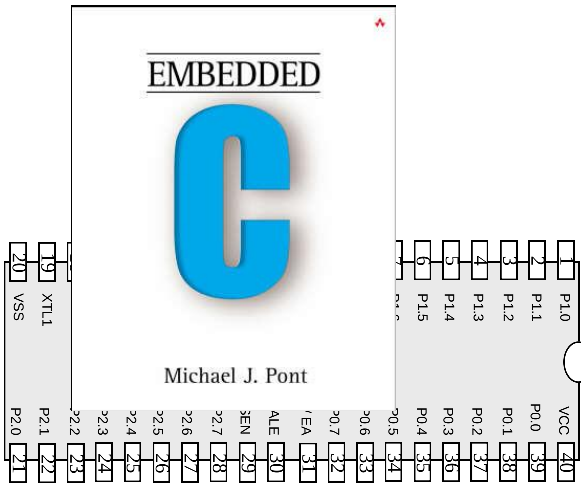
Programming Embedded Systems

A 10-week course, using C

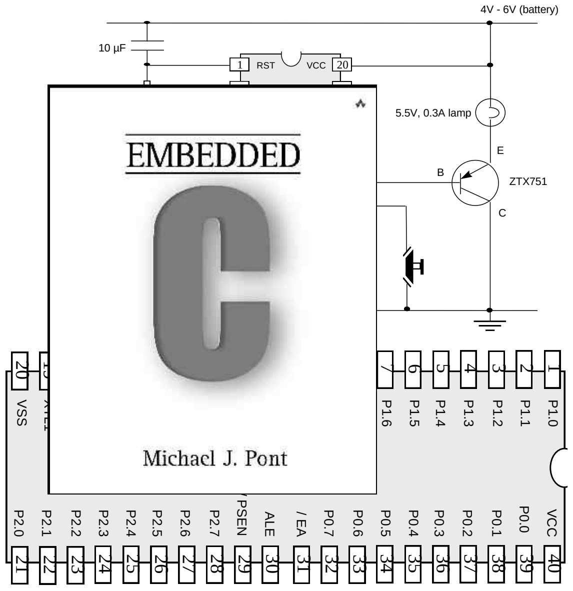


Michael J. Pont

[v1.4a]

Further info:
`http://www.safetty.net/training/beginners`

Seminar 1: “Hello, Embedded World”



Overview of this seminar

This introductory seminar will:

- Provide an overview of this course
- Introduce the 8051 microcontroller
- Present the "Super Loop" software architecture
- Describe how to use port pins
- Consider how you can generate delays (and why you might need to).

Overview of this course

This course is concerned with the implementation of software (and a small amount of hardware) for embedded systems constructed using a single microcontroller.

The processors examined in detail are from the 8051 family (including both ‘Standard’ and ‘Small’ devices).

All programming is in the ‘C’ language.

By the end of the course …

By the end of the course, you will be able to:

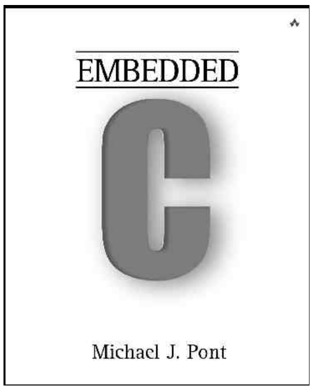
1. Design software for single-processor embedded applications based on small, industry standard, microcontrollers;
2. Implement the above designs using a modern, high-level programming language ('C'), and
3. Begin to understand issues of reliability and safety and how software design and programming decisions may have a positive or negative impact in this area.

Main course textbook

Throughout this course, we will be making heavy use of this book:

Embedded C
by Michael J. Pont (2002)

Addison-Wesley
[ISBN: 0-201-79523X]



Why use C?

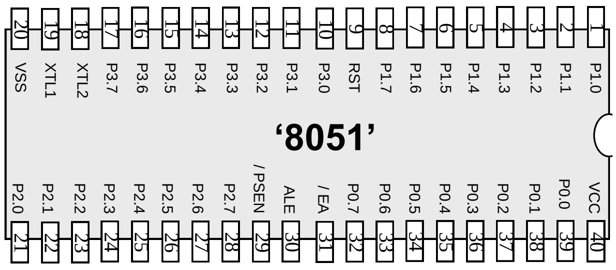
- It is a 'mid-level', with 'high-level' features (such as support for functions and modules), and 'low-level' features (such as good access to hardware via pointers);
- It is very efficient;
- It is popular and well understood;
- Even desktop developers who have used only Java or C++ can soon understand C syntax;
- Good, well-proven compilers are available for every embedded processor (8-bit to 32-bit or more);
- Experienced staff are available;
- Books, training courses, code samples and WWW sites discussing the use of the language are all widely available.

Overall, C may not be an **perfect** language for developing embedded systems, but it is a good choice (and is unlikely that a 'perfect' language will ever be created).

Pre-requisites!

- Throughout this course, it will be assumed that you have had previous programming experience: this might be in - for example - Java or C++.
- For most people with such a background, “getting to grips” with C is straightforward.

The 8051 microcontroller



Typical features of a modern 8051:

- Thirty-two input / output lines.
- Internal data (RAM) memory - 256 **bytes**.
- Up to 64 kbytes of ROM memory (usually flash)
- Three 16-bit timers / counters
- Nine interrupts (two external) with two priority levels.
- Low-power Idle and Power-down modes.

The different members of this family are suitable for everything from automotive and aerospace systems to TV "remotes".

The “super loop” software architecture

Problem

What is the minimum software environment you need to create an embedded C program?

Solution

```
void main(void)
   {
   /* Prepare for task X */
   X_Init();

   while(1) /* 'for ever' (Super Loop) */
      {
      X();  /* Perform the task */
      }
   }
```

Crucially, the ‘super loop’, or ‘endless loop’, is required because we have no operating system to return to: our application will keep looping until the system power is removed.

Strengths and weaknesseses of "super loops"

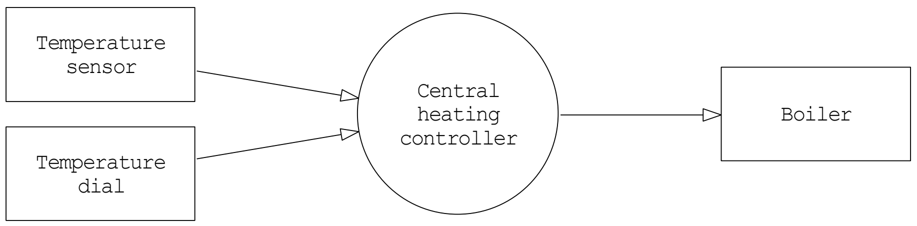
- ☺ **The main strength of Super Loop systems is their simplicity. This makes them (comparatively) easy to build, debug, test and maintain.**
- ☺ **Super Loops are highly efficient: they have minimal hardware resource implications.**
- ☺ **Super Loops are highly portable.**

BUT:

- ☹ **If your application requires accurate timing (for example, you need to acquire data precisely every 2 ms), then this framework will not provide the accuracy or flexibility you require.**
- ☹ **The basic Super Loop operates at 'full power' (normal operating mode) at all times. This may not be necessary in all applications, and can have a dramatic impact on system power consumption.**

[As we will see in Seminar 6, a scheduler can address these problems.]

Example: Central-heating controller



```
void main(void)
   {
   /* Init the system */
   C_HEAT_Init();

   while(1) /* 'for ever' (Super Loop) */
      {
      /* Find out what temperature the user requires
         (via the user interface) */
      C_HEAT_Get_Required_Temperature();

      /* Find out what the current room temperature is
         (via temperature sensor) */
      C_HEAT_Get_Actual_Temperature();

      /* Adjust the gas burner, as required */
      C_HEAT_Control_Boiler();
      }
   }
```

Reading from (and writing to) port pins

Problem

How do you write software to read from and /or write to the ports on an (8051) microcontroller?

Background

The Standard 8051s have four 8-bit ports.

All of the ports are bidirectional: that is, they may be used for both input and output.

SFRs and ports

Control of the 8051 ports through software is carried out using what are known as 'special function registers' (SFRs).

Physically, the SFR is a area of memory in internal RAM:

- P0 is at address 0x80
- P1 at address 0x90
- P2 at address 0xA0
- P3 at address 0xB0

NOTE: 0x means that the number format is HEXADECIMAL
- see Embedded C, Chapter 2.

SFRs and ports

A typical SFR header file for an 8051 family device will contain the lines:

```
sfr P0   = 0x80;
sfr P1   = 0x90;
sfr P2   = 0xA0;
sfr P3   = 0xB0;
```

Having declared the SFR variables, we can write to the ports in a straightforward manner. For example, we can send some data to Port 1 as follows:

```
unsigned char Port_data;

Port_data = 0x0F;

P1 = Port_data;  /* Write 00001111 to Port 1 */
```

Similarly, we can read from (for example) Port 1 as follows:

```
unsigned char Port_data;

P1 = 0xFF;       /* Set the port to 'read mode' */
Port_data = P1;  /* Read from the port */
```

Note that, in order to read from a pin, we need to ensure that the last thing written to the pin was a '1'.

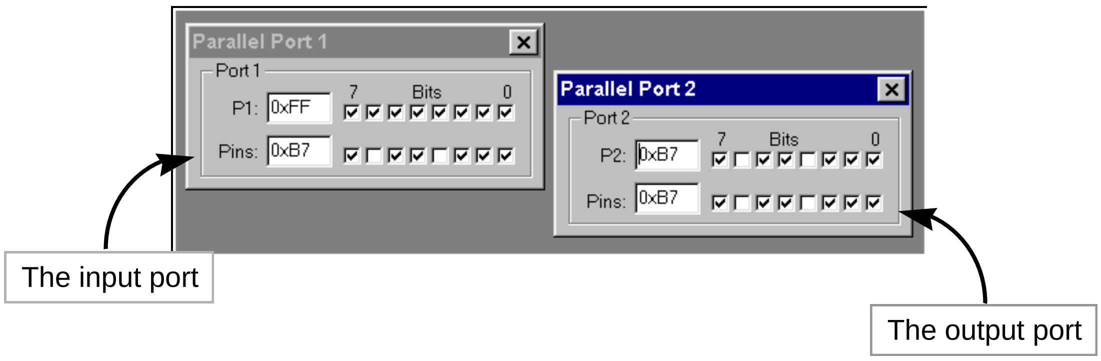
Creating and using `sbit` variables

To write to a single pin, we can make use of an `sbit` variable in the Keil (C51) compiler to provide a finer level of control.

Here's a clean way of doing this:

```
#define LED_PORT P3

#define LED_ON 0        /* Easy to change the logic here */
#define LED_OFF 1

...

sbit Warning_led = LED_PORT^0; /* LED is connected to pin 3.0 */

...

Warning_led = LED_ON;
... /* delay */
Warning_led = LED_OFF;
... /* delay */
Warning_led = LED_ON;
... /* etc */
```

Example: Reading and writing bytes



```
void main (void)
   {
   unsigned char Port1_value;

   /* Must set up P1 for reading */
   P1 = 0xFF;

   while(1)
     {
     /* Read the value of P1 */
     Port1_value = P1;

     /* Copy the value to P2 */
     P2 = Port1_value;
     }
   }
```

Creating “software delays”

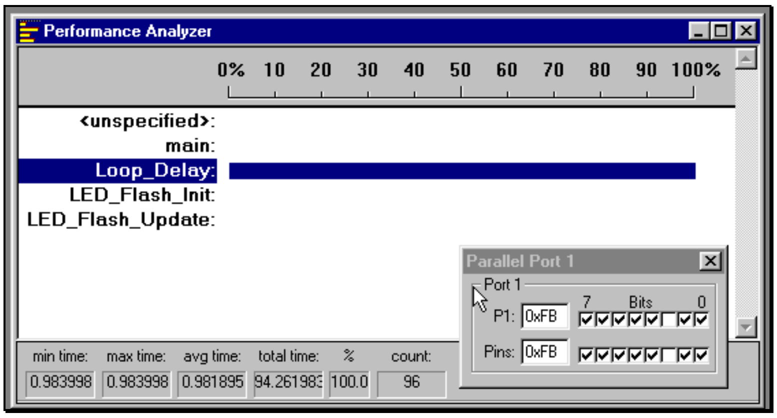
Problem

How do you create a simple delay without using any hardware (timer) resources?

Solution

```
Loop_Delay()
   {
   unsigned int x,y;

   for (x=0; x <= 65535; x++)
      {
      y++;
      }
   }


Longer_Loop_Delay()
   {
   unsigned int x, y, z;

   for (x=0; x<=65535; x++)
      {
      for (y=0; y<=65535; y++);
         {
         z++;
         }
      }
   }
```

Using the performance analyzer to test software delays


Performance Analyzer

0% 10 20 30 40 50 60 70 80 90 100%

<unspecified>:
main:
Loop_Delay:
LED_Flash_Init:
LED_Flash_Update:

min time:	max time:	avg time:	total time:	%	count:
0.983998	0.983998	0.981895	94.26198:	100.0	96

Parallel Port 1

Port 1

P1: 0xFB

Pins: 0xFB

Strengths and weaknesses of software-only delays

- ☺ **SOFTWARE DELAY can be used to produce very short delays.**
- ☺ **SOFTWARE DELAY requires no hardware timers.**
- ☺ **SOFTWARE DELAY will work on any microcontroller.**

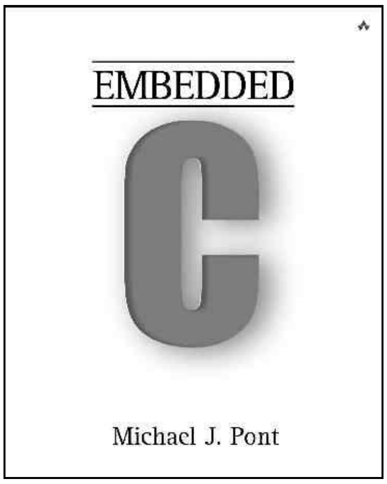
BUT:

- ☹ **It is very difficult to produce precisely timed delays.**
- ☹ **The loops must be re-tuned if you decide to use a different processor, change the clock frequency, or even change the compiler optimisation settings.**

Preparation for the next seminar

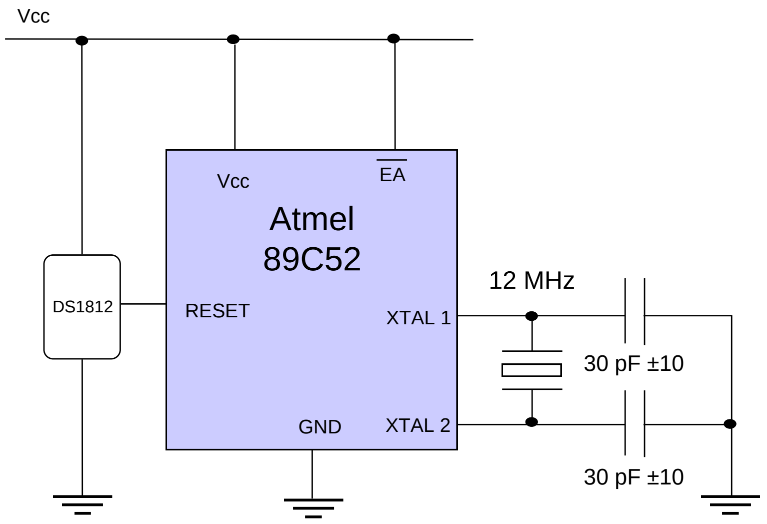
In the lab session associated with this seminar, you will use a hardware simulator to try out the techniques discussed here. This will give you a chance to focus on the software aspects of embedded systems, without dealing with hardware problems.

In the next seminar, we will prepare to create your first test systems on "real hardware".

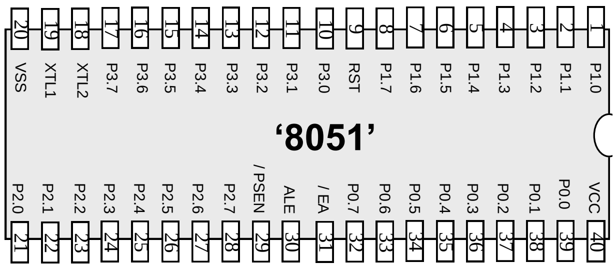


Please read Chapters 1, 2 and 3 before the next seminar

Seminar 2: Basic hardware foundations (resets, oscillators and port I/O)



Review: The 8051 microcontroller



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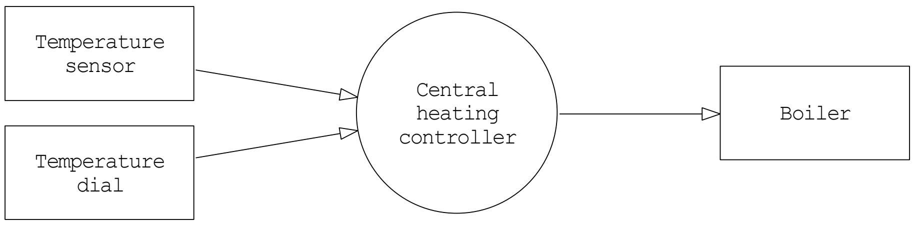

```
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   {
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      {
      /* Find out what temperature the user requires
         (via the user interface) */
      C_HEAT_Get_Required_Temperature();

      /* Find out what the current room temperature is
         (via temperature sensor) */
      C_HEAT_Get_Actual_Temperature();

      /* Adjust the gas burner, as required */
      C_HEAT_Control_Boiler();
      }
   }
```

Overview of this seminar

This seminar will:

- Consider the techniques you need to construct your first "real" embedded system (on a breadboard).

Specifically, we'll look at:

- Oscillator circuits
- Reset circuits
- Controlling LEDs

Oscillator Hardware

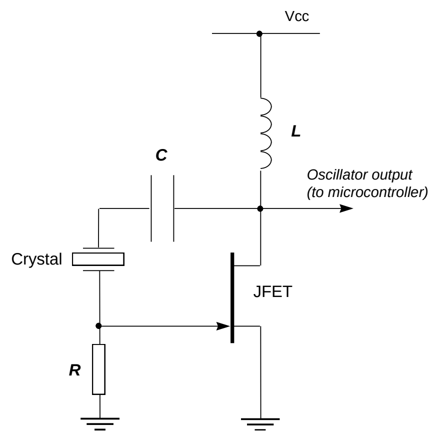
- All digital computer systems are driven by some form of oscillator circuit.
- This circuit is the 'heartbeat' of the system and is crucial to correct operation.

For example:

- If the oscillator fails, the system will not function at all.
- If the oscillator runs irregularly, any timing calculations performed by the system will be inaccurate.

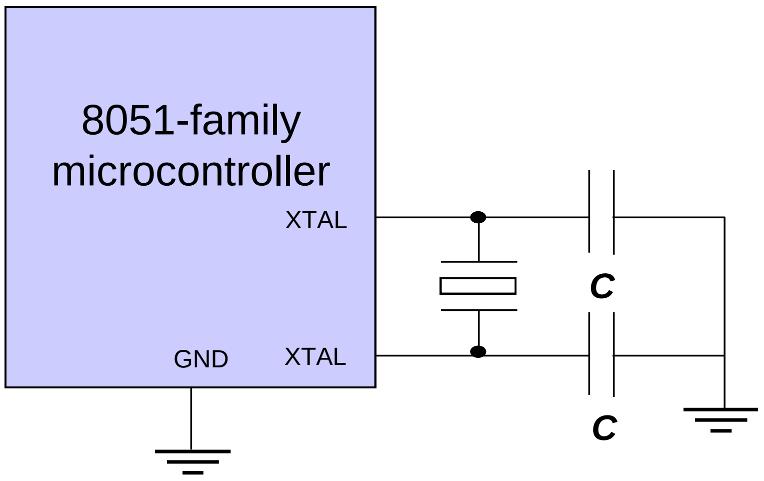
CRYSTAL OSCILLATOR

Crystals may be used to generate a popular form of oscillator circuit known as a Pierce oscillator.



- A variant of the Pierce oscillator is common in the 8051 family. To create such an oscillator, most of the components are included on the microcontroller itself.
- The user of this device must generally only supply the crystal and two small capacitors to complete the oscillator implementation.

How to connect a crystal to a microcontroller



In the absence of specific information, a capacitor value of 30 pF will perform well in most circumstances.

Oscillator frequency and machine cycle period

- In the original members of the 8051 family, the machine cycle takes **twelve oscillator periods**.

- In later family members, such as the Infineon C515C, a machine cycle takes six oscillator periods; in more recent devices such as the Dallas 89C420, only one oscillator period is required per machine cycle.
- As a result, the later members of the family operating at the same clock frequency execute instructions much more rapidly.

