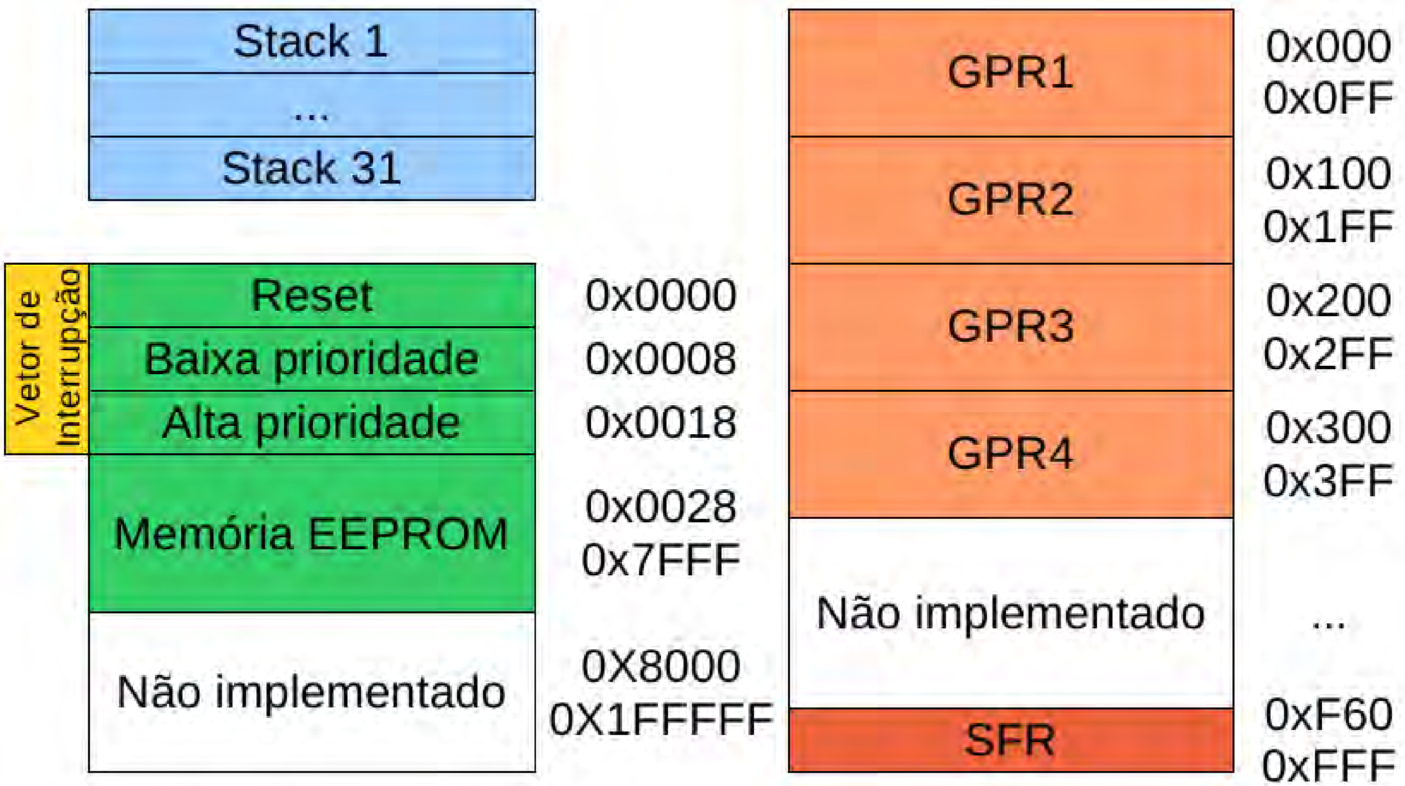
Embedded programming concepts



[redacted] PICmicro® MCU Processor with Indexed addressing

Embedded programming concepts

- Memory segmentation



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

File Name		Bit 7	Bit 6	Bit 5	Bit 4	Bit 3	Bit 2	Bit 1	Bit 0	Default/ Unprogrammed Value
300000h	CONFIG1L	—	—	USBDIV	CPUDIV1	CPUDIV0	PLLDIV2	PLLDIV1	PLLDIV0	--00 0000
300001h	CONFIG1H	IESO	FCMEN	—	—	FOSC3	FOSC2	FOSC1	FOSC0	00-- 0101
300002h	CONFIG2L	—	—	VREGEN	BORV1	BORV0	BOREN1	BOREN0	$\overline{\text{PWRTEN}}$	--01 1111
300003h	CONFIG2H	—	—	—	WDTPS3	WDTPS2	WDTPS1	WDTPS0	WDTEN	---1 1111
300005h	CONFIG3H	MCLRE	—	—	—	—	LPT1OSC	PBADEN	CCP2MX	1--- -011
300006h	CONFIG4L	$\overline{\text{DEBUG}}$	XINST	ICPRT(3)	—	—	LVP	—	STVREN	100- -1-1
300008h	CONFIG5L	—	—	—	—	CP3(1)	CP2	CP1	CP0	---- 1111
300009h	CONFIG5H	CPD	CPB	—	—	—	—	—	—	11-- ----
30000Ah	CONFIG6L	—	—	—	—	WRT3(1)	WRT2	WRT1	WRT0	---- 1111
30000Bh	CONFIG6H	WRTD	WRTB	WRTC	—	—	—	—	—	111- ----
30000Ch	CONFIG7L	—	—	—	—	EBTR3(1)	EBTR2	EBTR1	EBTR0	---- 1111
30000Dh	CONFIG7H	—	EBTRB	—	—	—	—	—	—	-1-- ----
3FFFFEh	DEVID1	DEV2	DEV1	DEV0	REV4	REV3	REV2	REV1	REV0	xxxx xxxx(2)
3FFFFFh	DEVID2	DEV10	DEV9	DEV8	DEV7	DEV6	DEV5	DEV4	DEV3	0001 0010(2)

Legend: x = unknown, u = unchanged, - = unimplemented. Shaded cells are unimplemented, read as '0'.

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

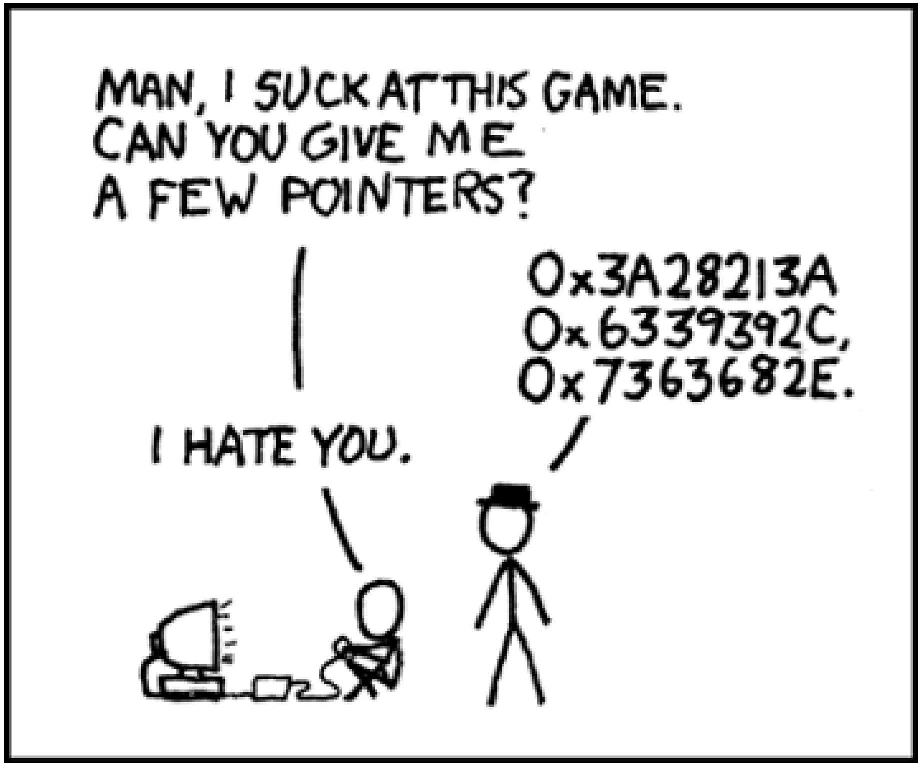
2: See Register 25-13 and Register 25-14 for DEVID values. DEVID registers are read-only and cannot be programmed by the user.

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

Embedded programming concepts

```
#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

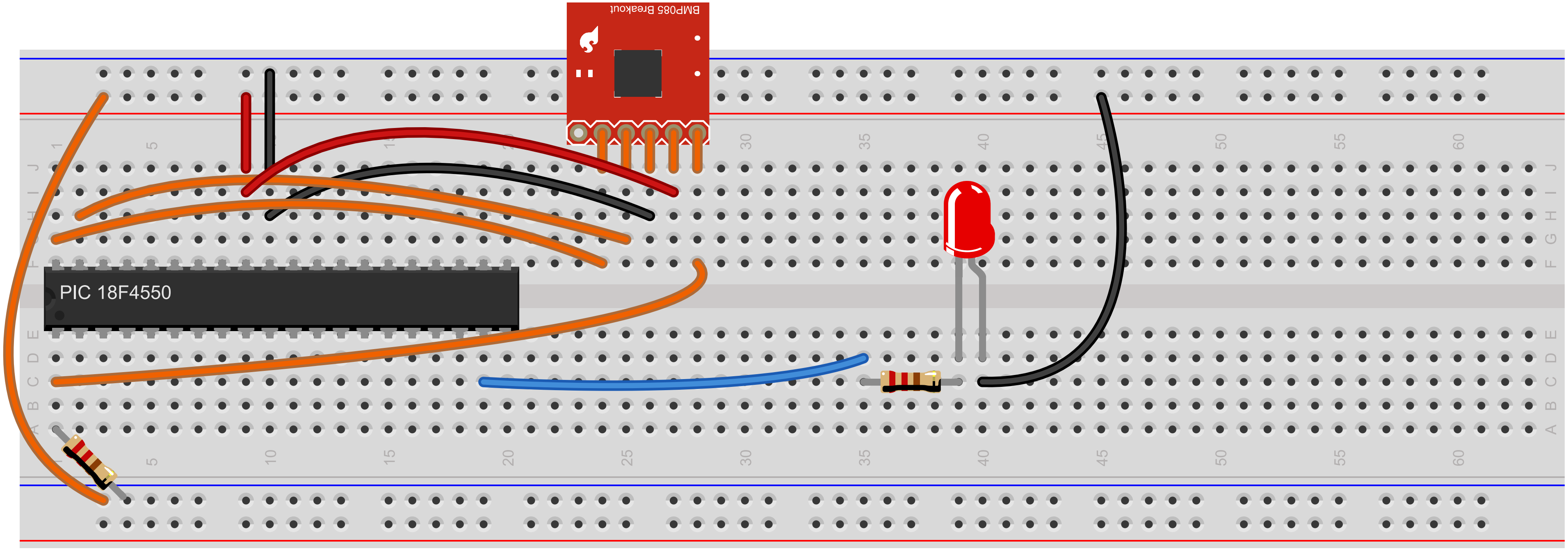
```
char mask;
mask = 1 << 2;
arg = arg | mask;

//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
- Open MPLABX IDE
  - configure SDCC and PICkit
- Create a project to
  - Blink a led