Keep the clock frequency as low as possible

Many developers select an oscillator / resonator frequency that is at or near the maximum value supported by a particular device.

This can be a mistake:

- Many application do not require the levels of performance that a modern 8051 device can provide.
- The electromagnetic interference (EMI) generated by a circuit increases with clock frequency.
- In most modern (CMOS-based) 8051s, there is an almost linear relationship between the oscillator frequency and the power-supply current. As a result, by using the lowest frequency necessary it is possible to reduce the power requirement: this can be useful in many applications.
- When accessing low-speed peripherals (such as slow memory, or LCD displays), programming and hardware design can be greatly simplified - and the cost of peripheral components, such as memory latches, can be reduced - if the chip is operating more slowly.

In general, you should operate at the *lowest* possible oscillator frequency compatible with the performance needs of your application.

Stability issues

- A key factor in selecting an oscillator for your system is the issue of oscillator stability. In most cases, oscillator stability is expressed in figures such as '±20 ppm': '20 parts per million'.

- To see what this means in practice, consider that there are approximately 32 million seconds in a year. In every million seconds, your crystal may gain (or lose) 20 seconds. Over the year, a clock based on a 20 ppm crystal may therefore gain (or lose) about 32 x 20 seconds, or around 10 minutes.

Standard quartz crystals are typically rated from ±10 to ±100 ppm, and so may gain (or lose) from around 5 to 50 minutes per year.

Improving the stability of a crystal oscillator

- If you want a general crystal-controlled embedded system to keep accurate time, you can choose to keep the device in an oven (or fridge) at a fixed temperature, and fine-tune the software to keep accurate time. This is, however, rarely practical.

- 'Temperature Compensated Crystal Oscillators' (TCXOs) are available that provide - in an easy-to-use package - a crystal oscillator, and circuitry that compensates for changes in temperature. Such devices provide stability levels of up to ±0.1 ppm (or more): in a clock circuit, this should gain or lose no more than around 1 minute every 20 years.

  TCXOs can cost in excess of $100.00 per unit...

- One practical alternative is to determine the temperature-frequency characteristics for your chosen crystal, and include this information in your application.

  For the cost of a small temperature sensor (around $2.00), you can keep track of the temperature and adjust the timing as required.

Overall strengths and weaknesses

☺ Crystal oscillators are stable. Typically ±20-100 ppm = ±50 mins per year (up to ~1 minute / week).

☺ The great majority of 8051-based designs use a variant of the simple crystal-based oscillator circuit presented here: developers are therefore familiar with crystal-based designs.

☺ Quartz crystals are available at reasonable cost for most common frequencies. The only additional components required are usually two small capacitors. Overall, crystal oscillators are more expensive than ceramic resonators.

BUT:

☹ Crystal oscillators are susceptible to vibration.

☹ The stability falls with age.

CERAMIC RESONATOR

Overall strengths and weaknesses

☺ **Cheaper than crystal oscillators.**

☺ **Physically robust: less easily damage by physical vibration (or dropped equipment, etc) than crystal oscillator.**

☺ **Many resonators contain in-built capacitors, and can be used without any external components.**

☺ **Small size. About half the size of crystal oscillator.**

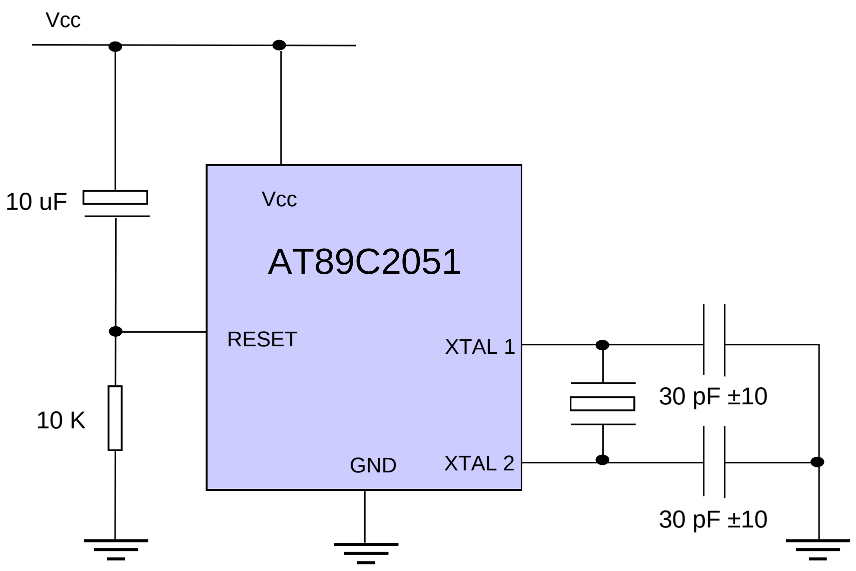
BUT:

☹ **Comparatively low stability: not general appropriate for use where accurate timing (over an extended period) is required. Typically ±5000 ppm = ±2500 min per year (up to ~50 minutes / week).**

Reset Hardware

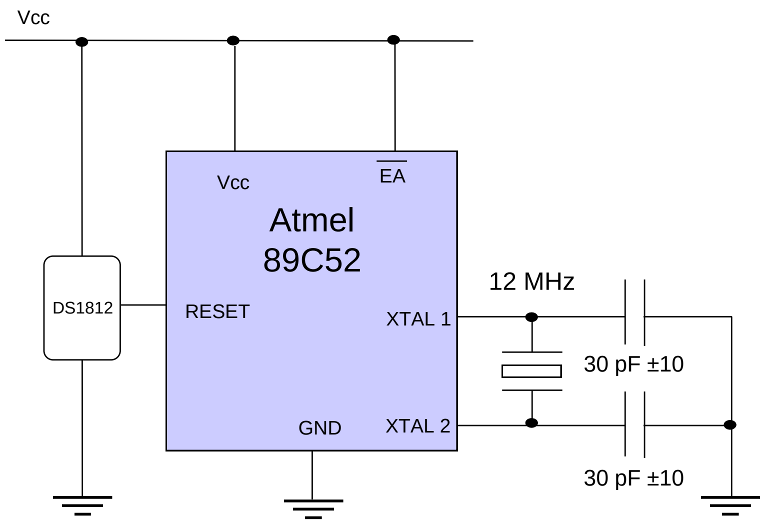
- The process of starting any microcontroller is a non-trivial one.
- The underlying hardware is complex and a small, manufacturer-defined, ‘reset routine’ must be run to place this hardware into an appropriate state before it can begin executing the user program. Running this reset routine takes time, and requires that the microcontroller’s oscillator is operating.
- An RC reset circuit is usually the simplest way of controlling the reset behaviour.

Example:



More robust reset circuits

Example:



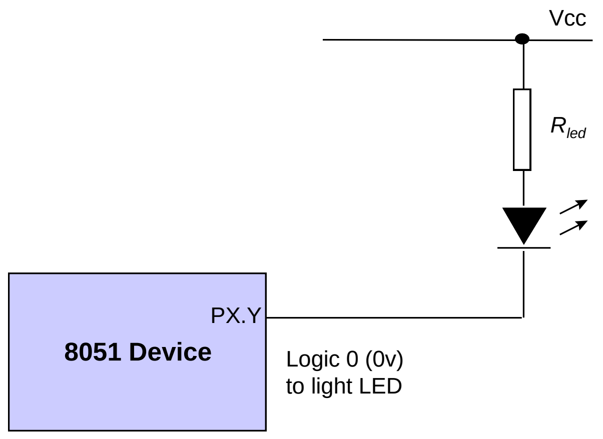
Driving DC Loads

- The port pins on a typical 8051 microcontroller can be set at values of either 0V or 5V (or, in a 3V system, 0V and 3V) under software control.

- Each pin can typically sink (or source) a current of around 10 mA.

- The total current we can source or sink per microcontroller (all 32 pins, where available) is typically 70 mA or less.

Naked LED



$$R_{led} = \frac{V_{cc} - V_{diode}}{I_{diode}}$$

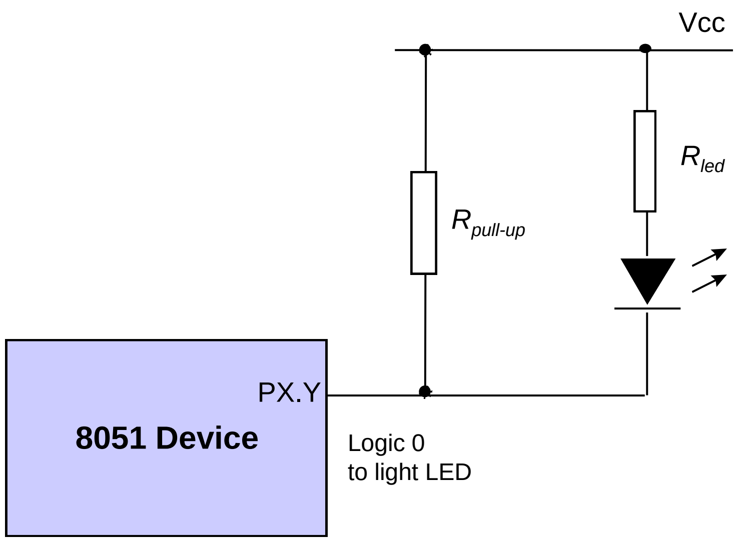
Connecting a single LED directly to a microcomputer port is usually possible.

- Supply voltage, V_{cc} = 5V,
- LED forward voltage, V_{diode} = 2V,
- Required diode current, I_{diode} = 15 mA (note that the data sheet for your chosen LED will provide this information).

This gives a required R value of 200Ω.

Use of pull-up resistors

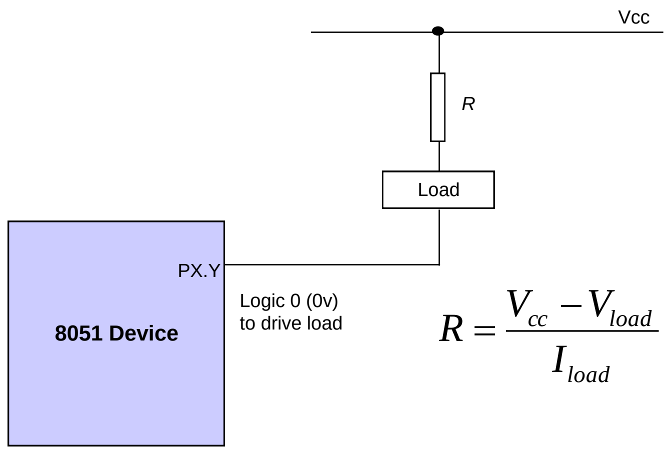
To adapt circuits for use on pins without internal pull-up resistors is straightforward: you simply need to add an external pull-up resistor:



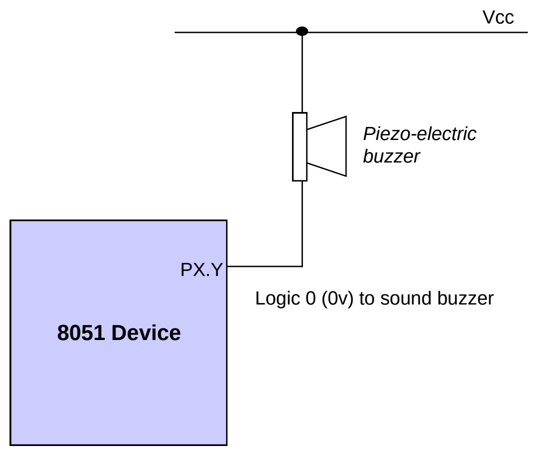
The value of the pull-up resistor should be between 1K and 10K. This requirement applies to all of the examples on this course.

NOTE:
This is usually only necessary on Port 0
(see Seminar 3 for further details).

Driving a low-power load without using a buffer

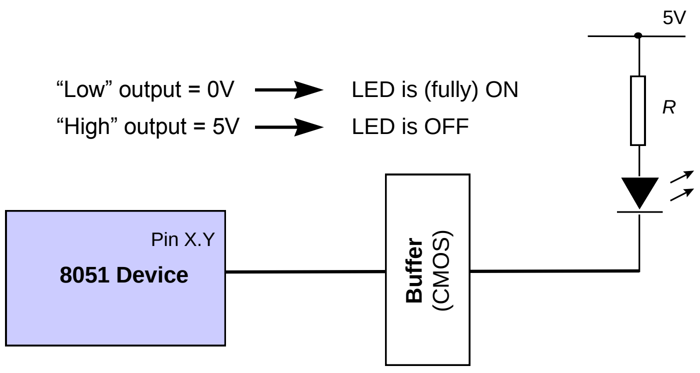


$$R = \frac{V_{cc} - V_{load}}{I_{load}}$$

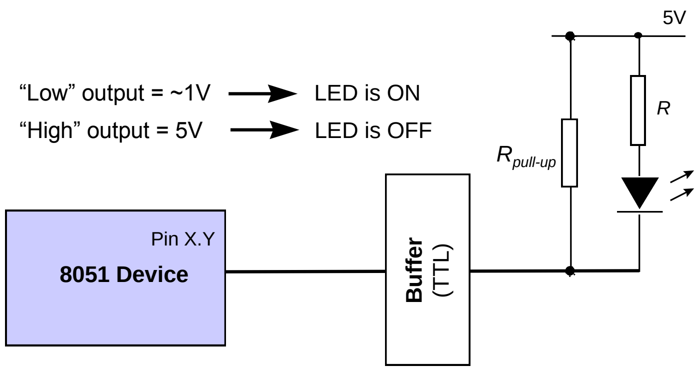


See "PATTERNS FOR TIME-TRIGGERED EMBEDDED SYSTEMS", p.115 (NAKED LOAD)

Using an IC Buffer



Using a CMOS buffer.



Using a TTL buffer.

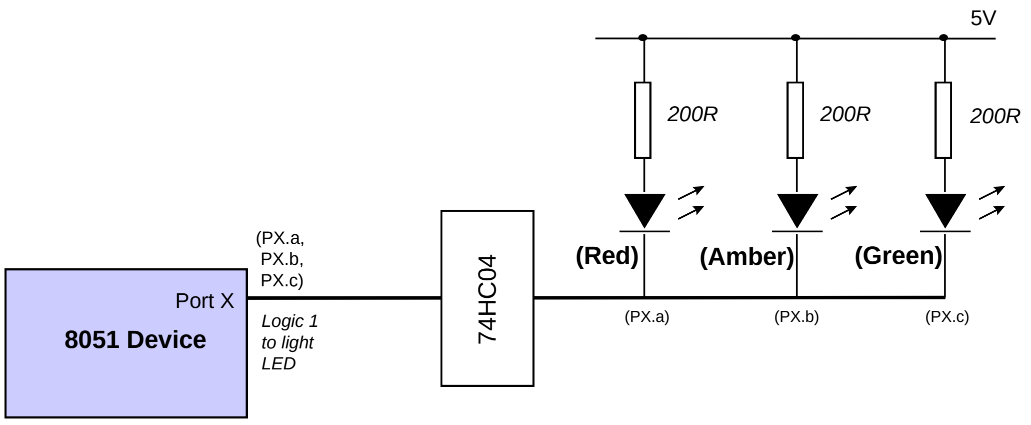
It makes sense to use CMOS logic in your buffer designs wherever possible. You should also make it clear in the design documentation that CMOS logic is to be used.

See "PATTERNS FOR TIME-TRIGGERED EMBEDDED SYSTEMS", p.118 (IC BUFFER)

Example: Buffering three LEDs with a 74HC04

This example shows a 74HC04 buffering three LEDs. As discussed in Solution, we do not require pull-up resistors with the HC (CMOS) buffers.

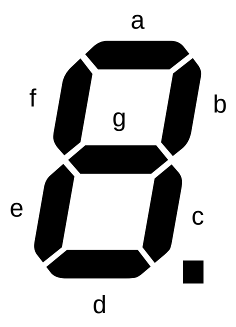
In this case, we assume that the LEDs are to be driven at 15 mA each, which is within the capabilities (50 mA total) of the buffer.



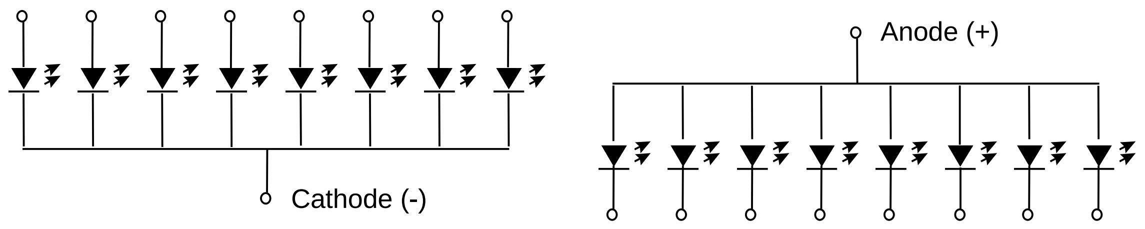
See "PATTERNS FOR TIME-TRIGGERED EMBEDDED SYSTEMS", p.123

What is a multi-segment LED?

Multiple LEDs are often arranged as multi-segment displays: combinations of eight segments and similar seven-segment displays (without a decimal point) are particularly common.



Such displays are arranged either as ‘common cathode’ or ‘common anode’ packages:



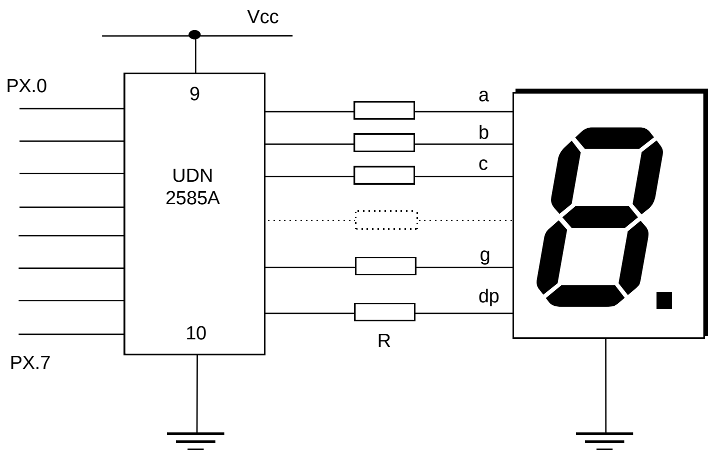
The required current per segment varies from about 2 mA (very small displays) to about 60 mA (very large displays, 100mm or more).

Driving a single digit

- In most cases, we require some form of buffer or driver IC between the port and the MS LED.

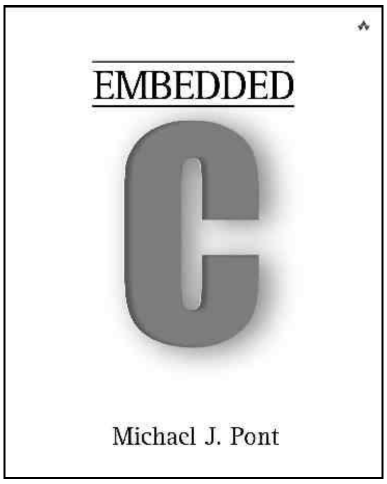
- **<u>For example</u>**, we can use UDN2585A.

  Each of the (8) channels in this buffer can simultaneously source up to 120 mA of current (at up to 25V): this is enough, for example, for even very large LED displays.



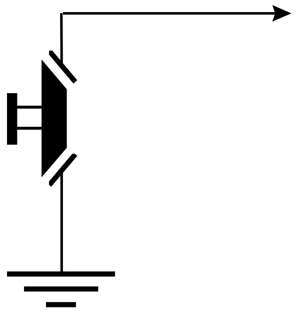
- Note that this is an inverting (current source) buffer. Logic 0 on the input line will light the corresponding LED segment.

Preparation for the next seminar



Please read Chapter 4
before the next seminar

Seminar 3: Reading Switches

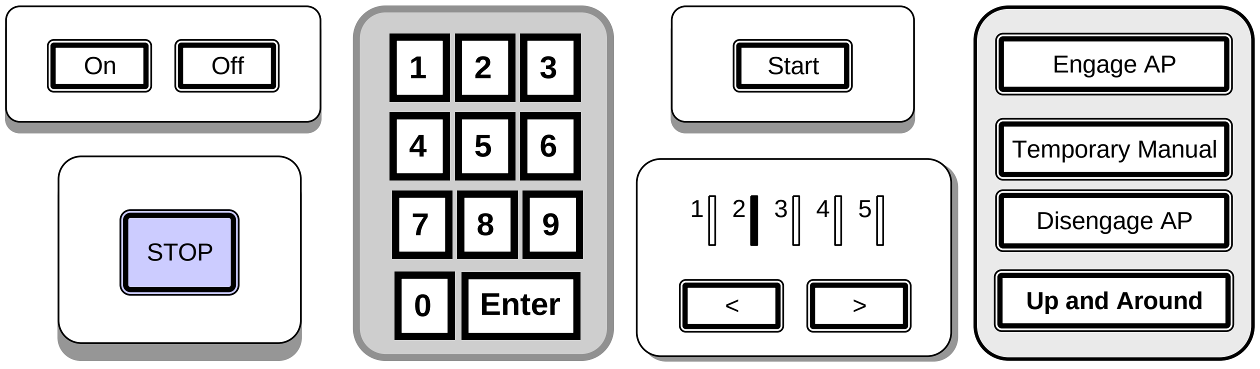


To pin on:

Port 1,
Port 2,
or
Port 3.

Introduction

- Embedded systems usually use switches as part of their user interface.
- This general rule applies from the most basic remote-control system for opening a garage door, right up to the most sophisticated aircraft autopilot system.
- Whatever the system you create, you need to be able to create a reliable switch interface.



In this seminar, we consider how you can read inputs from mechanical switches in your embedded application.

Before considering switches themselves, we will consider the process of reading the state of port pins.

Review: Basic techniques for reading from port pins

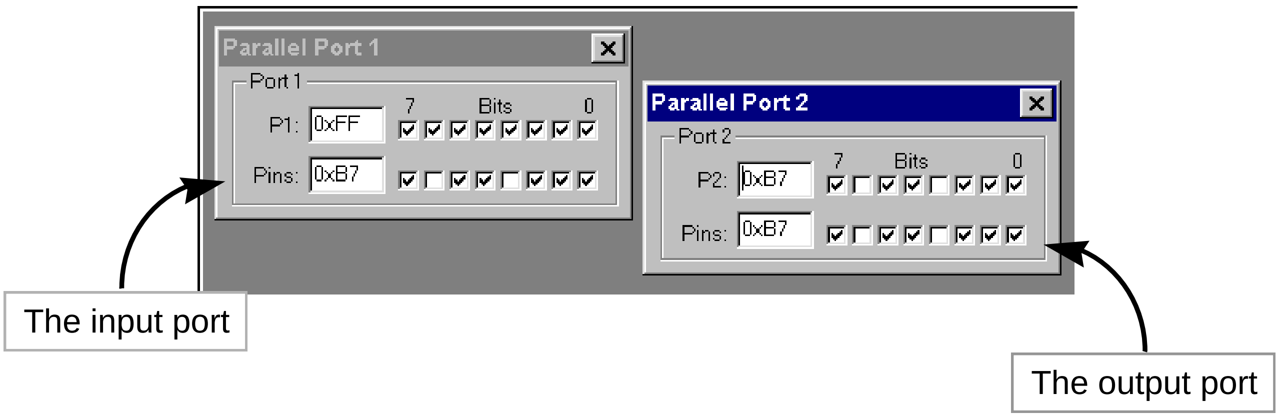
We can send some data to Port 1 as follows:

```
sfr P1 = 0x90;    /* Usually in header file */

P1 = 0x0F;        /* Write 00001111 to Port 1 */
```

In exactly the same way, we can read from Port 1 as follows:

```
unsigned char Port_data;

P1 = 0xFF;        /* Set the port to 'read mode' */
Port_data = P1;   /* Read from the port */
```

Example: Reading and writing bytes (review)



```
void main (void)
   {
   unsigned char Port1_value;

   /* Must set up P1 for reading */
   P1 = 0xFF;

   while(1)
     {
     /* Read the value of P1 */
     Port1_value = P1;

     /* Copy the value to P2 */
     P2 = Port1_value;
     }
   }
```

Example: Reading and writing bits (simple version)

```
/*------------------------------------------------------------------*-

   Bits1.C (v1.00)

-*------------------------------------------------------------------*/

#include <Reg52.H>

sbit Switch_pin = P1^0;
sbit LED_pin = P1^1;

/* ............................................................... */

void main (void)
   {
   bit x;

   /* Set switch pin for reading */
   Switch_pin = 1;

   while(1)
     {
     x = Switch_pin;    /* Read Pin 1.0 */
     LED_pin = x;       /* Write to Pin 1.1 */
     }
   }

/*------------------------------------------------------------------*-
  ---- END OF FILE ---------------------------------------
-*------------------------------------------------------------------*/
```

Experienced ‘C’ programmers please note these lines:

```
sbit Switch_pin = P1^0;
sbit LED_pin = P1^1;
```

Here we gain access to two port pins through the use of an sbit variable declaration. The symbol ‘^’ is used, but the XOR bitwise operator is NOT involved.

Example: Reading and writing bits (generic version)

The six bitwise operators:

Operator	Description
&	Bitwise AND
|	Bitwise OR (inclusive OR)
^	Bitwise XOR (exclusive OR)
<<	Left shift
>>	Right shift
~	One's complement

A	B	A **AND** B	A **OR** B	A **XOR** B
0	0	0	0	0
0	1	0	1	1
1	0	0	1	1
1	1	1	1	0

```
/* Desktop program - illustrating the use of bitwise operators */

#include <stdio.h>

void Display_Byte(const unsigned char);

/* ............................................................... */

int main()
   {
   unsigned char x = 0xFE;
   unsigned int y = 0x0A0B;

   printf("%-35s","x");
   Display_Byte(x);

   printf("%-35s","1s complement [~x]");
   Display_Byte(~x);

   printf("%-35s","Bitwise AND [x & 0x0f]");
   Display_Byte(x & 0x0f);

   printf("%-35s","Bitwise OR [x | 0x0f]");
   Display_Byte(x | 0x0f);

   printf("%-35s","Bitwise XOR [x ^ 0x0f]");
   Display_Byte(x ^ 0x0f);

   printf("%-35s","Left shift, 1 place [x <<= 1] ");
   Display_Byte(x <<= 1);

   x = 0xfe; /* Return x to original value */
   printf("%-35s","Right shift, 4 places [x >>= 4]");
   Display_Byte(x >>= 4);

   printf("\n\n");

   printf("%-35s","Display MS byte of unsigned int y");
   Display_Byte((unsigned char) (y >> 8));

   printf("%-35s","Display LS byte of unsigned int y");
   Display_Byte((unsigned char) (y & 0xFF));

   return 0;
   }
```

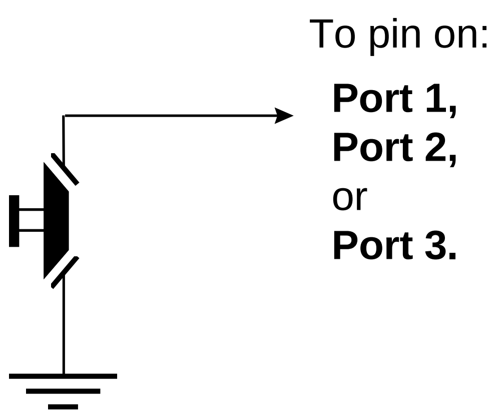
```
/* ------------------------------------------------------------------ */

void Display_Byte(const unsigned char CH)
   {
   unsigned char i, c = CH;
   unsigned char Mask = 1 << 7;

   for (i = 1; i <= 8; i++)
      {
      putchar(c & Mask ? '1' : '0');
      c <<= 1;
      }

   putchar('\n');
   }
```

```
x                                  11111110
1s complement [~x]                 00000001
Bitwise AND [x & 0x0f]             00001110
Bitwise OR [x | 0x0f]              11111111
Bitwise XOR [x ^ 0x0f]             11110001
Left shift, 1 place [x <<= 1]      11111100
Right shift, 4 places [x >>= 4]    00001111


Display MS byte of unsigned int y  00001010
Display LS byte of unsigned int y  00001011
```

```
/*------------------------------------------------------------------*-

   Reading and writing individual port pins.

   NOTE: Both pins on the same port

-*------------------------------------------------------------------*/

#include <reg52.H>

void Write_Bit_P1(const unsigned char, const bit);
bit Read_Bit_P1(const unsigned char);

/* ................................................................ */

void main (void)
   {
   bit x;

   while(1)
     {
     x = Read_Bit_P1(0);    /* Read Port 1, Pin 0 */
     Write_Bit_P1(1,x);     /* Write to Port 1, Pin 1 */
     }
   }

/* ---------------------------------------------------------------- */

void Write_Bit_P1(const unsigned char PIN, const bit VALUE)
   {
   unsigned char p = 0x01;  /* 00000001 */

   /* Left shift appropriate number of places */
   p <<= PIN;

   /* If we want 1 output at this pin */
   if (VALUE == 1)
      {
      P1 |= p;  /* Bitwise OR */
      return;
      }

   /* If we want 0 output at this pin */
   p = ~p;  /* Complement */
   P1 &= p; /* Bitwise AND   */
   }
```

```
/* ------------------------------------------------------------------ */

bit Read_Bit_P1(const unsigned char PIN)
   {
   unsigned char p = 0x01;  /* 00000001 */

   /* Left shift appropriate number of places */
   p <<= PIN;

   /* Write a 1 to the pin (to set up for reading) */
   Write_Bit_P1(PIN, 1);

   /* Read the pin (bitwise AND) and return */
   return (P1 & p);
   }

/*------------------------------------------------------------------*-
  ---- END OF FILE ---------------------------------------
-*------------------------------------------------------------------*/
```

The need for pull-up resistors



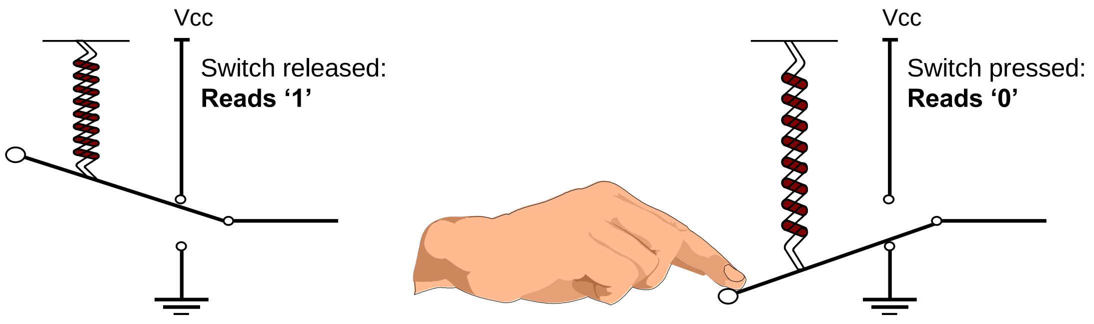
This hardware operates as follows:

- When the switch is open, it has no impact on the port pin. An internal resistor on the port 'pulls up' the pin to the supply voltage of the microcontroller (typically 5V). If we read the pin, we will see the value '1'.
- When the switch is closed (pressed), the pin voltage will be 0V. If we read the the pin, we will see the value '0'.

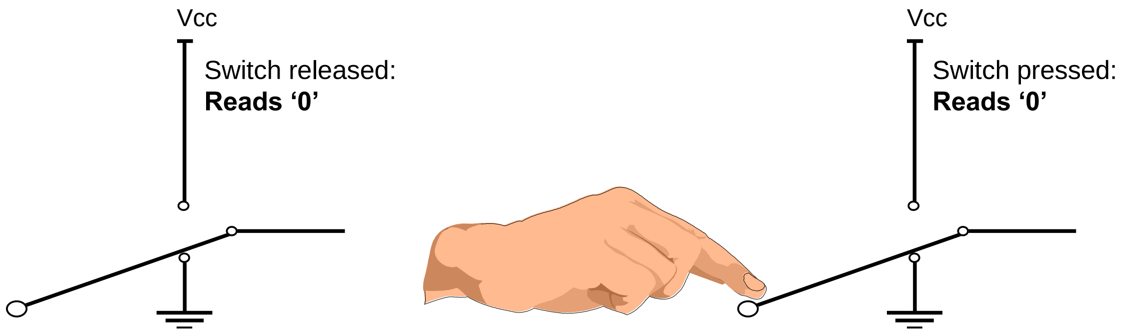
The need for pull-up resistors

We briefly looked at pull-up resistors in Seminar 2.

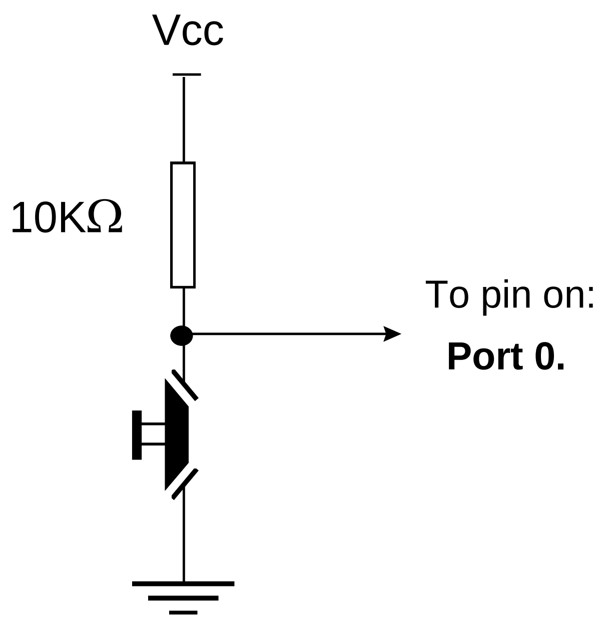
With pull-ups:



Without pull-ups:

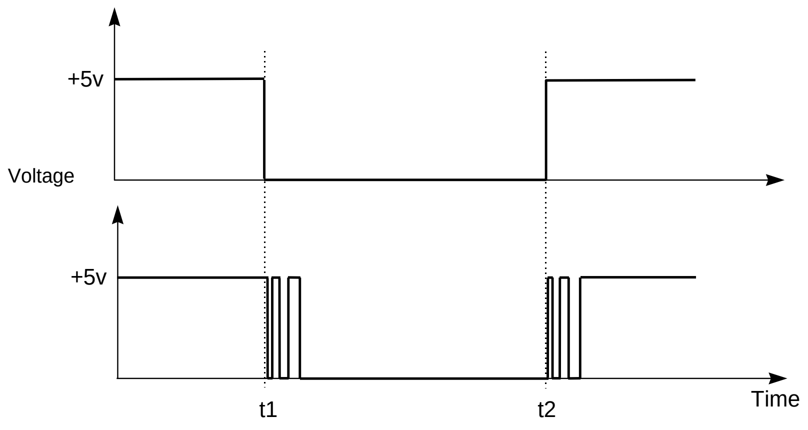


The need for pull-up resistors



Dealing with switch bounce

In practice, all mechanical switch contacts *bounce* (that is, turn on and off, repeatedly, for a short period of time) after the switch is closed or opened.



As far as the microcontroller is concerned, each ‘bounce’ is equivalent to one press and release of an ‘ideal’ switch. Without appropriate software design, this can give rise to a number of problems, not least:

- Rather than reading ‘A’ from a keypad, we may read ‘AAAAA’
- Counting the number of times that a switch is pressed becomes extremely difficult.
- If a switch is depressed once, and then released some time later, the ‘bounce’ may make it appear as if the switch has been pressed again (at the time of release).

Creating some simple software to check for a valid switch input is straightforward:

1. We read the relevant port pin.
2. If we think we have detected a switch depression, we wait for 20 ms and then read the pin again.
3. If the second reading confirms the first reading, we assume the switch really has been depressed.

Note that the figure of '20 ms' will, of course, depend on the switch used.

Example: Reading switch inputs (basic code)

This switch-reading code is adequate if we want to perform operations such as:

- Drive a motor while a switch is pressed.
- Switch on a light while a switch is pressed.
- Activate a pump while a switch is pressed.

These operations could be implemented using an electrical switch, without using a microcontroller; however, use of a microcontroller may well be appropriate if we require more complex behaviour. For example:

- Drive a motor while a switch is pressed
  Condition: If the safety guard is not in place, don't turn the motor. Instead sound a buzzer for 2 seconds.
- Switch on a light while a switch is pressed
  Condition: To save power, ignore requests to turn on the light during daylight hours.
- Activate a pump while a switch is pressed
  Condition: If the main water reservoir is below 300 litres, do not start the main pump: instead, start the reserve pump and draw the water from the emergency tank.

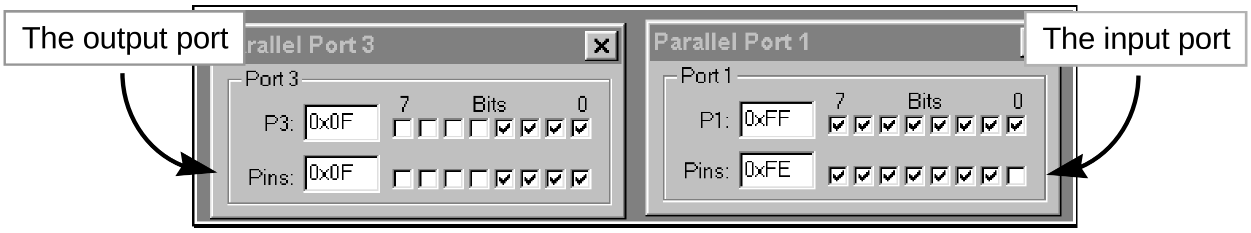
```
/*------------------------------------------------------------*-

   Switch_read.C (v1.00)

  --------------------------------------------------------

   A simple 'switch input' program for the 8051.
   - Reads (and debounces) switch input on Pin 1^0
   - If switch is pressed, changes Port 3 output

-*------------------------------------------------------------*/

#include <Reg52.h>

/* Connect switch to this pin */
sbit Switch_pin = P1^0;

/* Display switch status on this port */
#define Output_port P3

/* Return values from Switch_Get_Input() */
#define SWITCH_NOT_PRESSED (bit) 0
#define SWITCH_PRESSED (bit) 1

/* Function prototypes */
void SWITCH_Init(void);
bit  SWITCH_Get_Input(const unsigned char DEBOUNCE_PERIOD);
void DISPLAY_SWITCH_STATUS_Init(void);
void DISPLAY_SWITCH_STATUS_Update(const bit);
void DELAY_LOOP_Wait(const unsigned int DELAY_MS);
```

```
/* ------------------------------------------------------------- */
void main(void)
   {
   bit Sw_state;

   /* Init functions */
   SWITCH_Init();
   DISPLAY_SWITCH_STATUS_Init();

   while(1)
      {
      Sw_state = SWITCH_Get_Input(30);

      DISPLAY_SWITCH_STATUS_Update(Sw_state);
      }
   }

/*------------------------------------------------------------*-

  SWITCH_Init()

  Initialisation function for the switch library.

-*------------------------------------------------------------*/
void SWITCH_Init(void)
   {
   Switch_pin = 1; /* Use this pin for input */
   }
```

```
/*------------------------------------------------------------------*-

  SWITCH_Get_Input()

  Reads and debounces a mechanical switch as follows:

  1. If switch is not pressed, return SWITCH_NOT_PRESSED.

  2. If switch is pressed, wait for the DEBOUNCE_PERIOD (in ms).
     Then:
     a. If switch is no longer pressed, return SWITCH_NOT_PRESSED.
     b. If switch is still pressed, return SWITCH_PRESSED

  See Switch_Wait.H for details of return values.

-*------------------------------------------------------------------*/
bit SWITCH_Get_Input(const unsigned char DEBOUNCE_PERIOD)
   {
   bit Return_value = SWITCH_NOT_PRESSED;

   if (Switch_pin == 0)
      {
      /* Switch is pressed */

      /* Debounce - just wait... */
      DELAY_LOOP_Wait(DEBOUNCE_PERIOD);

      /* Check switch again */
      if (Switch_pin == 0)
         {
         Return_value = SWITCH_PRESSED;
         }
      }

   /* Now return switch value */
   return Return_value;
   }
```

```
/*------------------------------------------------------------*-

  DISPLAY_SWITCH_STATUS_Init()

  Initialization function for the DISPLAY_SWITCH_STATUS library.

-*------------------------------------------------------------*/
void DISPLAY_SWITCH_STATUS_Init(void)
   {
   Output_port = 0xF0;
   }

/*------------------------------------------------------------*-

  DISPLAY_SWITCH_STATUS_Update()

  Simple function to display data (SWITCH_STATUS)
  on LEDs connected to port (Output_Port)

-*------------------------------------------------------------*/
void DISPLAY_SWITCH_STATUS_Update(const bit SWITCH_STATUS)
   {
   if (SWITCH_STATUS == SWITCH_PRESSED)
      {
      Output_port = 0x0F;
      }
   else
      {
      Output_port = 0xF0;
      }
   }
```

```
/*------------------------------------------------------------------*-

  DELAY_LOOP_Wait()

  Delay duration varies with parameter.

  Parameter is, *ROUGHLY*, the delay, in milliseconds,
  on 12MHz 8051 (12 osc cycles).

  You need to adjust the timing for your application!

-*------------------------------------------------------------------*/
void DELAY_LOOP_Wait(const unsigned int DELAY_MS)
   {
   unsigned int x, y;

   for (x = 0; x <= DELAY_MS; x++)
      {
      for (y = 0; y <= 120; y++);
      }
   }
```

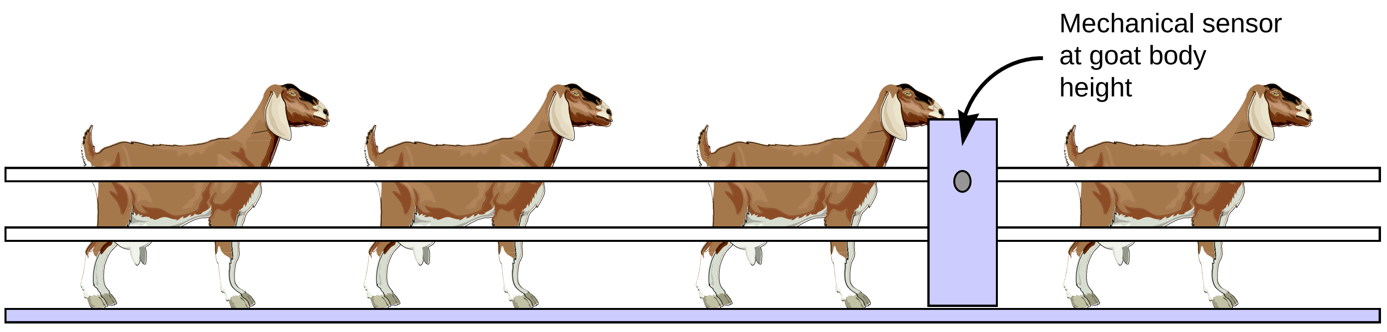

The output port
rallel Port 3
Port 3
P3: 0x0F
7 Bits 0
Pins: 0x0F
Parallel Port 1
Port 1
P1: 0xFF
7 Bits 0
Pins: 0xFE
The input port

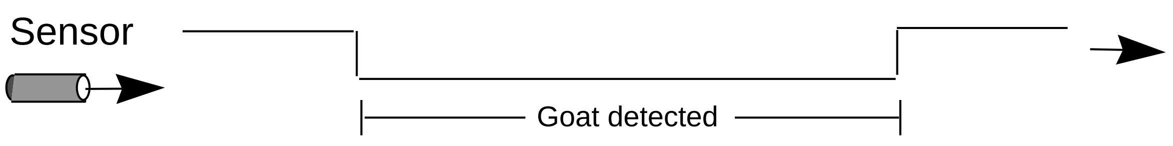
Example: Counting goats

- With the simple code in the previous example, problems can arise whenever a switch is pressed for a period longer than the debounce interval.