First lab



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First Lab

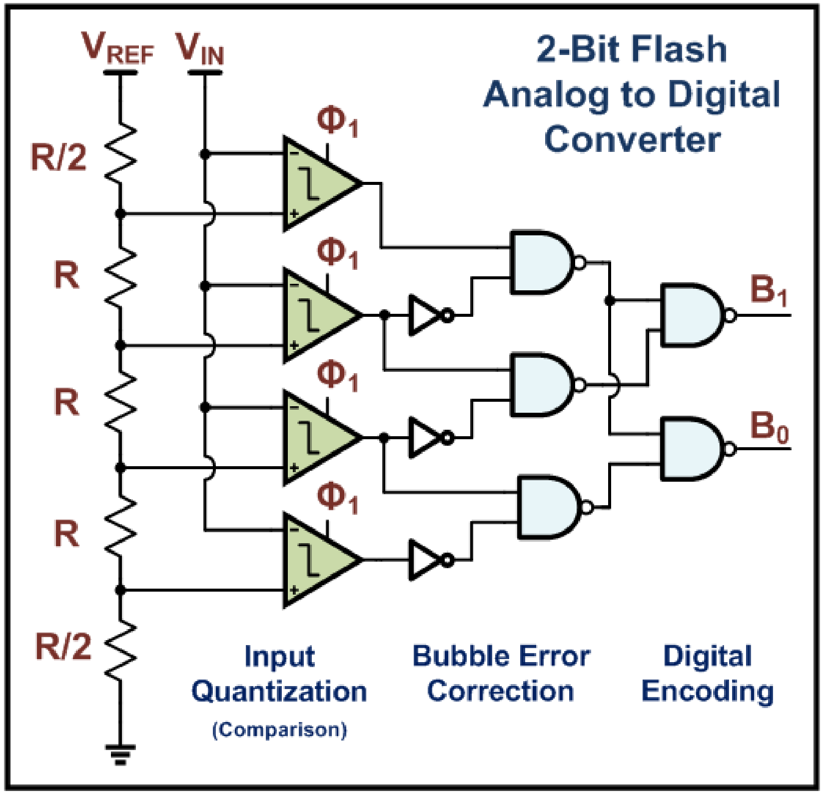
```
#define PORTD (*(volatile __near unsigned char*)0xF83)
#define TRISD (*(volatile __near unsigned char*)0xF95)

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

Second lab

- Using ADC potentiometer as input

Peripherals setup

- Analog to digital converter



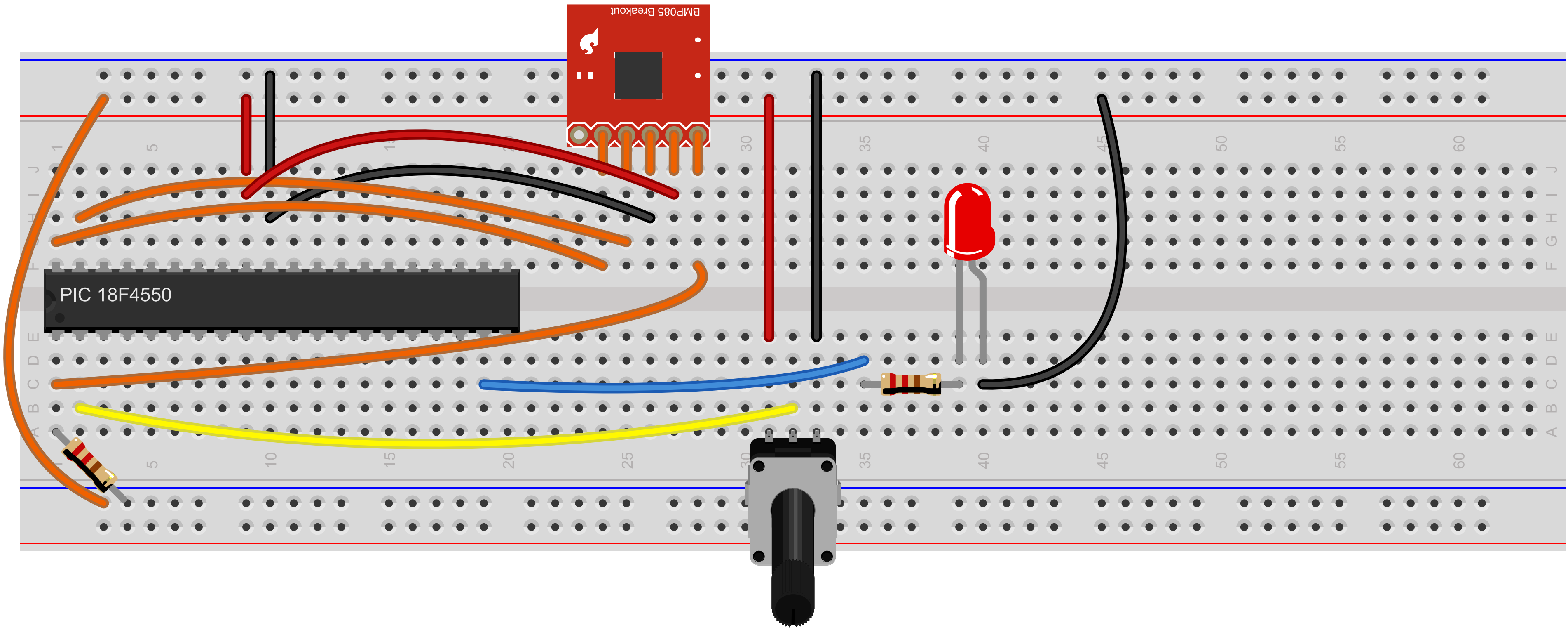
ADC setup

```
#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;
}
```

Second lab



Second Lab

```c
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

LCD communication

```
#define RS 6
#define EN 7
void delayMicroseconds(int ms) {
        int i;
        for (; ms > 0; ms--) {
                for (i = 0; i < 30; i++);
        }
}
void pulseEnablePin() {
     BitClr(PORTC, EN);
     delayMicroseconds(1);
     // send a pulse to enable
     BitSet(PORTC, EN);
     delayMicroseconds(1);
     BitClr(PORTC, EN);
}
```

LCD communication

```
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);
}
```

LCD communication

```
void lcdCommand(int value) {
    pushByte(value, 0);
    delayMicroseconds(40);
}

void lcdChar(int value) {
    pushByte(value, 1);
    delayMicroseconds(2);
}
```