- This is a concern, because in many cases, users will press switches for at least 500 ms (or until they receive feedback that the system has detected the switch press). As a result, a user typing “Hello” on a keypad may see: “HHHHHHHHHeeeeeeeeellllllllllllllllooooooooooo” appear on the screen.

One consequence is that this code is **not suitable** for applications where we need to count the number of times that a switch is pressed and then released.



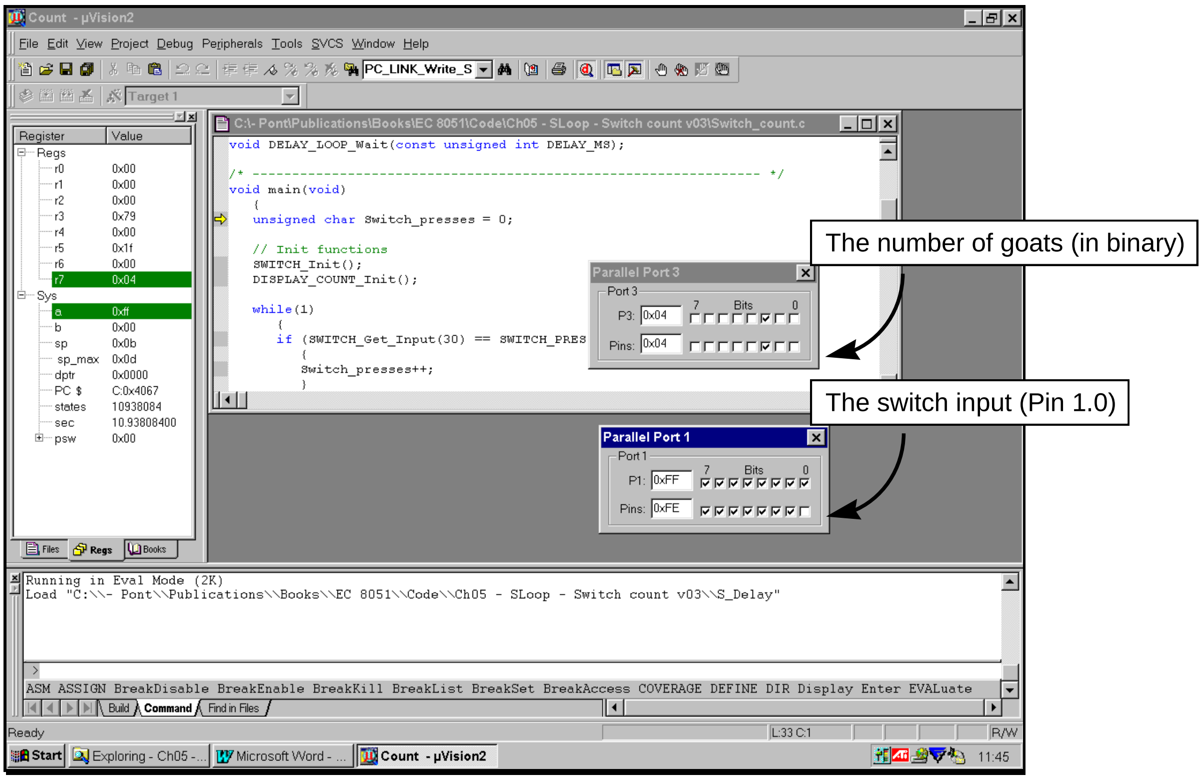


If we try to use the code in the previous example, **<u>the goat sensor will not allow us to count the number of goats but will instead provide an indication of the time taken for the goats to pass the sensor</u>**.

```
/*------------------------------------------------------------*-

   A 'goat counting' program for the 8051...

-*------------------------------------------------------------*/

#include <Reg52.h>

/* Connect switch to this pin */
sbit Switch_pin = P1^0;

/* Display count (binary) on this port */
#define Count_port P3

/* Return values from Switch_Get_Input() */
#define SWITCH_NOT_PRESSED (bit) 0
#define SWITCH_PRESSED (bit) 1

/* Function prototypes */
void SWITCH_Init(void);
bit  SWITCH_Get_Input(const unsigned char DEBOUNCE_PERIOD);
void DISPLAY_COUNT_Init(void);
void DISPLAY_COUNT_Update(const unsigned char);
void DELAY_LOOP_Wait(const unsigned int DELAY_MS);

/* ------------------------------------------------------------- */
void main(void)
   {
   unsigned char Switch_presses = 0;

   /* Init functions */
   SWITCH_Init();
   DISPLAY_COUNT_Init();

   while(1)
      {
      if (SWITCH_Get_Input(30) == SWITCH_PRESSED)
         {
         Switch_presses++;
         }

      DISPLAY_COUNT_Update(Switch_presses);
      }
   }
```

```
/*------------------------------------------------------------*/

void SWITCH_Init(void)
   {
   Switch_pin = 1; /* Use this pin for input */
   }

/*------------------------------------------------------------*-

  SWITCH_Get_Input()

  Reads and debounces a mechanical switch as follows:

  1. If switch is not pressed, return SWITCH_NOT_PRESSED.

2. If switch is pressed, wait for the DEBOUNCE_PERIOD (in ms).
     Then:
     a. If switch is no longer pressed, return SWITCH_NOT_PRESSED.
     b. If switch is still pressed, wait (indefinitely) for
        switch to be released, *then* return SWITCH_PRESSED

  See Switch_Wait.H for details of return values.

-*------------------------------------------------------------*/
bit SWITCH_Get_Input(const unsigned char DEBOUNCE_PERIOD)
   {
   bit Return_value = SWITCH_NOT_PRESSED;

   if (Switch_pin == 0)
      {
      /* Switch is pressed */

      /* Debounce - just wait... */
      DELAY_LOOP_Wait(DEBOUNCE_PERIOD);

      /* Check switch again */
      if (Switch_pin == 0)
         {
         /* Wait until the switch is released. */
         while (Switch_pin == 0);
         Return_value = SWITCH_PRESSED;
         }
      }

   /* Now (finally) return switch value */
   return Return_value;
   }
```

```
/*------------------------------------------------------------------*-

  DISPLAY_COUNT_Init()

  Initialisation function for the DISPLAY COUNT library.

-*------------------------------------------------------------------*/
void DISPLAY_COUNT_Init(void)
   {
   Count_port = 0x00;
   }

/*------------------------------------------------------------------*-

  DISPLAY_COUNT_Update()

  Simple function to display tByte data (COUNT)
  on LEDs connected to port (Count_Port)

-*------------------------------------------------------------------*/
void DISPLAY_COUNT_Update(const unsigned char COUNT)
   {
   Count_port = COUNT;
   }

/*------------------------------------------------------------------*-

  DELAY_LOOP_Wait()

  Delay duration varies with parameter.

  Parameter is, *ROUGHLY*, the delay, in milliseconds,
  on 12MHz 8051 (12 osc cycles).

  You need to adjust the timing for your application!

-*------------------------------------------------------------------*/
void DELAY_LOOP_Wait(const unsigned int DELAY_MS)
   {
   unsigned int x, y;

   for (x = 0; x <= DELAY_MS; x++)
      {
      for (y = 0; y <= 120; y++);
      }
   }
```


Count - µVision2
File Edit View Project Debug Peripherals Tools SVCS Window Help
PC_LINK_Write_S
Target 1
C:\- Pont\Publications\Books\EC 8051\Code\Ch05 - SLoop - Switch count v03\Switch_count.c
Parallel Port 3
Port 3
Parallel Port 1
Port 1
Files Regs Books
Build Command Find in Files
Ready
L:33 C:1
R/W
Start Exploring - Ch05 -... Microsoft Word - ... Count - µVision2
11:45
The number of goats (in binary)
The switch input (Pin 1.0)

Register	Value
Regs	
r0	0x00
r1	0x00
r2	0x00
r3	0x79
r4	0x00
r5	0x1f
r6	0x00
r7	0x04
Sys	
a	0xff
b	0x00
sp	0x0b
sp_max	0x0d
dptr	0x0000
PC $	C:0x4067
states	10938084
sec	10.93808400
psw	0x00

```
void DELAY_LOOP_Wait(const unsigned int DELAY_MS);

/* ------------------------------------------------------------- */
void main(void)
   {
   unsigned char Switch_presses = 0;

   // Init functions
   SWITCH_Init();
   DISPLAY_COUNT_Init();

   while(1)
      {
      if (SWITCH_Get_Input(30) == SWITCH_PRES
         {
         Switch_presses++;
         }
```

```
P3:   0x04
Pins: 0x04

P1:   0xFF
Pins: 0xFE
```

```
Running in Eval Mode (2K)
Load "C:\\- Pont\\Publications\\Books\\EC 8051\\Code\\Ch05 - SLoop - Switch count v03\\S_Delay"
```

```
ASM ASSIGN BreakDisable BreakEnable BreakKill BreakList BreakSet BreakAccess COVERAGE DEFINE DIR Display Enter EVALuate
```

Conclusions

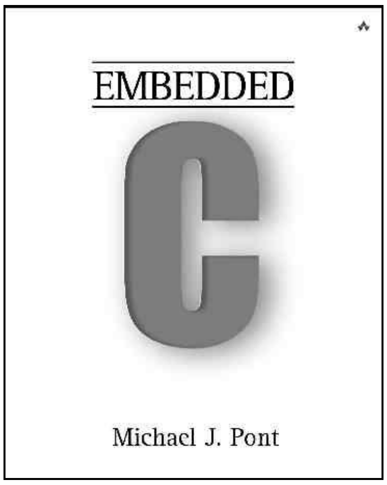
The switch interface code presented and discussed in this seminar has allowed us to do two things:

- To perform an activity while a switch is depressed;
- To respond to the fact that a user has pressed – and then released – a switch.

In both cases, we have illustrated how the switch may be ‘debounced’ in software.

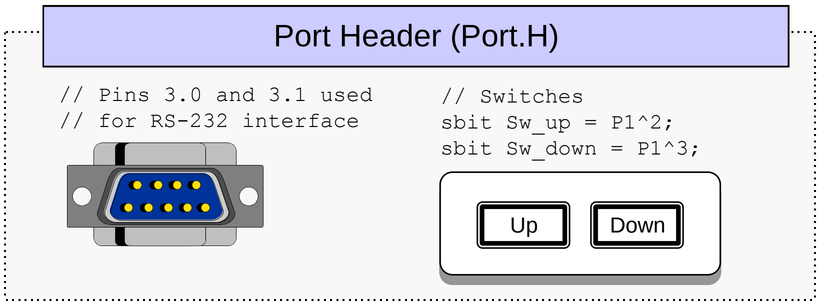
Preparation for the next seminar

In the next seminar, we turn our attention to techniques that can help you re-use the code you develop in subsequent projects.



Please read **Chapter 5**
before the next seminar

Seminar 4:
Adding Structure to Your Code



Introduction

We will do three things in this seminar:

1. We will describe how to use an object-oriented style of programming with C programs, allowing the creation of libraries of code that can be easily adapted for use in different embedded projects;

2. We will describe how to create and use a 'Project Header' file. This file encapsulates key aspects of the hardware environment, such as the type of processor to be used, the oscillator frequency and the number of oscillator cycles required to execute each instruction. This helps to document the system, and makes it easier to port the code to a different processor.

3. We will describe how to create and use a 'Port Header' file. This brings together all details of the port access from the whole system. Like the Project Header, this helps during porting and also serves as a means of documenting important system features.

We will use all three of these techniques in the code examples presented in subsequent seminars.

Object-Oriented Programming with C

Language generation	Example languages
-	Machine Code
First-Generation Language (1GL)	Assembly Language.
Second-Generation Languages (2GLs)	COBOL, FORTRAN
Third-Generation Languages (3GLs)	C, Pascal, Ada 83
Fourth-Generation Languages (4GLs)	C++, Java, Ada 95

Graham notes[1]:

> *"[The phrase] 'object-oriented' has become almost synonymous with modernity, goodness and worth in information technology circles."*

Jalote notes[2]:

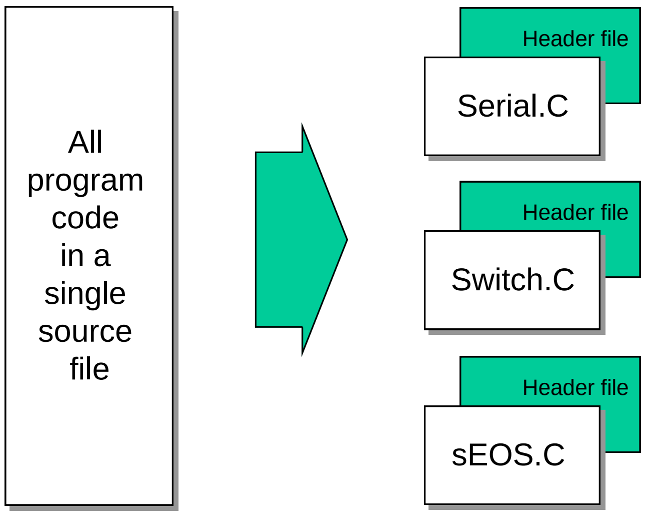
> *"One main claimed advantage of using object orientation is that an OO model closely represents the problem domain, which makes it easier to produce and understand designs."*

O-O languages are not readily available for small embedded systems, primarily because of the overheads that can result from the use of some of the features of these languages.

[1] **Graham, I.** (1994) *"Object-Oriented Methods,"* (2nd Ed.) Addison-Wesley. Page 1.

[2] **Jalote, P.** (1997) *"An Integrated Approach to Software Engineering"*, (2nd Ed.) Springer-Verlag. Page 273.

It is possible to create 'file-based-classes' in C without imposing a significant memory or CPU load.



Example of “O-O C”

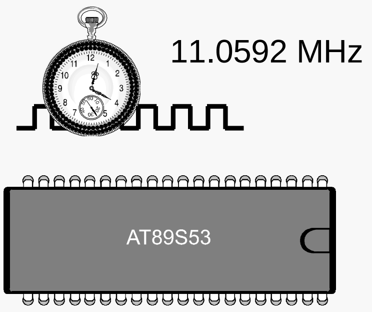
```
/*------------------------------------------------------------------*-

   PC_IO.H (v1.00)

  --------------------------------------------------------

   - see PC_IO.C for details.

-*------------------------------------------------------------------*/

#ifndef _PC_IO_H
#define _PC_IO_H

/* ------ Public constants ------------------------------------ */

/* Value returned by PC_LINK_Get_Char_From_Buffer if no char is
   available in buffer */
#define PC_LINK_IO_NO_CHAR 127

/* ------ Public function prototypes -------------------------- */

void PC_LINK_IO_Write_String_To_Buffer(const char* const);
void PC_LINK_IO_Write_Char_To_Buffer(const char);

char PC_LINK_IO_Get_Char_From_Buffer(void);

/* Must regularly call this function... */
void PC_LINK_IO_Update(void);

#endif

/*------------------------------------------------------------------*-
  ---- END OF FILE ----------------------------------------
-*------------------------------------------------------------------*/
```

```
/*------------------------------------------------------------------*-

   PC_IO.C (v1.00)

  ------------------------------------------------------------------

   [INCOMPLETE - STRUCTURE ONLY - see EC Chap 9 for complete library]

-*------------------------------------------------------------------*/

#include "Main.H"
#include "PC_IO.H"

/* ------ Public variable definitions ------------------------- */

tByte In_read_index_G;     /* Data in buffer that has been read */
tByte In_waiting_index_G;  /* Data in buffer not yet read */

tByte Out_written_index_G; /* Data in buffer that has been written */
tByte Out_waiting_index_G; /* Data in buffer not yet written */

/* ------ Private function prototypes ------------------------- */

static void PC_LINK_IO_Send_Char(const char);

/* ------ Private constants ----------------------------------- */

/* The receive buffer length */
#define RECV_BUFFER_LENGTH 8

/* The transmit buffer length */
#define TRAN_BUFFER_LENGTH 50

#define XON  0x11
#define XOFF 0x13

/* ------ Private variables ----------------------------------- */

static tByte Recv_buffer[RECV_BUFFER_LENGTH];
static tByte Tran_buffer[TRAN_BUFFER_LENGTH];

/*------------------------------------------------------------------*/
void PC_LINK_IO_Update(...)
   {
   ...
   }
```

```
/*------------------------------------------------------------------*/
void PC_LINK_IO_Write_Char_To_Buffer(...)
   {
   ...
   }

/*------------------------------------------------------------------*/
void PC_LINK_IO_Write_String_To_Buffer(...)
   {
   ...
   }

/*------------------------------------------------------------------*/
char PC_LINK_IO_Get_Char_From_Buffer(...)
   {
   ...
   }

/*------------------------------------------------------------------*/
void PC_LINK_IO_Send_Char(...)
   {
   ...
   }
```

The Project Header (`Main.H`)

Project Header (Main.H)



```
#include <AT89S53.H>
...
#define OSC_FREQ (11059200UL)
...
typedef unsigned char tByte;
...
```

```
/*------------------------------------------------------------------*-

   Main.H (v1.00)

-*------------------------------------------------------------------*/

#ifndef _MAIN_H
#define _MAIN_H

/*------------------------------------------------------------------
   WILL NEED TO EDIT THIS SECTION FOR EVERY PROJECT
  -------------------------------------------------------------- */

/* Must include the appropriate microcontroller header file here */
#include <reg52.h>

/* Oscillator / resonator frequency (in Hz) e.g. (11059200UL) */
#define OSC_FREQ (12000000UL)

/* Number of oscillations per instruction (12, etc)
   12 - Original 8051 / 8052 and numerous modern versions
    6 - Various Infineon and Philips devices, etc.
    4 - Dallas 320, 520 etc.
    1 - Dallas 420, etc. */
#define OSC_PER_INST (12)

/* --------------------------------------------------------------
   SHOULD NOT NEED TO EDIT THE SECTIONS BELOW
  -------------------------------------------------------------- */

/* Typedefs (see Chap 5)   */
typedef unsigned char tByte;
typedef unsigned int  tWord;
typedef unsigned long tLong;

/* Interrupts (see Chap 7)   */
#define INTERRUPT_Timer_0_Overflow 1
#define INTERRUPT_Timer_1_Overflow 3
#define INTERRUPT_Timer_2_Overflow 5

#endif

/*------------------------------------------------------------------*-
  ---- END OF FILE ---------------------------------------
-*------------------------------------------------------------------*/
```

The device header

```
/*-------------------------------------------------------------
  REG515C.H

  Header file for the Infineon C515C

  Copyright (c) 1995-1999 Keil Elektronik GmbH  All rights reserved.
------------------------------------------------------------------*/

...

/*  A/D Converter     */
sfr   ADCON0 = 0xD8;
...

/*  Interrupt System  */
sfr   IEN0   = 0xA8;
...

/*  Ports  */
sfr   P0     = 0x80;
sfr   P1     = 0x90;
sfr   P2     = 0xA0;
sfr   P3     = 0xB0;
sfr   P4     = 0xE8;
sfr   P5     = 0xF8;
sfr   P6     = 0xDB;
sfr   P7     = 0xFA;
...

/*  Serial Channel    */
sfr   SCON   = 0x98;
...

/*  Timer0 / Timer1   */
sfr   TCON   = 0x88;
...

/*  CAP/COM Unit / Timer2 */
sfr   CCEN   = 0xC1;
...
```

Oscillator frequency and oscillations per instruction

```
/* Oscillator / resonator frequency (in Hz) e.g. (11059200UL) */
#define OSC_FREQ (12000000UL)

/* Number of oscillations per instruction (12, etc)
   12 - Original 8051 / 8052 and numerous modern versions
    6 - Various Infineon and Philips devices, etc.
    4 - Dallas 320, 520 etc.
    1 - Dallas 420, etc. */
#define OSC_PER_INST (12)
```

We demonstrate how to use this information:

- For creating delays (Embedded C, Chapter 6),
- For controlling timing in an operating system (Chapter 7), and,
- For controlling the baud rate in a serial interface (Chapter 9).