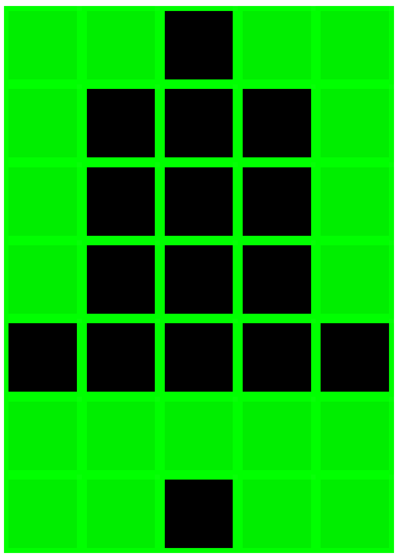
LCD communication

```
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

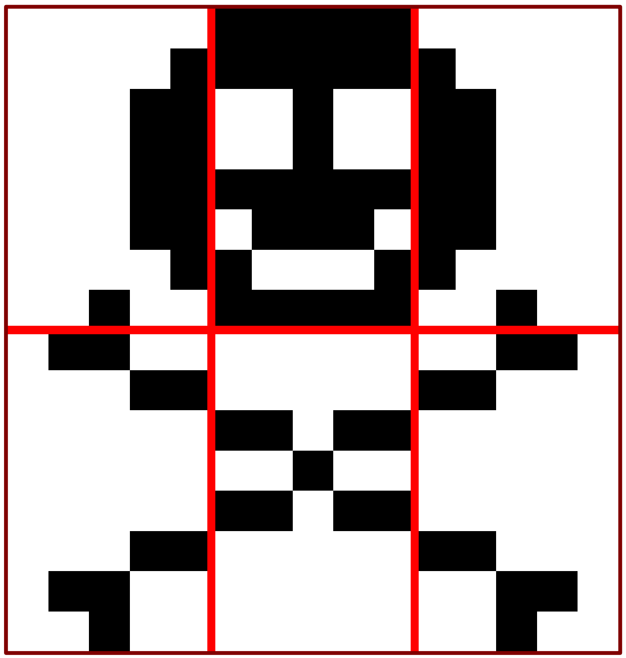
- The LCD can hold up to 8 custom characters
- Each character is a 5*8 matrix
- Translating: 40*64 b/w drawing area

LCD communication

Custom Pattern		Decimal	Hex
	Row 1:	4	0x04
	Row 2:	14	0x0E
	Row 3:	14	0x0E
	Row 4:	14	0x0E
	Row 5:	31	0x1F
	Row 6:	0	0x00
	Row 7:	4	0x04

Source: http://www.8051projects.net/lcd-interfacing/lcd-custom-character.php

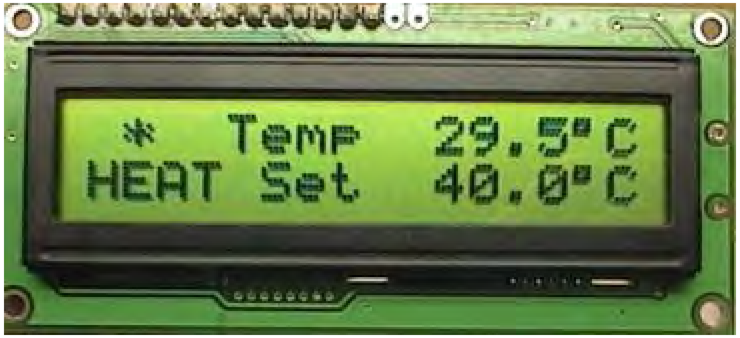
LCD communication



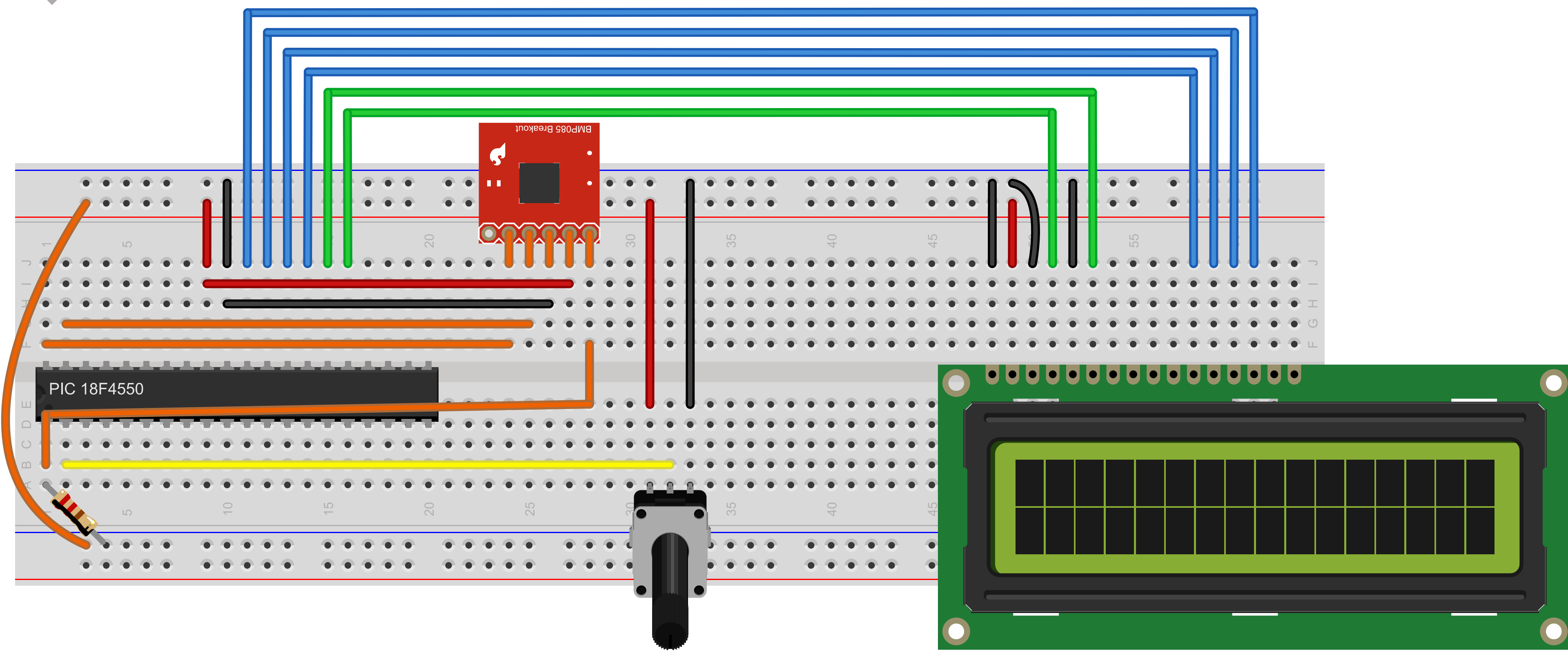
```c
void lcdDefconLogo(void) {
  int i;
  unsigned char defcon[] = {
    0x00, 0x01, 0x03, 0x03, 0x03, 0x03, 0x01, 0x04,
    0x0e, 0x1f, 0x04, 0x04, 0x1f, 0x0e, 0x11, 0x1f,
    0x00, 0x10, 0x18, 0x18, 0x18, 0x18, 0x10, 0x04,
    0x0c, 0x03, 0x00, 0x00, 0x00, 0x03, 0x0c, 0x04,
    0x00, 0x00, 0x1b, 0x04, 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