Common data types

```
typedef unsigned char tByte;
typedef unsigned int  tWord;
typedef unsigned long tLong;
```

In C, the `typedef` keyword allows us to provide aliases for data types: we can then use these aliases in place of the original types. Thus, in the projects you will see code like this:

```
tWord Temperature;
```

Rather than:

```
unsigned int Temperature;
```

The main reason for using these `typedef` statements is to simplify - and promote - the use of unsigned data types.

- The 8051 does not support signed arithmetic and extra code is required to manipulate signed data: this reduces your program speed and increases the program size.

- Use of bitwise operators generally makes sense only with unsigned data types: use of '`typedef`' variables reduces the likelihood that programmers will inadvertently apply these operators to signed data.

Finally, as in desktop programming, use of the `typedef` keyword in this way can make it easier to adapt your code for use on a different processor.

Interrupts

As we noted in “Embedded C” Chapter 2, interrupts are a key component of most embedded systems.

The following lines in the Project Header are intended to make it easier for you to use (timer-based) interrupts in your projects:

```
#define INTERRUPT_Timer_0_Overflow 1
#define INTERRUPT_Timer_1_Overflow 3
#define INTERRUPT_Timer_2_Overflow 5
```

We discuss how to make use of this facility in Embedded C, Ch. 7.

Summary: Why use the Project Header?

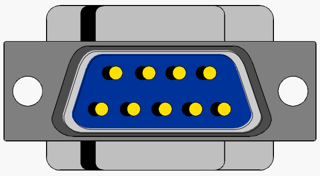
Use of PROJECT HEADER can help to make your code more readable, not least because anyone using your projects knows where to find key information, such as the model of microcontroller and the oscillator frequency required to execute the software.

The use of a project header can help to make your code more easily portable, by placing some of the key microcontroller-dependent data in one place: if you change the processor or the oscillator used then - in many cases - you will need to make changes only to the Project Header.

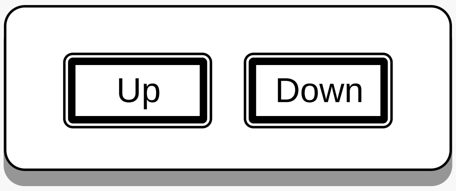
The Port Header (`Port.H`)

Port Header (Port.H)

```
// Pins 3.0 and 3.1 used
// for RS-232 interface
```



```
// Switches
sbit Sw_up = P1^2;
sbit Sw_down = P1^3;
```



The Port Header file is simple to understand and easy to apply.

Consider, for example, that we have three C files in a project (A, B, C), each of which require access to one or more port pins, or to a complete port.

File A may include the following:

```
/* File A */

sbit Pin_A = P3^2;

...
```

File B may include the following:

```
/* File B */

#define Port_B = P0;

...
```

File C may include the following:

```
/* File C */

sbit Pin_C = P2^7;

...
```

In this version of the code, all of the port access requirements are spread over multiple files.

There are many advantages obtained by integrating all port access in a single `Port.H` header file:

```
/* ----- Port.H ----- */

/* Port access for File B */
#define Port_B = P0;

/* Port access for File A */
sbit Pin_A = P3^2;

/* Port access for File C */
sbit Pin_C = P2^7;

...
```

```
/*------------------------------------------------------------------*-

   Port.H (v1.01)

  ------------------------------------------------------------------

  'Port Header' (see Chap 5) for project DATA_ACQ (see Chap 9)

-*------------------------------------------------------------------*/

#ifndef _PORT_H
#define _PORT_H

#include "Main.H"

/* ------ Menu_A.C ----------------------------------------- */
/* Uses whole of Port 1 and Port 2 for data acquisition  */
#define Data_Port1 P1
#define Data_Port2 P2


/* ------ PC_IO.C ------------------------------------------ */

/* Pins 3.0 and 3.1 used for RS-232 interface */

#endif

/*------------------------------------------------------------------*-
  ---- END OF FILE ------------------------------------------------
-*------------------------------------------------------------------*/
```

Re-structuring a “Hello World” example

```
/*------------------------------------------------------------------*-

   Main.H (v1.00)

-*------------------------------------------------------------------*/

#ifndef _MAIN_H
#define _MAIN_H

/*------------------------------------------------------------------
   WILL NEED TO EDIT THIS SECTION FOR EVERY PROJECT
  ------------------------------------------------------------------ */

/* Must include the appropriate microcontroller header file here */
#include <reg52.h>

/* Oscillator / resonator frequency (in Hz) e.g. (11059200UL) */
#define OSC_FREQ (12000000UL)

/* Number of oscillations per instruction (12, etc)
   12 - Original 8051 / 8052 and numerous modern versions
    6 - Various Infineon and Philips devices, etc.
    4 - Dallas 320, 520 etc.
    1 - Dallas 420, etc. */
#define OSC_PER_INST (12)

/* ------------------------------------------------------------------
   SHOULD NOT NEED TO EDIT THE SECTIONS BELOW
  ------------------------------------------------------------------ */

/* Typedefs (see Chap 5)   */
typedef unsigned char tByte;
typedef unsigned int  tWord;
typedef unsigned long tLong;

/* Interrupts (see Chap 7)   */
#define INTERRUPT_Timer_0_Overflow 1
#define INTERRUPT_Timer_1_Overflow 3
#define INTERRUPT_Timer_2_Overflow 5

#endif
```

```
/*------------------------------------------------------------------*-

   Port.H (v1.00)

  ------------------------------------------------------------------

   'Port Header' for project HELLO2 (see Chap 5)

-*------------------------------------------------------------------*/

#ifndef _PORT_H
#define _PORT_H

/* ------ LED_Flash.C ----------------------------------------------- */

/* Connect LED to this pin, via appropriate resistor */
sbit LED_pin = P1^5;

#endif

/*------------------------------------------------------------------*-
  ---- END OF FILE -------------------------------------------------
-*------------------------------------------------------------------*/
```

```
/*------------------------------------------------------------------*-

   Main.C (v1.00)

  ------------------------------------------------------------------

   A "Hello Embedded World" test program for 8051.

   (Re-structured version - multiple source files)

-*------------------------------------------------------------------*/

#include "Main.H"
#include "Port.H"

#include "Delay_Loop.h"
#include "LED_Flash.h"

void main(void)
   {
   LED_FLASH_Init();

   while(1)
      {
      /* Change the LED state (OFF to ON, or vice versa) */
      LED_FLASH_Change_State();

      /* Delay for *approx* 1000 ms */
      DELAY_LOOP_Wait(1000);
      }
   }

/*------------------------------------------------------------------*-
  ---- END OF FILE -------------------------------------------------
-*------------------------------------------------------------------*/
```

```
/*------------------------------------------------------------------*-

   LED_flash.H (v1.00)

  --------------------------------------------------------

   - See LED_flash.C for details.

-*------------------------------------------------------------------*/

#ifndef _LED_FLASH_H
#define _LED_FLASH_H

/* ------ Public function prototypes --------------------------- */

void LED_FLASH_Init(void);
void LED_FLASH_Change_State(void);

#endif

/*------------------------------------------------------------------*-
  ---- END OF FILE ----------------------------------------
-*------------------------------------------------------------------*/
```

```
/*------------------------------------------------------------------*-

   LED_flash.C (v1.00)

  --------------------------------------------------------

   Simple 'Flash LED' test function.

-*------------------------------------------------------------------*/

#include "Main.H"
#include "Port.H"

#include "LED_flash.H"

/* ------ Private variable definitions ------------------------- */

static bit LED_state_G;

/*------------------------------------------------------------------*-

  LED_FLASH_Init()

  Prepare for LED_Change_State() function - see below.

-*------------------------------------------------------------------*/
void LED_FLASH_Init(void)
   {
   LED_state_G = 0;
   }
```

```
/*------------------------------------------------------------------*-

  LED_FLASH_Change_State()

  Changes the state of an LED (or pulses a buzzer, etc) on a
  specified port pin.

  Must call at twice the required flash rate: thus, for 1 Hz
  flash (on for 0.5 seconds, off for 0.5 seconds) must call
  every 0.5 seconds.

-*------------------------------------------------------------------*/
void LED_FLASH_Change_State(void)
   {
   /* Change the LED from OFF to ON (or vice versa) */
   if (LED_state_G == 1)
      {
      LED_state_G = 0;
      LED_pin = 0;
      }
   else
      {
      LED_state_G = 1;
      LED_pin = 1;
      }
   }

/*------------------------------------------------------------------*-
  ---- END OF FILE --------------------------------------------------
-*------------------------------------------------------------------*/
```

```c
/*------------------------------------------------------------------*-

   Delay_Loop.H (v1.00)

  --------------------------------------------------------

   - See Delay_Loop.C for details.

-*------------------------------------------------------------------*/

#ifndef _DELAY_LOOP_H
#define _DELAY_LOOP_H

/* ------ Public function prototype ---------------------------- */
void DELAY_LOOP_Wait(const tWord DELAY_MS);

#endif

/*------------------------------------------------------------------*-
  ---- END OF FILE --------------------------------------
-*------------------------------------------------------------------*/
```

```
/*------------------------------------------------------------------*-

   Delay_Loop.C (v1.00)

  --------------------------------------------------------

   Create a simple software delay using a loop.

-*------------------------------------------------------------------*/

#include "Main.H"
#include "Port.H"

#include "Delay_loop.h"

/*------------------------------------------------------------------*-

  DELAY_LOOP_Wait()

  Delay duration varies with parameter.

  Parameter is, *ROUGHLY*, the delay, in milliseconds,
  on 12MHz 8051 (12 osc cycles).

  You need to adjust the timing for your application!

-*------------------------------------------------------------------*/
void DELAY_LOOP_Wait(const tWord DELAY_MS)
   {
   tWord x, y;

   for (x = 0; x <= DELAY_MS; x++)
      {
      for (y = 0; y <= 120; y++);
      }
   }

/*------------------------------------------------------------------*-
  ---- END OF FILE ----------------------------------------
-*------------------------------------------------------------------*/
```

Example: Re-structuring the Goat-Counting Example

```
/*------------------------------------------------------------------*-

   Main.H (v1.00)

-*------------------------------------------------------------------*/

#ifndef _MAIN_H
#define _MAIN_H

/*------------------------------------------------------------------
   WILL NEED TO EDIT THIS SECTION FOR EVERY PROJECT
  ------------------------------------------------------------------ */

/* Must include the appropriate microcontroller header file here */
#include <reg52.h>

/* Oscillator / resonator frequency (in Hz) e.g. (11059200UL) */
#define OSC_FREQ (12000000UL)

/* Number of oscillations per instruction (12, etc)
   12 - Original 8051 / 8052 and numerous modern versions
    6 - Various Infineon and Philips devices, etc.
    4 - Dallas 320, 520 etc.
    1 - Dallas 420, etc. */
#define OSC_PER_INST (12)

/* --------------------------------------------------------------
   SHOULD NOT NEED TO EDIT THE SECTIONS BELOW
  -------------------------------------------------------------- */

/* Typedefs (see Chap 5)   */
typedef unsigned char tByte;
typedef unsigned int  tWord;
typedef unsigned long tLong;

/* Interrupts (see Chap 7)   */
#define INTERRUPT_Timer_0_Overflow 1
#define INTERRUPT_Timer_1_Overflow 3
#define INTERRUPT_Timer_2_Overflow 5

#endif
```

```
/*------------------------------------------------------------------*-

   Port.H (v1.00)

  --------------------------------------------------------

   'Port Header' for project GOATS2 (see Chap 5)

-*------------------------------------------------------------------*/

#ifndef _PORT_H
#define _PORT_H

/* ------ Switch_Wait.C ------------------------------------------ */
/* Connect switch to this pin */
sbit Switch_pin = P1^0;

/* ------ Display_count.C ---------------------------------------- */
/* Display count (binary) on this port */
#define Count_port P3

#endif

/*------------------------------------------------------------------*-
  ---- END OF FILE ----------------------------------------
-*------------------------------------------------------------------*/
```

```
/*------------------------------------------------------------------*-

   Main.C (v1.00)

  ------------------------------------------------------------------

   A 'switch count' program for the 8051.

-*------------------------------------------------------------------*/

#include "Main.H"
#include "Port.H"

#include "Switch_wait.H"
#include "Display_count.H"

/* ------------------------------------------------------------------ */
void main(void)
   {
   tByte Switch_presses = 0;

   /* Init functions */
   SWITCH_Init();
   DISPLAY_COUNT_Init();

   while(1)
      {
      if (SWITCH_Get_Input(30) == SWITCH_PRESSED)
         {
         Switch_presses++;
         }

      DISPLAY_COUNT_Update(Switch_presses);
      }
   }

/*------------------------------------------------------------------*-
  ---- END OF FILE --------------------------------------------------
-*------------------------------------------------------------------*/
```

```
/*------------------------------------------------------------------*-

   Switch_wait.H (v1.00)

  --------------------------------------------------------

   - See Switch_wait.C for details.

-*------------------------------------------------------------------*/

#ifndef _SWITCH_WAIT_H
#define _SWITCH_WAIT_H

/* ------ Public constants -------------------------------------- */
/* Return values from Switch_Get_Input() */
#define SWITCH_NOT_PRESSED (bit) 0
#define SWITCH_PRESSED (bit) 1

/* ------ Public function prototype ----------------------------- */
void SWITCH_Init(void);
bit  SWITCH_Get_Input(const tByte DEBOUNCE_PERIOD);

#endif

/*------------------------------------------------------------------*-
  ---- END OF FILE ----------------------------------------
-*------------------------------------------------------------------*/
```

```
/*------------------------------------------------------------------*-

   Switch_Wait.C (v1.00)

  -------------------------------------------------------

   Simple library for debouncing a switch input.

   NOTE: Duration of function is highly variable!

-*------------------------------------------------------------------*/

#include "Main.H"
#include "Port.H"

#include "Switch_wait.h"
#include "Delay_loop.h"

/*------------------------------------------------------------------*-

  SWITCH_Init()

  Initialisation function for the switch library.

-*------------------------------------------------------------------*/
void SWITCH_Init(void)
   {
   Switch_pin = 1; /* Use this pin for input */
   }
```

```
/*------------------------------------------------------------------*-

  SWITCH_Get_Input()

  Reads and debounces a mechanical switch as follows:

  1. If switch is not pressed, return SWITCH_NOT_PRESSED.

  2. If switch is pressed, wait for DEBOUNCE_PERIOD (in ms).
     a. If switch is not pressed, return SWITCH_NOT_PRESSED.
     b. If switch is pressed, wait (indefinitely) for
        switch to be released, then return SWITCH_PRESSED

  See Switch_Wait.H for details of return values.

-*------------------------------------------------------------------*/
bit SWITCH_Get_Input(const tByte DEBOUNCE_PERIOD)
   {
   bit Return_value = SWITCH_NOT_PRESSED;

   if (Switch_pin == 0)
      {
      /* Switch is pressed */

      /* Debounce - just wait... */
      DELAY_LOOP_Wait(DEBOUNCE_PERIOD);

      /* Check switch again */
      if (Switch_pin == 0)
         {
         /* Wait until the switch is released. */
         while (Switch_pin == 0);
         Return_value = SWITCH_PRESSED;
         }
      }

   /* Now (finally) return switch value */
   return Return_value;
   }

/*------------------------------------------------------------------*-
  ---- END OF FILE ---------------------------------------
-*------------------------------------------------------------------*/
```

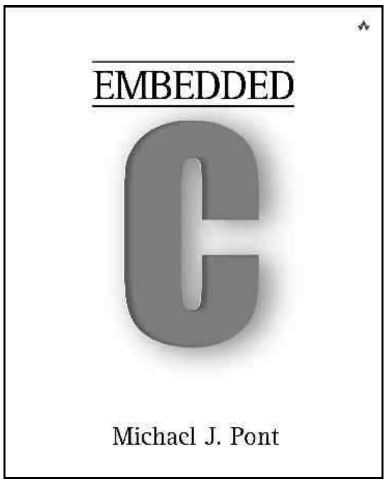
```
/*------------------------------------------------------------------*-

   Display_count.H (v1.00)

  --------------------------------------------------------

   - See Display_count.C for details.

-*------------------------------------------------------------------*/

#ifndef _DISPLAY_COUNT_H
#define _DISPLAY_COUNT_H

/* ------ Public function prototypes -------------------------- */
void DISPLAY_COUNT_Init(void);
void DISPLAY_COUNT_Update(const tByte);

#endif

/*------------------------------------------------------------------*-
  ---- END OF FILE ----------------------------------------
-*------------------------------------------------------------------*/
```

```
/*------------------------------------------------------------------*-

   Display_count.C (v1.00)

  ------------------------------------------------------------------

   Display an unsigned char on a port.

-*------------------------------------------------------------------*/

#include "Main.H"
#include "Port.H"

#include "Display_Count.H"

/*------------------------------------------------------------------*-

  DISPLAY_COUNT_Init()

  Initialisation function for the DISPLAY COUNT library.

-*------------------------------------------------------------------*/
void DISPLAY_COUNT_Init(void)
   {
   Count_port = 0x00;
   }

/*------------------------------------------------------------------*-

  DISPLAY_COUNT_Update()

  Simple function to display tByte data (COUNT)
  on LEDs connected to port (Count_Port)

-*------------------------------------------------------------------*/
void DISPLAY_COUNT_Update(const tByte COUNT)
   {
   Count_port = COUNT;
   }

/*------------------------------------------------------------------*-
  ---- END OF FILE -------------------------------------------------
-*------------------------------------------------------------------*/
```

```
/*------------------------------------------------------------------*-

   Delay_Loop.H (v1.00)

  --------------------------------------------------------

   - See Delay_Loop.C for details.

-*------------------------------------------------------------------*/

#ifndef _DELAY_LOOP_H
#define _DELAY_LOOP_H

/* ------ Public function prototype ---------------------------- */
void DELAY_LOOP_Wait(const tWord DELAY_MS);

#endif

/*------------------------------------------------------------------*-
  ---- END OF FILE ----------------------------------------
-*------------------------------------------------------------------*/
```

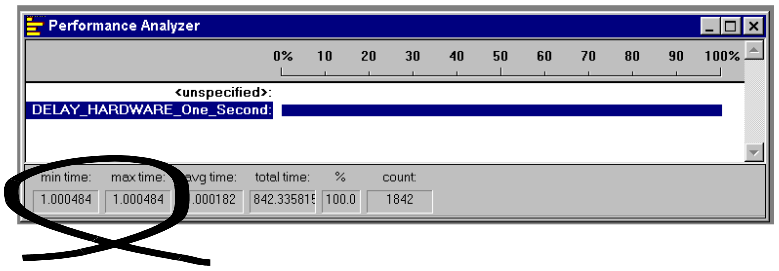
```
/*------------------------------------------------------------------*-

   Delay_Loop.C (v1.00)

  --------------------------------------------------------

   Create a simple software delay using a loop.

-*------------------------------------------------------------------*/

#include "Main.H"
#include "Port.H"

#include "Delay_loop.h"

/*------------------------------------------------------------------*-

  DELAY_LOOP_Wait()

  Delay duration varies with parameter.

  Parameter is, *ROUGHLY*, the delay, in milliseconds,
  on 12MHz 8051 (12 osc cycles).

  You need to adjust the timing for your application!

-*------------------------------------------------------------------*/
void DELAY_LOOP_Wait(const tWord DELAY_MS)
   {
   tWord x, y;

   for (x = 0; x <= DELAY_MS; x++)
      {
      for (y = 0; y <= 120; y++);
      }
   }

/*------------------------------------------------------------------*-
  ---- END OF FILE ----------------------------------------
-*------------------------------------------------------------------*/
```

Preparation for the next seminar



Please read **Chapter 6**
before the next seminar

Seminar 5:
Meeting Real-Time Constraints

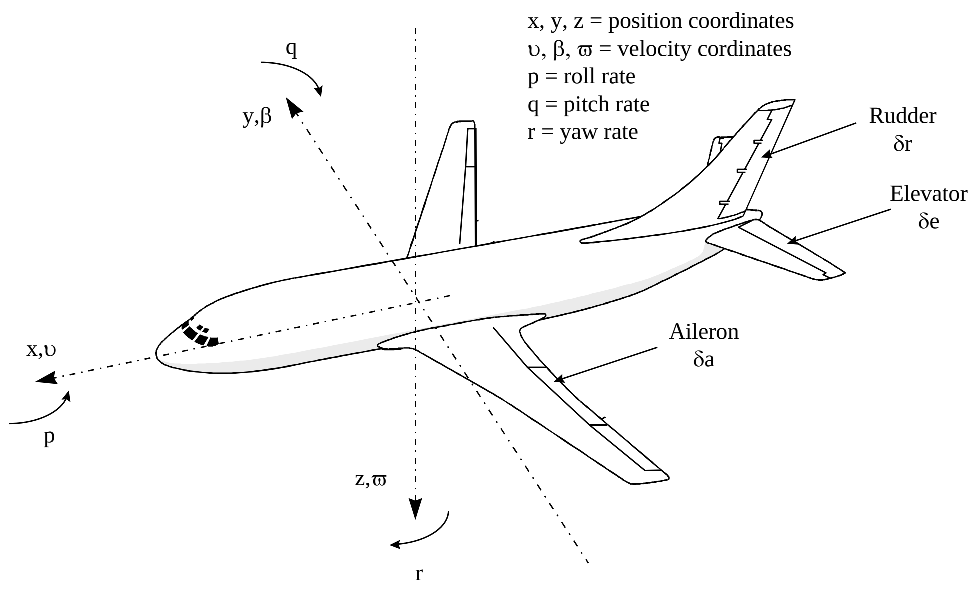


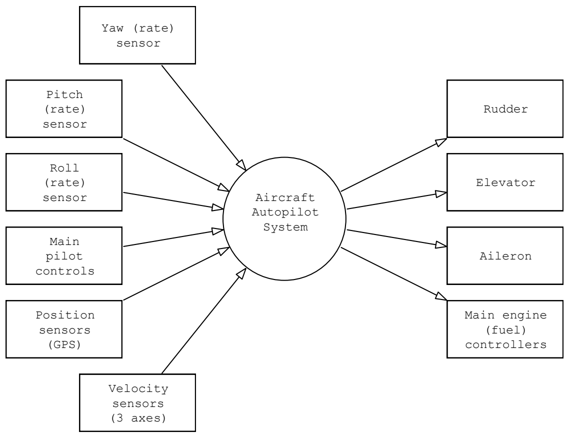
```
min time:  max time:  avg time:  total time:  %      count:
1.000484   1.000484   .000182    842.335815   100.0  1842
```

Introduction

In this seminar, we begin to consider the issues involved in the accurate measurement of time.

These issues are important because many embedded systems must satisfy real-time constraints.





```
bit SWITCH_Get_Input(const tByte DEBOUNCE_PERIOD)
   {
   tByte Return_value = SWITCH_NOT_PRESSED;

   if (Switch_pin == 0)
      {
      /* Switch is pressed */

      /* Debounce - just wait... */
      DELAY_LOOP_Wait(DEBOUNCE_PERIOD); /* POTENTIAL PROBLEM */

      /* Check switch again */
      if (Switch_pin == 0)
         {
         /* Wait until the switch is released. */
         while (Switch_pin == 0);       /* POTENTIAL CATASTROPHE */
         Return_value = SWITCH_PRESSED;
         }
      }

   /* Now (finally) return switch value */
   return Return_value;
   }
```

The first problem is that we wait for a 'debounce' period in order to confirm that the switch has been pressed. Because this delay is implemented using a software loop it may not be very precisely timed.

The second problem is even more serious in a system with real-time characteristics: we cause the system to wait - indefinitely - for the user to release the switch.

We'll see how to deal with both of these problems in this seminar

Creating "hardware delays"

All members of the 8051 family have at least two 16-bit timer / counters, known as Timer 0 and Timer 1.

These timers can be used to generate accurate delays.

```
/* Configure Timer 0 as a 16-bit timer  */
TMOD &= 0xF0; /* Clear all T0 bits (T1 left unchanged) */
TMOD |= 0x01; /* Set required T0 bits (T1 left unchanged)  */

ET0 = 0;  /* No interrupts */

/* Values for 50 ms delay */
TH0 = 0x3C;  /* Timer 0 initial value (High Byte) */
TL0 = 0xB0;  /* Timer 0 initial value (Low Byte) */

TF0 = 0;         /* Clear overflow flag */
TR0 = 1;         /* Start Timer 0 */

while (TF0 == 0); /* Loop until Timer 0 overflows (TF0 == 1) */

TR0 = 0;         /* Stop Timer 0 */
```

Now let's see how this works…

The TCON SFR

Bit	7 (msb)	6	5	4	3	2	1	0 (lsb)
NAME	TF1	TR1	TF0	TR0	IE1	IT1	IE0	IT0

TF1 Timer 1 overflow flag

Set by hardware on Timer 1 overflow.
(Cleared by hardware if processor vectors to interrupt routine.)

TR1 Timer 1 run control bit

Set / cleared by software to turn Timer 1 either 'ON' or 'OFF'.

TF0 Timer 0 overflow flag

Set by hardware on Timer 0 overflow.
(Cleared by hardware if processor vectors to interrupt routine.)

TR0 Timer 0 run control bit

Set / cleared by software to turn Timer 0 either 'ON' or 'OFF'.

Note that the overflow of the timers can be used to generate an interrupt. We will not make use of this facility in the Hardware Delay code.

To disable the generation of interrupts, we can use the C statements:

```
ET0 = 0; /* No interrupts (Timer 0) */
ET1 = 0; /* No interrupts (Timer 1) */
```

The TMOD SFR

Bit	7	6	5	4	3	2	1	0
NAME	Gate	$C / \overline{T}$	M1	M0	Gate	$C / \overline{T}$	M1	M0

Timer 1 *Timer 0*

Mode 1 (M1 = 0; M0 = 1)

16-bit timer/counter (with manual reload)

Mode 2 (M1 = 1; M0 = 0)

8-bit timer/counter (with 8-bit auto-reload)

GATE Gating control

When set, timer/counter "x" is enabled only while "INT x" pin is high and "TRx" control bit is set. When cleared timer "x" is enabled whenever "TRx" control bit is set.

$C / \overline{T}$ *Counter or timer select bit*

Set for counter operation (input from "Tx" input pin).
Cleared for timer operation (input from internal system clock).

Two further registers

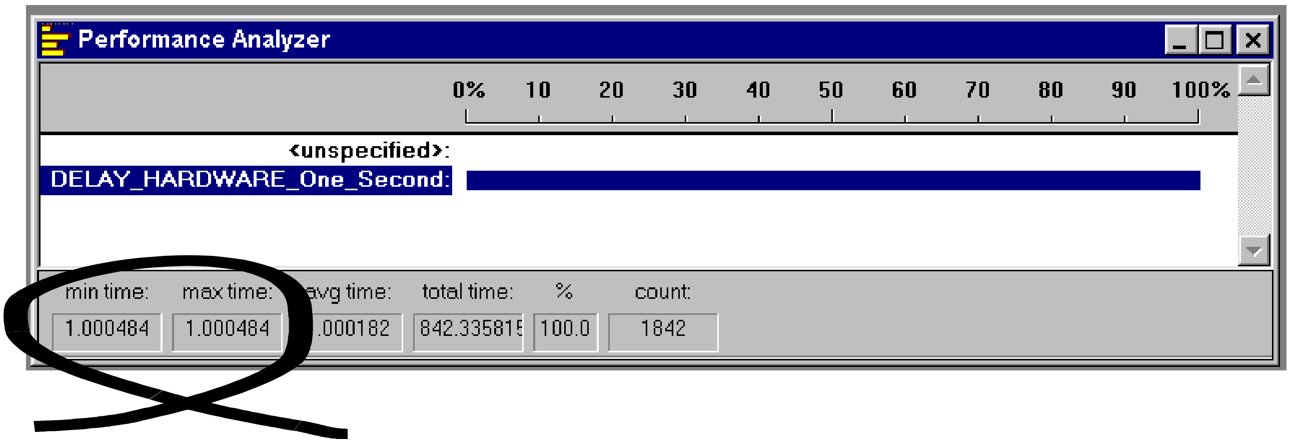
Before we can see how this hardware can be used to create delays, you need to be aware that there are an additional two registers associated with each timer: these are known as TL0 and TH0, and TL1 and TH1.

Example: Generating a precise 50 ms delay

```
/*------------------------------------------------------------------*-

   Hardware_Delay_50ms.C (v1.00)

  --------------------------------------------------------

   A test program for hardware-based delays.

-*------------------------------------------------------------------*/

#include <reg52.h>

sbit LED_pin = P1^5;
bit LED_state_G;

void LED_FLASH_Init(void);
void LED_FLASH_Change_State(void);

void DELAY_HARDWARE_One_Second(void);
void DELAY_HARDWARE_50ms(void);

/*..................................................................*/

void main(void)
   {
   LED_FLASH_Init();

   while(1)
      {
      /* Change the LED state (OFF to ON, or vice versa) */
      LED_FLASH_Change_State();

      /* Delay for approx 1000 ms */
      DELAY_HARDWARE_One_Second();
      }
   }
```

```
/*------------------------------------------------------------------*-

  LED_FLASH_Init()

  Prepare for LED_Change_State() function - see below.

-*------------------------------------------------------------------*/
void LED_FLASH_Init(void)
   {
   LED_state_G = 0;
   }

/*------------------------------------------------------------------*-

  LED_FLASH_Change_State()

  Changes the state of an LED (or pulses a buzzer, etc) on a
  specified port pin.

  Must call at twice the required flash rate: thus, for 1 Hz
  flash (on for 0.5 seconds, off for 0.5 seconds) must call
  every 0.5 seconds.

-*------------------------------------------------------------------*/
void LED_FLASH_Change_State(void)
   {
   /* Change the LED from OFF to ON (or vice versa) */
   if (LED_state_G == 1)
      {
      LED_state_G = 0;
      LED_pin = 0;
      }
   else
      {
      LED_state_G = 1;
      LED_pin = 1;
      }
   }
```

```
/*------------------------------------------------------------------*-

  DELAY_HARDWARE_One_Second()

  Hardware delay of 1000 ms.

  *** Assumes 12MHz 8051 (12 osc cycles) ***

-*------------------------------------------------------------------*/
void DELAY_HARDWARE_One_Second(void)
   {
   unsigned char d;

   /* Call DELAY_HARDWARE_50ms() twenty times */
   for (d = 0; d < 20; d++)
      {
      DELAY_HARDWARE_50ms();
      }
   }

/*------------------------------------------------------------------*-

  DELAY_HARDWARE_50ms()

  *** Assumes 12MHz 8051 (12 osc cycles) ***

-*------------------------------------------------------------------*/
void DELAY_HARDWARE_50ms(void)
   {
   /* Configure Timer 0 as a 16-bit timer  */
   TMOD &= 0xF0; /* Clear all T0 bits (T1 left unchanged) */
   TMOD |= 0x01; /* Set required T0 bits (T1 left unchanged)  */

   ET0 = 0;      /* No interrupts */

   /* Values for 50 ms delay */
   TH0 = 0x3C;  /* Timer 0 initial value (High Byte) */
   TL0 = 0xB0;  /* Timer 0 initial value (Low Byte) */

   TF0 = 0;          /* Clear overflow flag */
   TR0 = 1;          /* Start timer 0 */

   while (TF0 == 0); /* Loop until Timer 0 overflows (TF0 == 1) */

   TR0 = 0;          /* Stop Timer 0 */
   }
```



```
<unspecified>:
DELAY_HARDWARE_One_Second:

min time:   max time:   avg time:   total time:   %       count:
1.000484    1.000484    .000182     842.33581     100.0   1842
```

In this case, we assume - again - the standard 12 MHz / 12 oscillations-per-instruction microcontroller environment.

We require a 50 ms delay, so the timer requires the following number of increments before it overflows:

$$\frac{50ms}{1000ms} \times 1000000 = 50000 \text{ increments.}$$

The timer overflows when it is incremented from its maximum count of 65535.

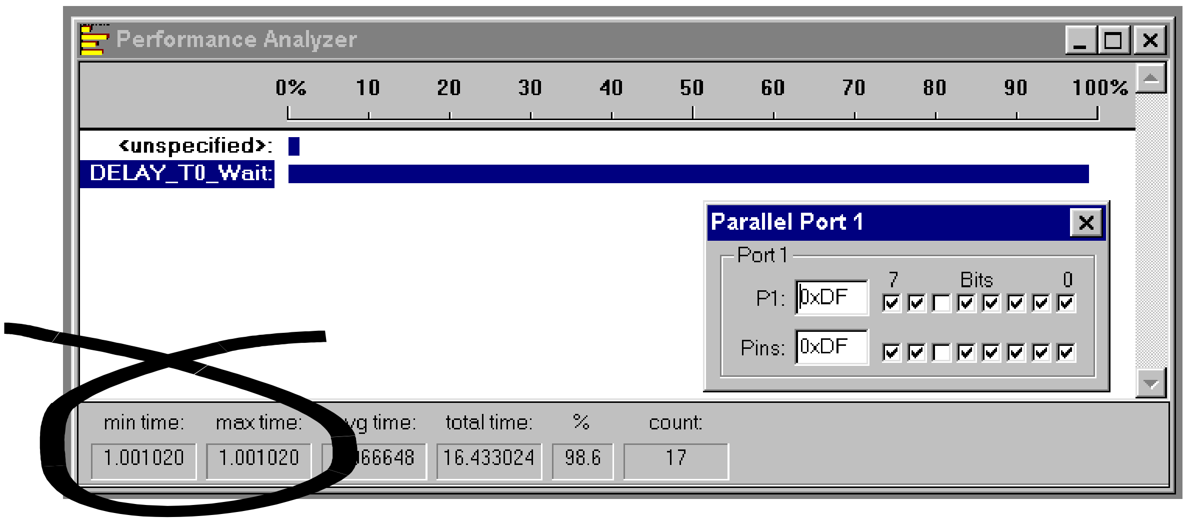
Thus, the initial value we need to load to produce a 50 ms delay is:

65536 - 50000 = 15536 (decimal) = 0x3CB0

Example: Creating a portable hardware delay

```
/*------------------------------------------------------------------*-

   Main.C (v1.00)

  ------------------------------------------------------------------

   Flashing LED with hardware-based delay (T0).

-*------------------------------------------------------------------*/

#include "Main.H"
#include "Port.H"

#include "Delay_T0.h"
#include "LED_Flash.h"

void main(void)
   {
   LED_FLASH_Init();

   while(1)
      {
      /* Change the LED state (OFF to ON, or vice versa) */
      LED_FLASH_Change_State();

      /* Delay for *approx* 1000 ms */
      DELAY_T0_Wait(1000);
      }
   }

/*------------------------------------------------------------------*-
  ---- END OF FILE --------------------------------------------------
-*------------------------------------------------------------------*/
```

```
/* Timer preload values for use in simple (hardware) delays
   - Timers are 16-bit, manual reload ('one shot').

   NOTE: These values are portable but timings are *approximate*
         and *must* be checked by hand if accurate timing is required.

   Define Timer 0 / Timer 1 reload values for ~1 msec delay
   NOTE: Adjustment made to allow for function call overheard etc. */
#define PRELOAD01  (65536 - (tWord)(OSC_FREQ / (OSC_PER_INST * 1020)))
#define PRELOAD01H (PRELOAD01 / 256)
#define PRELOAD01L (PRELOAD01 % 256)

/*----------------------------------------------------------------*/

void DELAY_T0_Wait(const tWord N)
   {
   tWord ms;

   /* Configure Timer 0 as a 16-bit timer  */
   TMOD &= 0xF0; /* Clear all T0 bits (T1 left unchanged) */
   TMOD |= 0x01; /* Set required T0 bits (T1 left unchanged)  */

   ET0 = 0;      /* No interrupts */

   /* Delay value is *approximately* 1 ms per loop    */
   for (ms = 0; ms < N; ms++)
      {
      TH0 = PRELOAD01H;
      TL0 = PRELOAD01L;

      TF0 = 0;          /* Clear overflow flag */
      TR0 = 1;          /* Start timer 0 */

      while (TF0 == 0); /* Loop until Timer 0 overflows (TF0 == 1) */

      TR0 = 0;          /* Stop Timer 0 */
      }
   }
```



min time:	max time:	avg time:	total time:	%	count:
1.001020	1.001020	66648	16.433024	98.6	17

The need for ‘timeout’ mechanisms - example

The Philips 8Xc552 is an Extended 8051 device with a number of on-chip peripherals, including an 8-channel, 10-bit ADC. Philips provide an application note (AN93017) that describes how to use this feature of the microcontroller.

This application note includes the following code:

```
/* Wait until AD conversion finishes (checking ADCI) */
while ((ADCON & ADCI) == 0);
```

Such code is potentially unreliable, because there are circumstances under which our application may ‘hang’. This might occur for one or more of the following reasons:

- If the ADC has been incorrectly initialised, we cannot be sure that a data conversion will be carried out.
- If the ADC has been subjected to an excessive input voltage, then it may not operate at all.
- If the variable ADCON or ADCI were not correctly initialised, they may not operate as required.

The Philips example is not intended to illustrate ‘production’ code. Unfortunately, however, code in this form is common in embedded applications.

Two possible solutions: **Loop timeouts** and **hardware timeouts**.