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Time to break;

Back @ 14:00

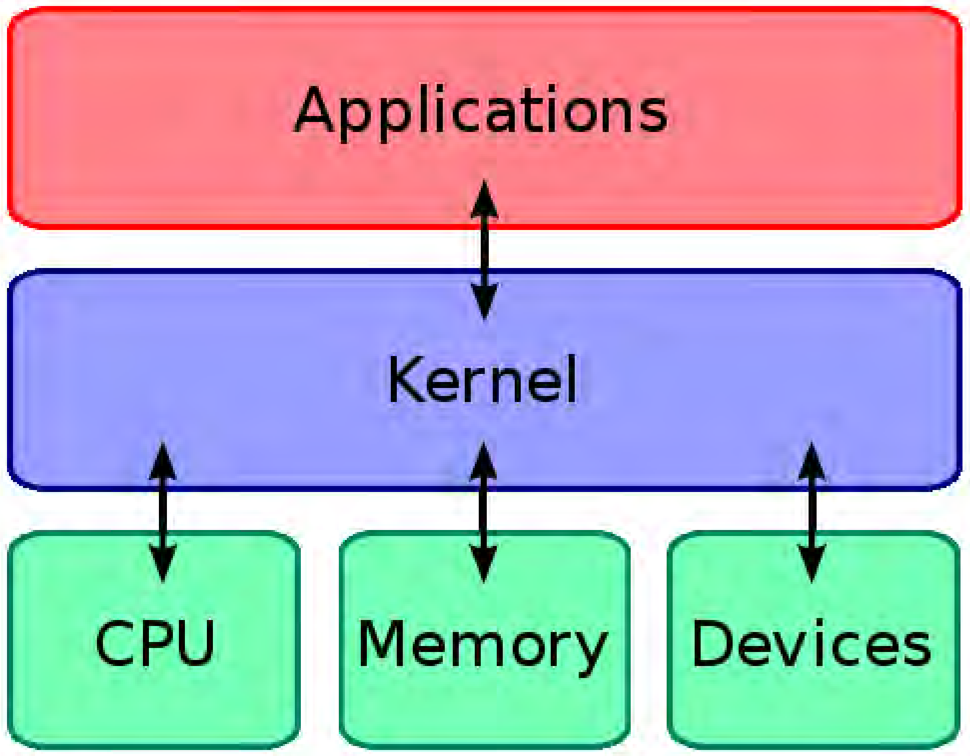
//afternoon topics

```
void main (void){
 //variable declaration
    kernel_project(1);
 //initialization
    concepts(2);
 //hard-work
    microkernel(3);
    device_driver_controller(4);
}
```

```
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);
}
```

what_is_a_kernel(1.1);

kernel_project(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);

- Improve home design
- Reuse code more efficiently
- Full control over the source
- Specific tweeks to the kernel
  - Faster context switch routine
  - More control over driver issues (interrupts)

`kernel_project(1);`

Develop my own kernel?

Why **not**?

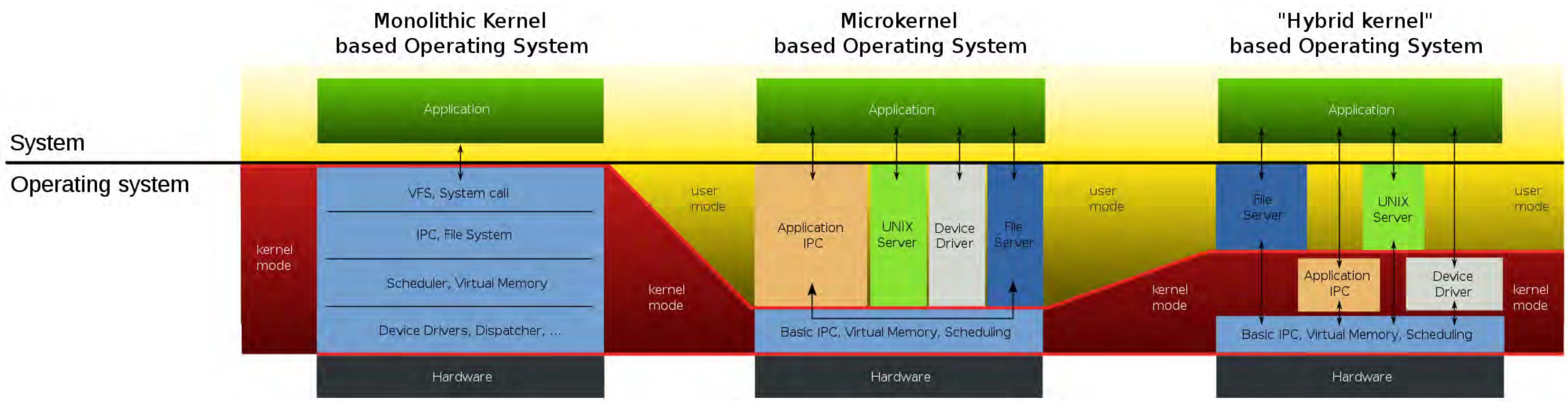
kernel_project(1);

- 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

kernel_project(1);



kernel_project(1);

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

kernel_project(1);

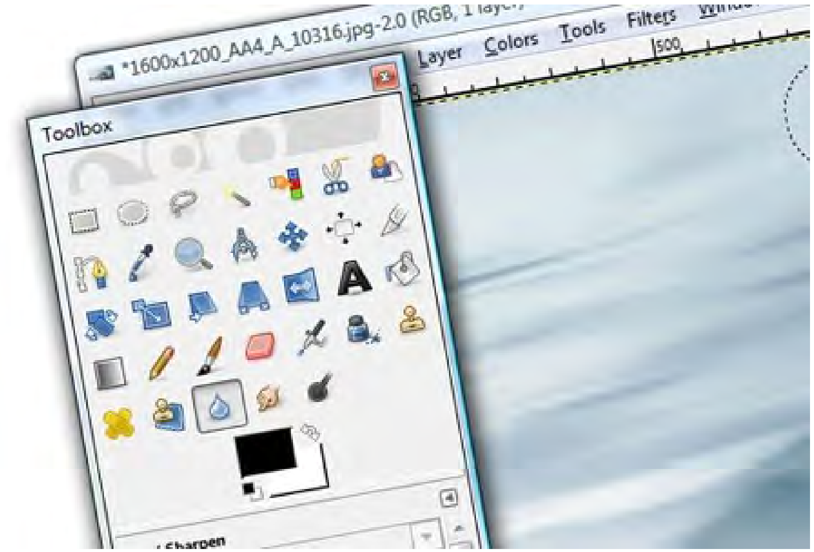
- Our decisions:
  - Microkernel
  - Non-preemptive
  - Cooperative
  - No memory management
  - Process scheduled based on timer
  - Isolate drivers using a controller

```
void concepts (float i){
    function_pointers(2.1);
    structs(2.2);
    circular_buffers(2.3);
    temporal_conditions(2.4);
    void_pointers(2.5);
}
```