Creating loop timeouts

Basis of loop timeout:

```
tWord Timeout_loop = 0;

...

while (++Timeout_loop);
```

Original ADC code:

```
/* Wait until AD conversion finishes (checking ADCI) */
while ((ADCON & ADCI) == 0);
```

Modified version, with a loop timeout:

```
tWord Timeout_loop = 0;

/* Take sample from ADC
   Wait until conversion finishes (checking ADCI)
   - simple loop timeout */
while (((ADCON & ADCI) == 0) && (++Timeout_loop != 0));
```

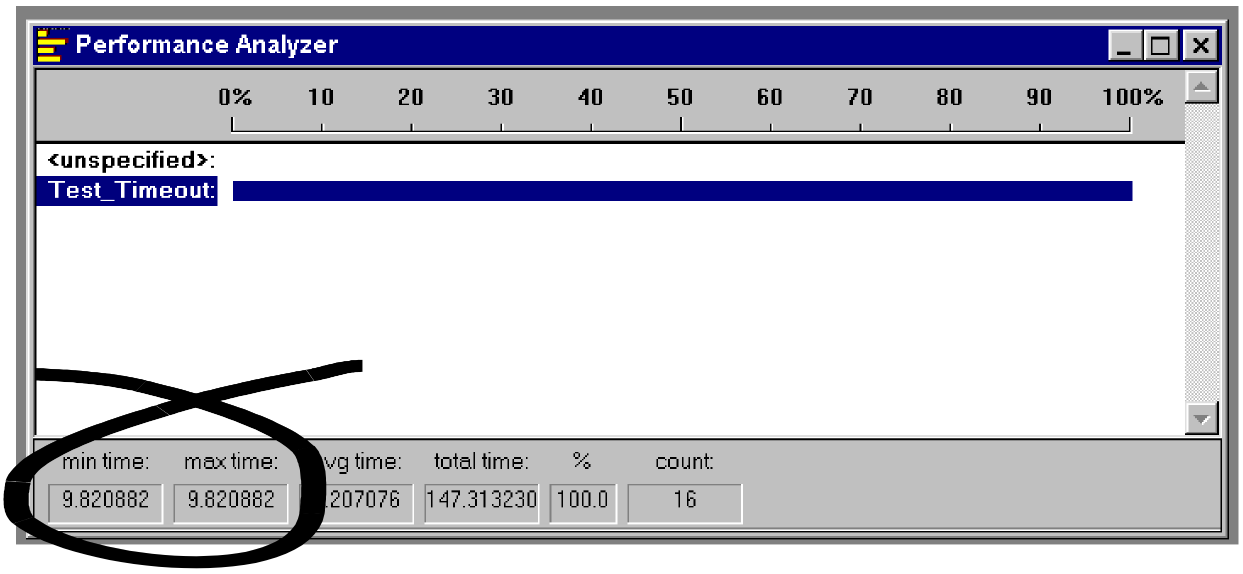
Note that this alternative implementation is also useful:

```
while (((ADCON & ADCI) == 0) && (Timeout_loop != 0))
   {
   Timeout_loop++;  /* Disable for use in hardware simulator */
   }
```

```
/*------------------------------------------------------------------*-

   TimeoutL.H (v1.00)

  --------------------------------------------------------

   Simple software (loop) timeout delays for the 8051 family.

   * THESE VALUES ARE NOT PRECISE - YOU MUST ADAPT TO YOUR SYSTEM *

-*------------------------------------------------------------------*/

#ifndef _TIMEOUTL_H
#define _TIMEOUTL_H

/* ------ Public constants ------------------------------------ */

/* Vary this value to change the loop duration
   THESE ARE APPROX VALUES FOR VARIOUS TIMEOUT DELAYS
   ON 8051, 12 MHz, 12 Osc / cycle

   *** MUST BE FINE TUNED FOR YOUR APPLICATION ***

   *** Timings vary with compiler optimisation settings *** */

/* tWord */
#define LOOP_TIMEOUT_INIT_001ms 65435
#define LOOP_TIMEOUT_INIT_010ms 64535
#define LOOP_TIMEOUT_INIT_500ms 14535
/* tLong */
#define LOOP_TIMEOUT_INIT_10000ms 4294795000UL

#endif

/*------------------------------------------------------------------*-
  ---- END OF FILE ----------------------------------------
-*------------------------------------------------------------------*/
```

Example: Testing loop timeouts

```
/*------------------------------------------------------------------*-

   Main.C (v1.00)

-*------------------------------------------------------------------*/

#include <reg52.H>

#include "TimeoutL.H"

/* Typedefs (see Chap 5)   */
typedef unsigned char tByte;
typedef unsigned int  tWord;
typedef unsigned long tLong;

/* Function prototypes */
void Test_Timeout(void);

/*------------------------------------------------------------------*/
void main(void)
   {
   while(1)
      {
      Test_Timeout();
      }
   }

/*------------------------------------------------------------------*/
void Test_Timeout(void)
   {
   tLong Timeout_loop = LOOP_TIMEOUT_INIT_10000ms;

   /* Simple loop timeout... */
   while (++Timeout_loop != 0);
   }
```



```
<unspecified>:
Test_Timeout:

min time:   max time:   vg time:   total time:   %       count:
9.820882    9.820882    .207076    147.313230    100.0   16
```

Example: A more reliable switch interface

```
bit SWITCH_Get_Input(const tByte DEBOUNCE_PERIOD)
   {
   tByte Return_value = SWITCH_NOT_PRESSED;
   tLong Timeout_loop = LOOP_TIMEOUT_INIT_10000ms;

   if (Switch_pin == 0)
      {
      /* Switch is pressed */

      /* Debounce - just wait... */
      DELAY_T0_Wait(DEBOUNCE_PERIOD);

      /* Check switch again */
      if (Switch_pin == 0)
         {
         /* Wait until the switch is released.
            (WITH TIMEOUT LOOP - 10 seconds) */
         while ((Switch_pin == 0) && (++Timeout_loop != 0));

         /* Check for timeout */
         if (Timeout_loop == 0)
            {
            Return_value = SWITCH_NOT_PRESSED;
            }
         else
            {
            Return_value = SWITCH_PRESSED;
            }
         }
      }

   /* Now (finally) return switch value */
   return Return_value;
   }
```

Creating hardware timeouts

```
/* Configure Timer 0 as a 16-bit timer  */
TMOD &= 0xF0; /* Clear all T0 bits (T1 left unchanged) */
TMOD |= 0x01; /* Set required T0 bits (T1 left unchanged)  */

ET0 = 0;      /* No interrupts */

/* Simple timeout feature - approx 10 ms */
TH0 = PRELOAD_10ms_H; /* See Timeout.H for PRELOAD details */
TL0 = PRELOAD_10ms_L;
TF0 = 0; /* Clear flag */
TR0 = 1; /* Start timer */

while (((ADCON & ADCI) == 0) && !TF0);
```

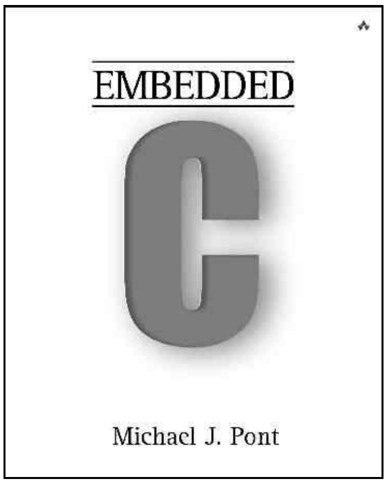
```
/*------------------------------------------------------------------*-

   TimeoutH.H (v1.00)

-*------------------------------------------------------------------*/

#ifndef _TIMEOUTH_H
#define _TIMEOUTH_H

/* ------ Public constants ------------------------------------ */

/* Timer T_ values for use in simple (hardware) timeouts */
   - Timers are 16-bit, manual reload ('one shot'). */

   NOTE: These macros are portable but timings are *approximate*
         and *must* be checked by hand for accurate timing. */

/* Define initial Timer 0 / Timer 1 values for ~50 µs delay */
#define T_50micros (65536 - (tWord)((OSC_FREQ /
26000)/(OSC_PER_INST)))
#define T_50micros_H (T_50micros / 256)
#define T_50micros_L (T_50micros % 256)

...

/* Define initial Timer 0 / Timer 1 values for ~10 msec delay */
#define T_10ms  (65536 - (tWord)(OSC_FREQ / (OSC_PER_INST * 100)))
#define T_10ms_H (T_10ms / 256)
#define T_10ms_L  (T_10ms % 256)

/* Define initial Timer 0 / Timer 1 values for ~15 msec delay */
#define T_15ms  (65536 - (tWord)(OSC_FREQ / (OSC_PER_INST * 67)))
#define T_15ms_H (T_15ms / 256)
#define T_15ms_L  (T_15ms % 256)

/* Define initial Timer 0 / Timer 1 values for ~20 msec delay */
#define T_20ms  (65536 - (tWord)(OSC_FREQ / (OSC_PER_INST * 50)))
#define T_20ms_H (T_20ms / 256)
#define T_20ms_L  (T_20ms % 256)

/* Define initial Timer 0 / Timer 1 values for ~50 msec delay */
#define T_50ms  (65536 - (tWord)(OSC_FREQ / (OSC_PER_INST * 20)))
#define T_50ms_H (T_50ms / 256)
#define T_50ms_L (T_50ms % 256)

#endif
```

Conclusions

The delay and timeout considered in this seminar are widely used in embedded applications.

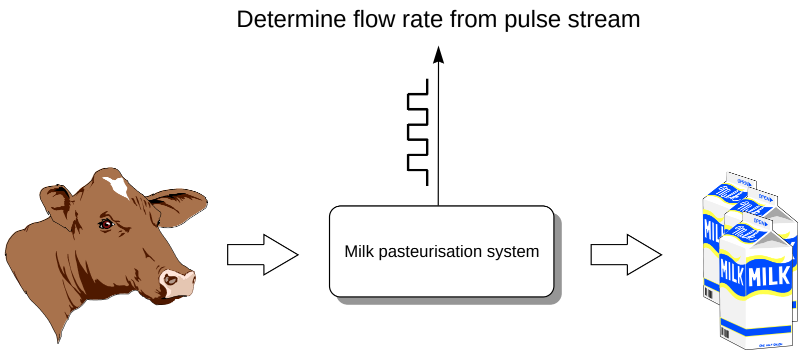
In the next seminar we go on to consider another key software component in many embedded applications: the operating system.

Preparation for the next seminar



Please read **Chapter 7**
before the next seminar

Seminar 6: Creating an Embedded Operating System

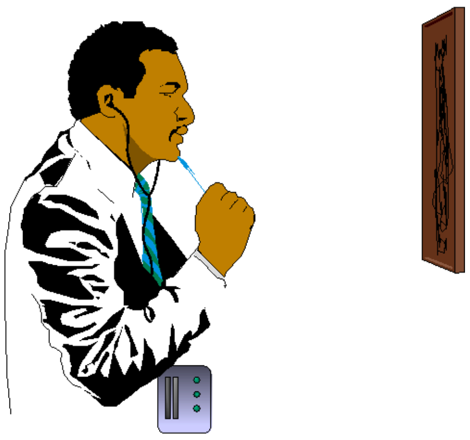

Determine flow rate from pulse stream
Milk pasteurisation system
MILK
MILK

Introduction

```
void main(void)
   {
   /* Prepare run function X */
   X_Init();

   while(1) /* 'for ever' (Super Loop) */
      {
      X();  /* Run function X */
      }
   }
```

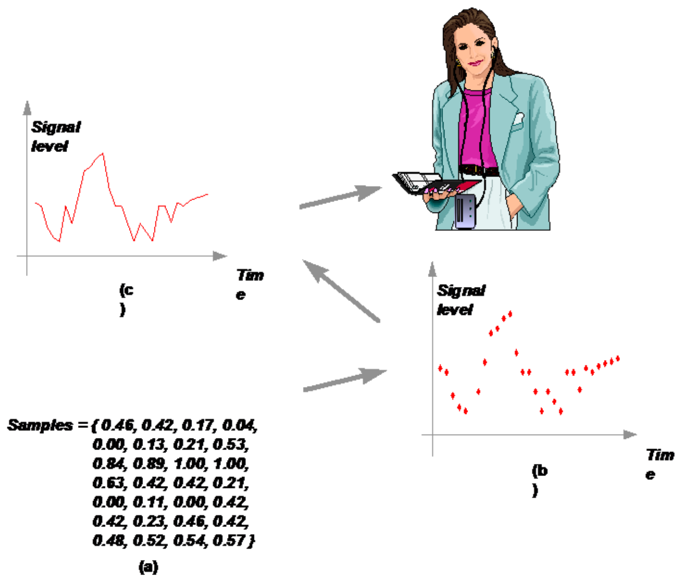
A particular limitation with this architecture is that it is very difficult to execute function `X()` at precise intervals of time: as we will see, this is a very significant drawback.

For example …



"Item 345 was painted by Selvio Guaranteen early in the 16th century. At this time, Guaranteen, who is generally known as a member of the Slafordic School, was ..."

"Now turn to your left, and locate Item 346, a small painting which was until recently also thought to have been painted by Guarateen but which is now ...".


Signal level
Time
(c)
Signal level
Time
(b)
Samples = { 0.46, 0.42, 0.17, 0.04, 0.00, 0.13, 0.21, 0.53, 0.84, 0.89, 1.00, 1.00, 0.63, 0.42, 0.42, 0.21, 0.00, 0.11, 0.00, 0.42, 0.42, 0.23, 0.46, 0.42, 0.48, 0.52, 0.54, 0.57 }
(a)

Consider a collection of requirements assembled from a range of different embedded projects (in no particular order):

- The current speed of the vehicle must be measured at 0.5 second intervals.
- The display must be refreshed 40 times every second
- The calculated new throttle setting must be applied every 0.5 seconds.
- A time-frequency transform must be performed 20 times every second.
- The engine vibration data must be sampled 1000 times per second.
- The frequency-domain data must be classified 20 times every second.
- The keypad must be scanned every 200 ms.
- The master (control) node must communicate with all other nodes (sensor nodes and sounder nodes) once per second.
- The new throttle setting must be calculated every 0.5 seconds
- The sensors must be sampled once per second

In practice, many embedded systems must be able to support this type of 'periodic function'.

```
void main(void)
   {
   Init_System();

   while(1) /* 'for ever' (Super Loop) */
      {
      X();          /* Call the function (10 ms duration) */
      Delay_50ms(); /* Delay for 50 ms */
      }
   }
```

This will be fine, if:

1. We know the precise duration of function `X()`, and,
2. This duration never varies.

Timer-based interrupts (the core of an embedded OS)

```
#define INTERRUPT_Timer_2_Overflow 5
...

void main(void)
   {
   Timer_2_Init();  /* Set up Timer 2 */

   EA = 1;          /* Globally enable interrupts */

   while(1);        /* An empty Super Loop */
   }

void Timer_2_Init(void)
   {
   /* Timer 2 is configured as a 16-bit timer,
      which is automatically reloaded when it overflows

      This code (generic 8051/52) assumes a 12 MHz system osc.
      The Timer 2 resolution is then 1.000 µs

      Reload value is FC18 (hex) = 64536 (decimal)
      Timer (16-bit) overflows when it reaches 65536 (decimal)
      Thus, with these setting, timer will overflow every 1 ms */
   T2CON   = 0x04;   /* Load T2 control register */

   TH2     = 0xFC;   /* Load T2 high byte */
   RCAP2H  = 0xFC;   /* Load T2 reload capt. reg. high byte */
   TL2     = 0x18;   /* Load T2 low byte */
   RCAP2L  = 0x18;   /* Load T2 reload capt. reg. low byte */

   /* Timer 2 interrupt is enabled, and ISR will be called
      whenever the timer overflows - see below. */
   ET2     = 1;

   /* Start Timer 2 running */
   TR2   = 1;
   }

void X(void) interrupt INTERRUPT_Timer_2_Overflow
   {
   /* This ISR is called every 1 ms */
   /* Place required code here... */
   }
```

The interrupt service routine (ISR)

The interrupt generated by the overflow of Timer 2, invokes the ISR:

```
/* ------------------------------------------------------------------ */
void X(void) interrupt INTERRUPT_Timer_2_Overflow
   {
   /* This ISR is called every 1 ms */

   /* Place required code here... */
   }
```

The link between this function and the timer overflow is made using the Keil keyword `interrupt`:

```
void X(void) interrupt INTERRUPT_Timer_2_Overflow
```

…plus the following `#define` directive:

```
#define INTERRUPT_Timer_2_Overflow 5
```

Interrupt source	Address	IE Index
Power On Reset	0x00	-
External Interrupt 0	0x03	0
Timer 0 Overflow	0x0B	1
External Interrupt 1	0x13	2
Timer 1 Overflow	0x1B	3
UART Receive/Transmit	0x23	4
Timer 2 Overflow	0x2B	5

Automatic timer reloads

```
/* Preload values for 50 ms delay */
TH0 = 0x3C;         /* Timer 0 initial value (High Byte) */
TL0 = 0xB0;         /* Timer 0 initial value (Low Byte) */

TF0 = 0;            /* Clear overflow flag */
TR0 = 1;            /* Start timer 0 */

while (TF0 == 0); /* Loop until Timer 0 overflows (TF0 == 1) */

TR0 = 0;            /* Stop Timer 0 */
```

For our operating system, we have slightly different requirements:

- We require a long series of interrupts, at precisely-determined intervals.
- We would like to generate these interrupts without imposing a significant load on the CPU.

Timer 2 matches these requirements precisely.

In this case, the timer is reloaded using the contents of the 'capture' registers (note that the names of these registers vary slightly between chip manufacturers):

```
RCAP2H  = 0xFC;   /* Load T2 reload capt. reg. high byte */
RCAP2L  = 0x18;   /* Load T2 reload capt. reg. low byte */
```

This automatic reload facility ensures that the timer keeps generating the required ticks, at precise 1 ms intervals, with very little software load, and without any intervention from the user's program.

Introducing sEOS

```
void main(void)
   {
   Init_System();

   while(1) /* 'for ever' (Super Loop) */
      {
      X();           /* Call the function (10 ms duration) */
      Delay_50ms(); /* Delay for 50 ms */
      }
   }
```

In this case:

- We use a Super Loop and delay code
- We call `X()` every 60 ms - approximately.

Now let's look at a better way of doing this ...

Introducing sEOS

See "Embedded C", Chapter 7

```
/*------------------------------------------------------------------*-

   Main.c (v1.00)

  ------------------------------------------------------------------

   Demonstration of sEOS running a dummy task.

-*------------------------------------------------------------------*/

#include "Main.H"
#include "Port.H"
#include "Simple_EOS.H"

#include "X.H"

/* ------------------------------------------------------------------ */

void main(void)
   {
   /* Prepare for dummy task */
   X_Init();

   /* Set up simple EOS (60 ms tick interval) */
   sEOS_Init_Timer2(60);

   while(1) /* Super Loop */
      {
      /* Enter idle mode to save power */
      sEOS_Go_To_Sleep();
      }
   }

/*------------------------------------------------------------------*-
  ---- END OF FILE -------------------------------------------------
-*------------------------------------------------------------------*/
```

```
/*------------------------------------------------------------*-

   Simple_EOS.C (v1.00)

  --------------------------------------------------

   Main file for Simple Embedded Operating System (sEOS).

   Demonstration version with dummy task X().

-*------------------------------------------------------------*/

#include "Main.H"
#include "Simple_EOS.H"

/* Header for dummy task  */
#include "X.H"

/*------------------------------------------------------------*-

  sEOS_ISR()

  Invoked periodically by Timer 2 overflow:
  see sEOS_Init_Timer2() for timing details.

-*------------------------------------------------------------*/
sEOS_ISR() interrupt INTERRUPT_Timer_2_Overflow
   {
   /* Must manually reset the T2 flag  */
   TF2 = 0;

   /*===== USER CODE - Begin ============================= */

   /* Call dummy task here */
   X();

   /*===== USER CODE - End =============================== */
   }
```

```
/*------------------------------------------------------------*-

  sEOS_Init_Timer2()

-*------------------------------------------------------------*/
void sEOS_Init_Timer2(const tByte TICK_MS)
   {
   tLong Inc;
   tWord Reload_16;
   tByte Reload_08H, Reload_08L;

   /* Timer 2 is configured as a 16-bit timer,
      which is automatically reloaded when it overflows */
   T2CON   = 0x04;   /* Load T2 control register */

   /* Number of timer increments required (max 65536) */
   Inc = ((tLong)TICK_MS * (OSC_FREQ/1000)) /
          (tLong)OSC_PER_INST;

   /* 16-bit reload value */
   Reload_16 = (tWord) (65536UL - Inc);

   /* 8-bit reload values (High & Low) */
   Reload_08H = (tByte)(Reload_16 / 256);
   Reload_08L = (tByte)(Reload_16 % 256);

   /* Used for manually checking timing (in simulator) */
   /*P2 = Reload_08H; */
   /*P3 = Reload_08L; */

   TH2     = Reload_08H;   /* Load T2 high byte */
   RCAP2H  = Reload_08H;   /* Load T2 reload capt. reg h byte */
   TL2     = Reload_08L;   /* Load T2 low byte */
   RCAP2L  = Reload_08L;   /* Load T2 reload capt. reg l byte */

   /* Timer 2 interrupt is enabled, and ISR will be called
      whenever the timer overflows. */
   ET2     = 1;

   /* Start Timer 2 running */
   TR2   = 1;

   EA = 1;            /* Globally enable interrupts */
   }
```

```
/*------------------------------------------------------------*-

  sEOS_Go_To_Sleep()

  This operating system enters 'idle mode' between clock ticks
  to save power.  The next clock tick will return processor
  to the normal operating state.

-*------------------------------------------------------------*/
void sEOS_Go_To_Sleep(void)
   {
   PCON |= 0x01;    /* Enter idle mode (generic 8051 version) */
   }

/*------------------------------------------------------------*-
  ---- END OF FILE -------------------------------------
-*------------------------------------------------------------*/
```

```
/*------------------------------------------------------------------*-

   X.C (v1.00)

  ------------------------------------------------------------------

   Dummy task to introduce sEOS.

-*------------------------------------------------------------------*/

#include "X.H"

/*------------------------------------------------------------------*-

  X_Init()

  Dummy task init function.

-*------------------------------------------------------------------*/
void X_Init(void)
   {
   /* Dummy task init... */
   }

/*------------------------------------------------------------------*-

  X()

  Dummy task called from sEOS ISR.

-*------------------------------------------------------------------*/
void X(void)
   {
   /* Dummy task... */
   }

/*------------------------------------------------------------------*-
  ---- END OF FILE -------------------------------------------------
-*------------------------------------------------------------------*/
```

Tasks, functions and scheduling

- In discussions about embedded systems, you will frequently hear and read about 'task design', 'task execution times' and 'multi-tasking' systems.