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;
}
```

concepts(2);

- 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.
  - Awkard declaration (it is best to use a typedef)

concepts(2);

```
//defining the type pointerTest
//it is a pointer to function that:
//   receives no parameter
//   returns no parameter
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
```

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concepts(2);

Re-code the image editor engine using function pointers

concepts(2);

```
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;
}
```

concepts(2);

- 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

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

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

concepts(2);

```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;
}
```

concepts(2);

```
 // 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;
}
```

```
circular_buffers(2.3);
```

concepts(2);

- Circular Buffers
  - "Endless" memory spaces
  - Use FIFO aproach
  - Store temporary data
  - Can implemented using vectors or linked-lists

concepts(2);

- Vector implementation
  - Uses less space
  - Need special caution when cycling
  - Problem to differentiate full from empty

concepts(2);

```c
#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;
}
```

temporal_conditions(2.4);

concepts(2);

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);

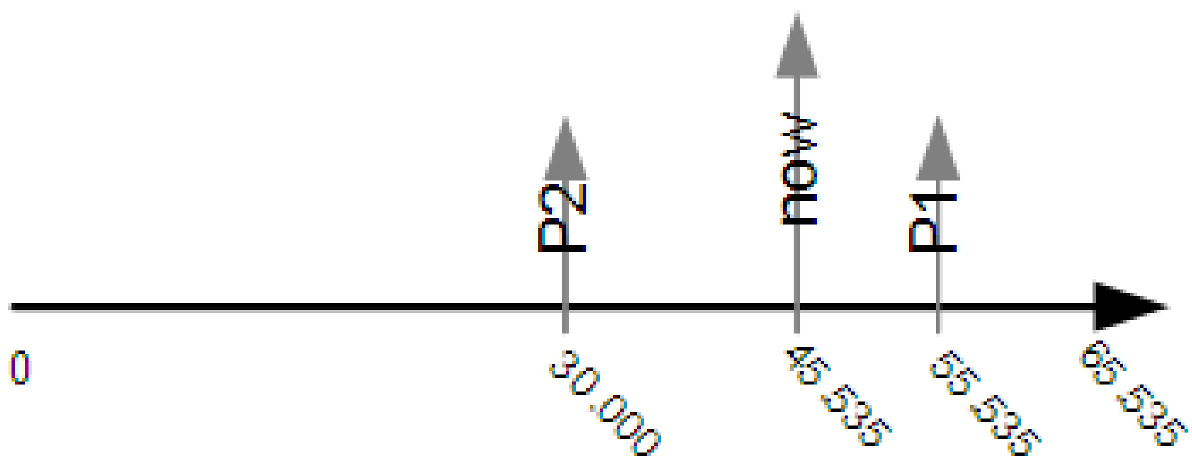
- To implement temporal conditions:
  1. There must be a tick event that occurs with a precise frequency
  2. The kernel must be informed of the execution frequency needed for each process.
  3. The sum of process duration must “fit” within the processor available time.

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

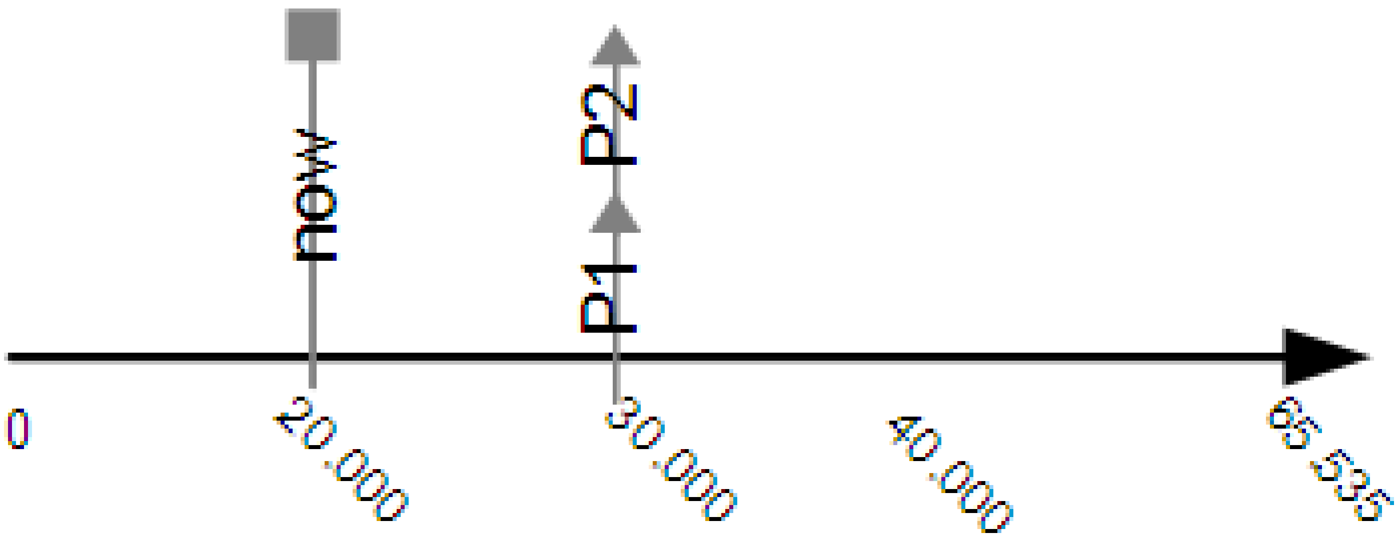
concepts(2);

- Scheduling processes:
  - Using a finite timer to schedule will result in overflow
  - Example: scheduling 2 processes for 10 and 50 seconds ahead.



concepts(2);

- And if two process are to be called in the same time?



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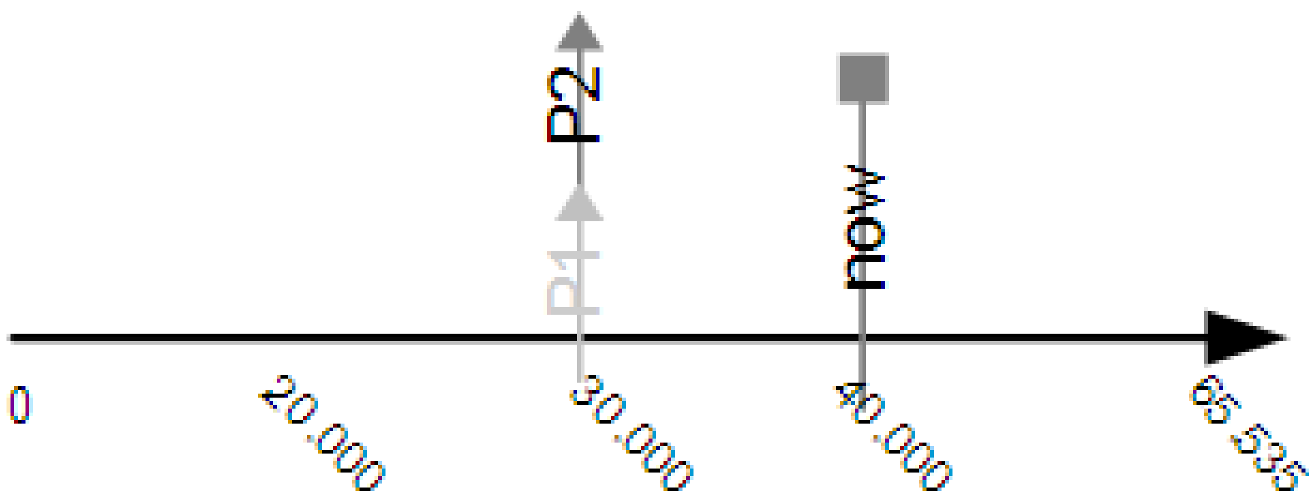
concepts(2);

- Question:
  - From the timeline above (only the timeline) is P2 late or it was scheduled to happen 55(s) from now?



concepts(2);

- 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?

void_pointers(2.5);

concepts(2);

- 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);
}
```

concepts(2);

```
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);
```

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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);
```

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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

```
//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");
}
```

microkernel(3);

- 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

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

microkernel(3);

```c
//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

microkernel(3);

```c
//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);

```
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;
      }
   }
}
```

microkernel(3);

- 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

```
//process struct
typedef struct {
      ptrFunc
function;
      int period;
      int start;
} process;
```

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microkernel(3);

- We must create an function that will run on each timer interrupt updating the counters

```
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;
      }
}
```

microkernel(3);

- The add process function will be the responsible to initialize correctly the fields

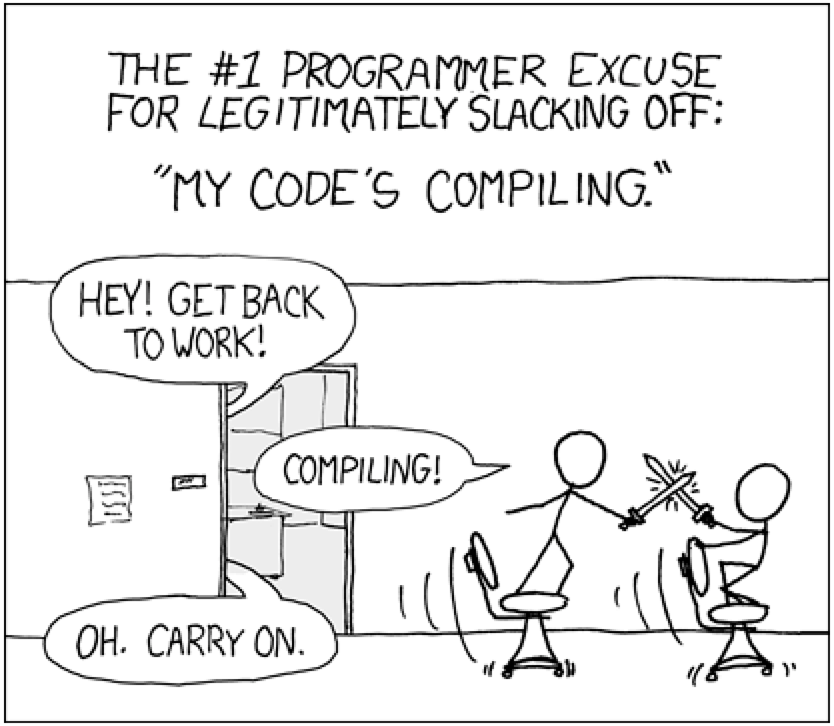
```
char AddProc(process newProc){
    //checking for free space
    if ( ((end+1)%SLOT_SIZE) != start){
        pool[end] = newProc;
        //increment start timer with period
        pool[end].start += newProc.period;
        end = (end+1)%SLOT_SIZE;
        return SUCCESS;
    }
    return FAIL;
}
```

microkernel(3);

```
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_controler (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);
```

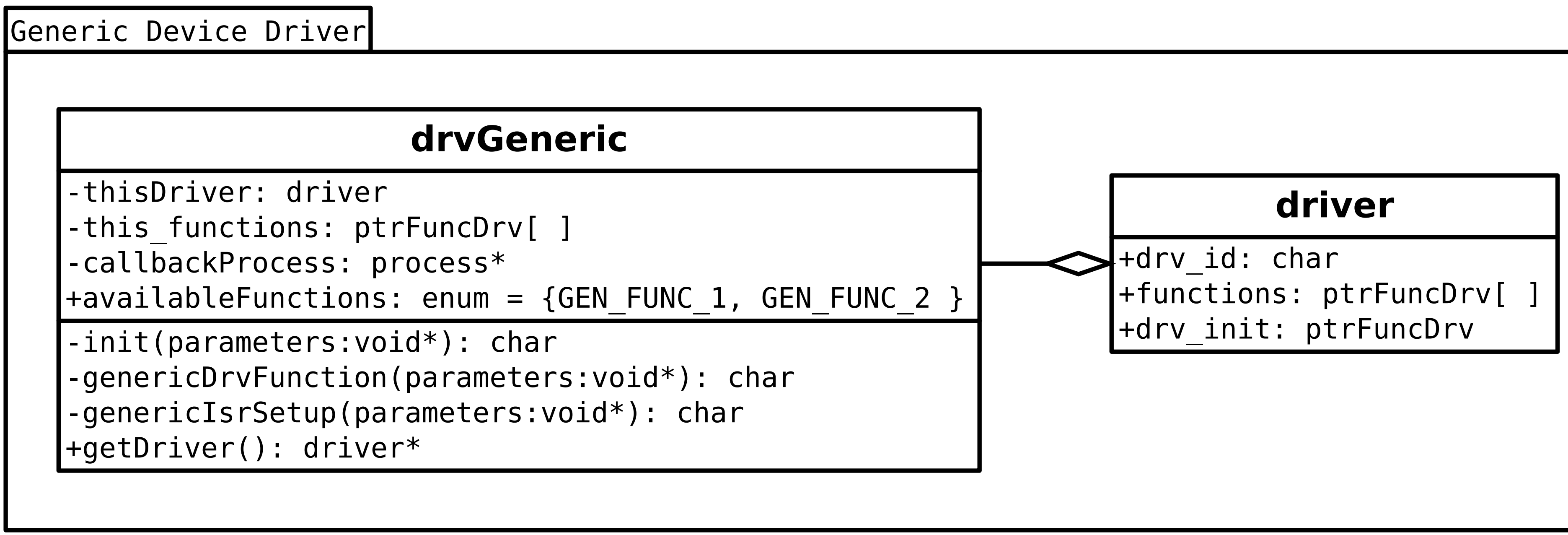
device_driver_controller(4);

- 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);



```
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 correcly
    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 DRV_FUNC_NOT_FOUND;
}
```

device_driver_controller(4);

```
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, 'O');
    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?

device_driver_controller(4);

- In order to simplify the design, each driver build its function define enum.

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

- The controller builds a driver define enum

```
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

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

```c
//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);

```c
//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;
}
```

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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?

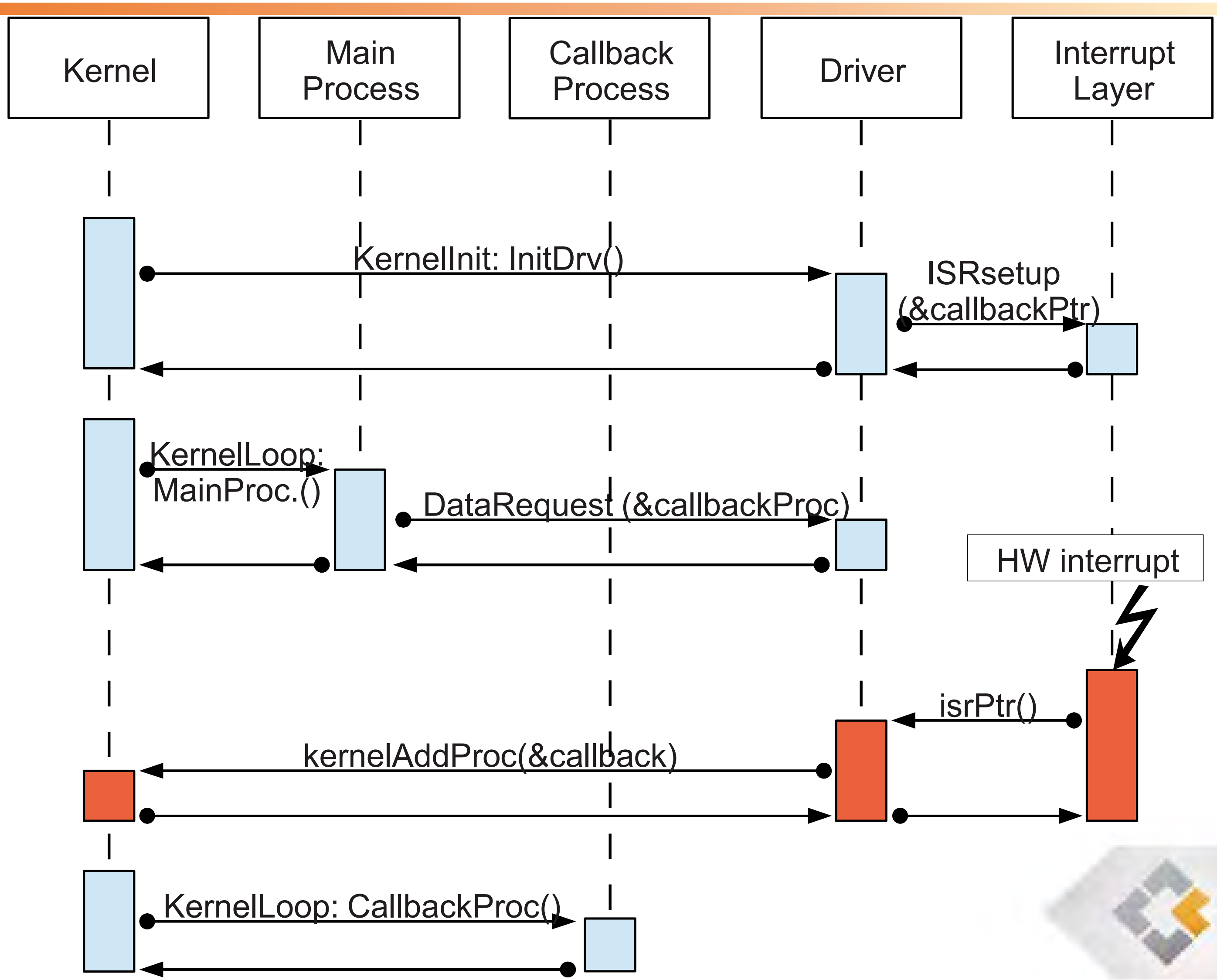
device_driver_controller(4);

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);



device_driver_controller(4);

```c
//********** 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;
}
```

device_driver_controller(4);

```
//********** 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);

```c
//********** 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!

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Portal embarcados