- In this context, the term 'task' is usually used to refer to **a function that is executed on a periodic basis**.

- In the case of sEOS, the tasks will be implemented **using functions which are called from the timer-driven interrupt service routine**.

Setting the tick interval

In the function `main()`, we can see that the control of the tick interval has been largely automated:

```
/* Set up simple EOS (60 ms tick interval) */
sEOS_Init_Timer2(60);
```

In this example, a tick interval of 60 ms is used: this means that the ISR (the 'update' function) at the heart of sEOS will be invoked every 60 ms:

```
/*------------------------------------------------------------------*-

  sEOS_ISR()

  Invoked periodically by Timer 2 overflow:
  see sEOS_Init_Timer2() for timing details.

-*------------------------------------------------------------------*/
sEOS_ISR() interrupt INTERRUPT_Timer_2_Overflow
   {
   …
   }
```

The ‘automatic’ tick interval control is achieved using the C pre-processor, and the information included in the project header file (`Main.H`):

```
/* Oscillator / resonator frequency (in Hz) e.g. (11059200UL) */
#define OSC_FREQ (12000000UL)

/* Number of oscillations per instruction (12, etc) */
...
#define OSC_PER_INST (12)
```

This information is then used to calculate the required timer reload values in `Simple_EOS.C` as follows:

```
   /* Number of timer increments required (max 65536) */
   Inc = ((tLong)TICK_MS * (OSC_FREQ/1000)) / (tLong)OSC_PER_INST;

   /* 16-bit reload value */
   Reload_16 = (tWord) (65536UL - Inc);

   /* 8-bit reload values (High & Low) */
   Reload_08H = (tByte)(Reload_16 / 256);
   Reload_08L = (tByte)(Reload_16 % 256);
```

…

```
   TH2     = Reload_08H;   /* Load T2 high byte */
   RCAP2H  = Reload_08H;   /* Load T2 reload capt. reg h byte */
   TL2     = Reload_08L;   /* Load T2 low byte */
   RCAP2L  = Reload_08L;   /* Load T2 reload capt. reg l byte */
```

- If using a 12 MHz oscillator, then accurate timing can usually be obtained over a range of tick intervals from 1 ms to 60 ms (approximately).
- If using other clock frequencies (e.g. 11.0592 MHz), precise timing can only be obtained at a much more limited range of tick intervals.
- If you are developing an application where precise timing is required, you must check the timing calculations by hand.

```
/* Used for manually checking timing (in simulator) */
P2 = Reload_08H;
P3 = Reload_08L;
```

Saving power

Using sEOS, we can reduce the power consumption of the application by having the processor enter idle mode when it finishes executing the ISR.

This is achieved through the function `sEOS_Go_To_Sleep()`:

```
/*------------------------------------------------------------------*-

  sEOS_Go_To_Sleep()

  This operating system enters 'idle mode' between clock ticks
  to save power.  The next clock tick will return processor
  to the normal operating state.

-*------------------------------------------------------------------*/
void sEOS_Go_To_Sleep(void)
   {
   PCON |= 0x01;    /* Enter idle mode (generic 8051 version) */
   }
```

Note that the processor will automatically return to 'Normal' mode when the timer next overflows (generating an interrupt).

Device	Normal	Idle	Power Down
Atmel 89S53	11 mA	2 mA	60 µA

Using sEOS in your own projects

When using sEOS in your own applications, you will need to include a copy of the files `Simple_EOS.C` and `Simple_EOS.H` in your project: the .C file will then need to be edited - in the area indicated below - in order to match your requirements:

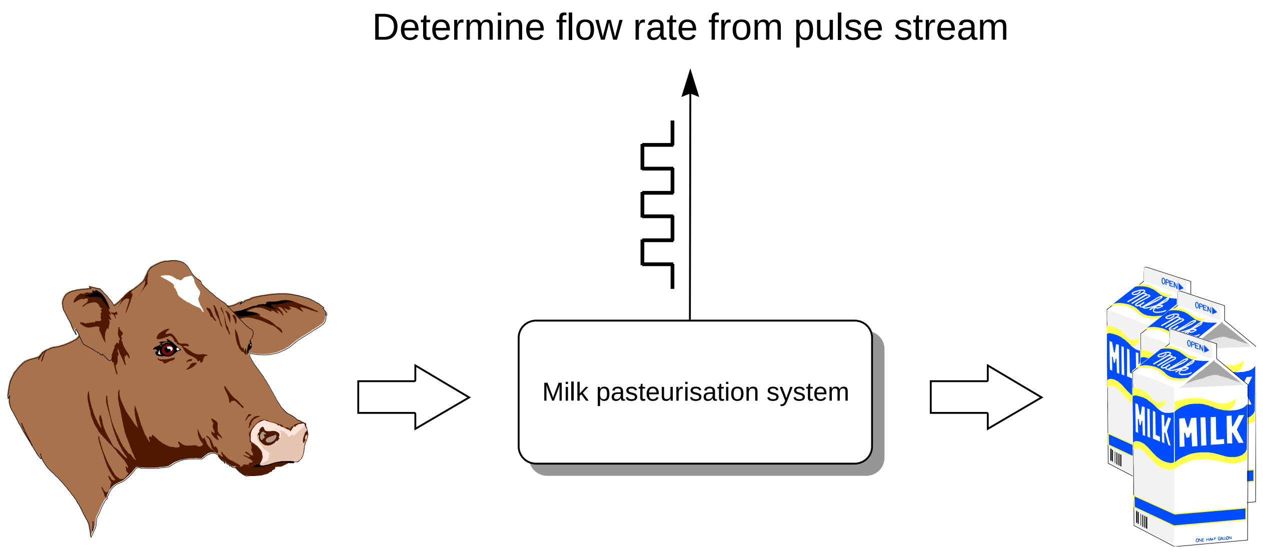
```
sEOS_ISR() interrupt INTERRUPT_Timer_2_Overflow
   {
   /* Must manually reset the T2 flag  */
   TF2 = 0;

   /*===== USER CODE - Begin ============================== */

   /* ADD YOUR FUNCTION (TASK) CALLS HERE... */

   /*===== USER CODE - End ================================ */
   }
```

Is this approach portable?

- The presence of an on-chip timer which can be used to generate interrupts in this way is by no means restricted to the 8051 family: almost all processors intended for use in embedded applications have timers which can be used in a manner very similar to that described here.

- For example, similar timers are included on other 8-bit microcontrollers (e.g. Microchip PIC family, the Motorola HC08 family), and also on 16-bit devices (e.g. the Infineon C167 family) as well as on 32-bit processors (e.g. the ARM family, the Motorola MPC500 family).

Example: Milk pasteurization


Determine flow rate from pulse stream
Milk pasteurisation system
MILK
MILK

```
/*------------------------------------------------------------------*-

   Port.H (v1.00)

  -------------------------------------------------------- 

  Port Header file for the milk pasteurization example
  ("Embedded C" Chapter 7)

-*------------------------------------------------------------------*/

/* ------ Pulse_Count.C ---------------------------------- */

/* Connect pulse input to this pin - debounced in software */
sbit  Sw_pin = P3^0;

/* Connect alarm to this pin (set if pulse is below threshold) */
sbit Alarm_pin = P3^7;

/* ------ Bargraph.C --------------------------------------- */

/* Bargraph display on these pins (the 8 port pins may be
   distributed over several ports, if required). */
sbit Pin0 = P1^0;
sbit Pin1 = P1^1;
sbit Pin2 = P1^2;
sbit Pin3 = P1^3;
sbit Pin4 = P1^4;
sbit Pin5 = P1^5;
sbit Pin6 = P1^6;
sbit Pin7 = P1^7;


/*------------------------------------------------------------------*-
  ---- END OF FILE -------------------------------------------------
-*------------------------------------------------------------------*/
```

```
/*------------------------------------------------------------------*-

   Main.c (v1.00)

  ------------------------------------------------------------------

   Milk pasteurization example.

-*------------------------------------------------------------------*/

#include "Main.H"
#include "Port.H"
#include "Simple_EOS.H"
#include "Bargraph.H"

#include "Pulse_Count.H"

/* ................................................................ */

void main(void)
   {
   PULSE_COUNT_Init();
   BARGRAPH_Init();

   /* Set up simple EOS (30ms tick interval) */
   sEOS_Init_Timer2(30);

   while(1) /* Super Loop */
      {
      /* Enter idle mode to save power */
      sEOS_Go_To_Sleep();
      }
   }

/*------------------------------------------------------------------*-
  ---- END OF FILE -------------------------------------------------
-*------------------------------------------------------------------*/
```

```
/*------------------------------------------------------------------*-

   Simple_EOS.C (v1.00)

  --------------------------------------------------------

   Main file for Simple Embedded Operating System (sEOS) for 8051.

   -- This version for milk-flow-rate monitoring.

-*------------------------------------------------------------------*/

#include "Main.H"
#include "Simple_EOS.H"

#include "Pulse_count.H"


/*------------------------------------------------------------------*-

  sEOS_ISR()

  Invoked periodically by Timer 2 overflow:
  see sEOS_Init_Timer2() for timing details.

-*------------------------------------------------------------------*/
sEOS_ISR() interrupt INTERRUPT_Timer_2_Overflow
   {
   /* Must manually reset the T2 flag  */
   TF2 = 0;

   /*===== USER CODE - Begin ================================== */

   /* Call 'Update' function here */
   PULSE_COUNT_Update();

   /*===== USER CODE - End ==================================== */
   }
```

```
/*------------------------------------------------------------------*-

  sEOS_Init_Timer2()

  ...

-*------------------------------------------------------------------*/
void sEOS_Init_Timer2(const tByte TICK_MS)
   {
   tLong Inc;
   tWord Reload_16;
   tByte Reload_08H, Reload_08L;

   /* Timer 2 is configured as a 16-bit timer,
      which is automatically reloaded when it overflows */
   T2CON   = 0x04;   /* Load T2 control register */

   /* Number of timer increments required (max 65536) */
   Inc = ((tLong)TICK_MS * (OSC_FREQ/1000)) / (tLong)OSC_PER_INST;

   /* 16-bit reload value */
   Reload_16 = (tWord) (65536UL - Inc);

   /* 8-bit reload values (High & Low) */
   Reload_08H = (tByte)(Reload_16 / 256);
   Reload_08L = (tByte)(Reload_16 % 256);

   /* Used for manually checking timing (in simulator) */
   /*P2 = Reload_08H; */
   /*P3 = Reload_08L; */

   TH2     = Reload_08H;   /* Load T2 high byte */
   RCAP2H  = Reload_08H;   /* Load T2 reload capt. reg. high byte */
   TL2     = Reload_08L;   /* Load T2 low byte */
   RCAP2L  = Reload_08L;   /* Load T2 reload capt. reg. low byte */

   /* Timer 2 interrupt is enabled, and ISR will be called
      whenever the timer overflows. */
   ET2     = 1;

   /* Start Timer 2 running */
   TR2    = 1;

   EA = 1;            /* Globally enable interrupts */
   }
```

```
/*------------------------------------------------------------------*-

  sEOS_Go_To_Sleep()

  This operating system enters 'idle mode' between clock ticks
  to save power.  The next clock tick will return the processor
  to the normal operating state.

-*------------------------------------------------------------------*/
void sEOS_Go_To_Sleep(void)
   {
   PCON |= 0x01;    /* Enter idle mode (generic 8051 version) */
   }

/*------------------------------------------------------------------*-
  ---- END OF FILE --------------------------------------------
-*------------------------------------------------------------------*/
```

```
/*------------------------------------------------------------------*-

   Pulse_Count.C (v1.00)

  ------------------------------------------------------------------

   Count pulses from a mechanical switch or similar device.
                                          ___
   Responds to falling edge of pulse:        |___

-*------------------------------------------------------------------*/

#include "Main.H"
#include "Port.H"

#include "Bargraph.H"
#include "Pulse_Count.H"


/* ------ Private function prototypes ------------------------- */
void PULSE_COUNT_Check_Below_Threshold(const tByte);

/* ------ Public variable declarations ------------------------ */
/* The data to be displayed */
extern tBargraph Data_G;

/* ------ Public variable definitions ------------------------- */
/* Set only after falling edge is detected */
bit Falling_edge_G;

/* ------ Private variable definitions ------------------------ */
/* The results of successive tests of the pulse signal */
/* (NOTE: Can't have arrays of bits...) */
static bit Test4, Test3, Test2, Test1, Test0;

static tByte Total_G = 0;
static tWord Calls_G = 0;

/* ------ Private constants ----------------------------------- */

/* Allows changed of logic without hardware changes */
#define HI_LEVEL (0)
#define LO_LEVEL (1)
```

```
/*------------------------------------------------------------*-

  PULSE_COUNT_Init()

  Initialisation function for the switch library.

-*------------------------------------------------------------*/
void PULSE_COUNT_Init(void)
   {
   Sw_pin = 1; /* Use this pin for input */

   /* The tests (see text) */
   Test4 = LO_LEVEL;
   Test3 = LO_LEVEL;
   Test2 = LO_LEVEL;
   Test1 = LO_LEVEL;
   Test0 = LO_LEVEL;
   }

/*------------------------------------------------------------*-

  PULSE_COUNT_Check_Below_Threshold()

  Checks to see if pulse count is below a specified
  threshold value.  If it is, the alarm is sounded.

-*------------------------------------------------------------*/
void PULSE_COUNT_Check_Below_Threshold(const tByte THRESHOLD)
   {
   if (Data_G < THRESHOLD)
      {
      Alarm_pin = 0;
      }
   else
      {
      Alarm_pin = 1;
      }
   }
```

```
/*------------------------------------------------------------------*-

  PULSE_COUNT_Update()

  This is the main switch function.

  It should be called every 30 ms
  (to allow for typical 20ms debounce time).

-*------------------------------------------------------------------*/
void PULSE_COUNT_Update(void)
   {
   /* Clear timer flag */
   TF2 = 0;

   /* Shuffle the test results */
   Test4 = Test3;
   Test3 = Test2;
   Test2 = Test1;
   Test1 = Test0;

   /* Get latest test result */
   Test0 = Sw_pin;

   /* Required result:
      Test4 == HI_LEVEL
      Test3 == HI_LEVEL
      Test1 == LO_LEVEL
      Test0 == LO_LEVEL  */

   if ((Test4 == HI_LEVEL) &&
       (Test3 == HI_LEVEL) &&
       (Test1 == LO_LEVEL) &&
       (Test0 == LO_LEVEL))
      {
      /* Falling edge detected */
      Falling_edge_G = 1;
      }
   else
      {
      /* Default */
      Falling_edge_G = 0;
      }
   /* Calculate average every 45 calls to this task
      - maximum count over this period is 9 pulses
        if (++Calls_G < 45)  */

   /* 450 used here for test purposes (in simulator)
      [Because there is a limit to how fast you can simulate pulses
      by hand...] */
   if (++Calls_G < 450)
      {
      Total_G += (int) Falling_edge_G;
      }
   else
      {
      /* Update the display */
      Data_G = Total_G; /* Max is 9 */
      Total_G = 0;
      Calls_G = 0;
      PULSE_COUNT_Check_Below_Threshold(3);
      BARGRAPH_Update();
      }
   }

/*------------------------------------------------------------------*-
  ---- END OF FILE ---------------------------------------
-*------------------------------------------------------------------*/
```

```c
/*------------------------------------------------------------------*-

   Bargraph.h (v1.00)

  --------------------------------------------------------

   - See Bargraph.c for details.

-*------------------------------------------------------------------*/

#include "Main.h"

/* ------ Public data type declarations ------------------------ */

typedef tByte tBargraph;

/* ------ Public function prototypes --------------------------- */

void BARGRAPH_Init(void);
void BARGRAPH_Update(void);

/* ------ Public constants ------------------------------------- */

#define BARGRAPH_MAX (9)
#define BARGRAPH_MIN (0)

/*------------------------------------------------------------------*-
  ---- END OF FILE ---------------------------------------
-*------------------------------------------------------------------*/
```

```
/*------------------------------------------------------------------*-

   Bargraph.c (v1.00)

  --------------------------------------------------------

   Simple bargraph library.

-*------------------------------------------------------------------*/

#include "Main.h"
#include "Port.h"

#include "Bargraph.h"

/* ------ Public variable declarations ------------------------- */

/* The data to be displayed */
tBargraph Data_G;

/* ------ Private constants ----------------------------------- */

#define BARGRAPH_ON (1)
#define BARGRAPH_OFF (0)

/* ------ Private variables ----------------------------------- */

/* These variables store the thresholds
   used to update the display */
static tBargraph M9_1_G;
static tBargraph M9_2_G;
static tBargraph M9_3_G;
static tBargraph M9_4_G;
static tBargraph M9_5_G;
static tBargraph M9_6_G;
static tBargraph M9_7_G;
static tBargraph M9_8_G;
```

```
/*------------------------------------------------------------------*-

  BARGRAPH_Init()

  Prepare for the bargraph display.

-*------------------------------------------------------------------*/
void BARGRAPH_Init(void)
   {
   Pin0 = BARGRAPH_OFF;
   Pin1 = BARGRAPH_OFF;
   Pin2 = BARGRAPH_OFF;
   Pin3 = BARGRAPH_OFF;
   Pin4 = BARGRAPH_OFF;
   Pin5 = BARGRAPH_OFF;
   Pin6 = BARGRAPH_OFF;
   Pin7 = BARGRAPH_OFF;

   /* Use a linear scale to display data
      Remember: *9* possible output states
      - do all calculations ONCE */
   M9_1_G = (BARGRAPH_MAX - BARGRAPH_MIN) / 9;
   M9_2_G = M9_1_G * 2;
   M9_3_G = M9_1_G * 3;
   M9_4_G = M9_1_G * 4;
   M9_5_G = M9_1_G * 5;
   M9_6_G = M9_1_G * 6;
   M9_7_G = M9_1_G * 7;
   M9_8_G = M9_1_G * 8;
   }
```

```
/*------------------------------------------------------------------*-

  BARGRAPH_Update()

  Update the bargraph display.

-*------------------------------------------------------------------*/
void BARGRAPH_Update(void)
   {
   tBargraph Data = Data_G - BARGRAPH_MIN;

   Pin0 = ((Data >= M9_1_G) == BARGRAPH_ON);
   Pin1 = ((Data >= M9_2_G) == BARGRAPH_ON);
   Pin2 = ((Data >= M9_3_G) == BARGRAPH_ON);
   Pin3 = ((Data >= M9_4_G) == BARGRAPH_ON);
   Pin4 = ((Data >= M9_5_G) == BARGRAPH_ON);
   Pin5 = ((Data >= M9_6_G) == BARGRAPH_ON);
   Pin6 = ((Data >= M9_7_G) == BARGRAPH_ON);
   Pin7 = ((Data >= M9_8_G) == BARGRAPH_ON);
   }

/*------------------------------------------------------------------*-
  ---- END OF FILE ----------------------------------------
-*------------------------------------------------------------------*/
```

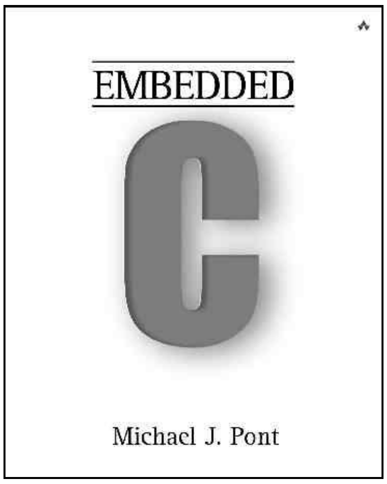
Conclusions

- The simple operating system ('sEOS') introduced in this seminar imposes a very low processor load but is nonetheless flexible and useful.

- The simple nature of sEOS also provides other benefits. For example, it means that developers themselves can, very rapidly, port the OS onto a new microcontroller environment. It also means that the architecture may be readily adapted to meet the needs of a particular application.

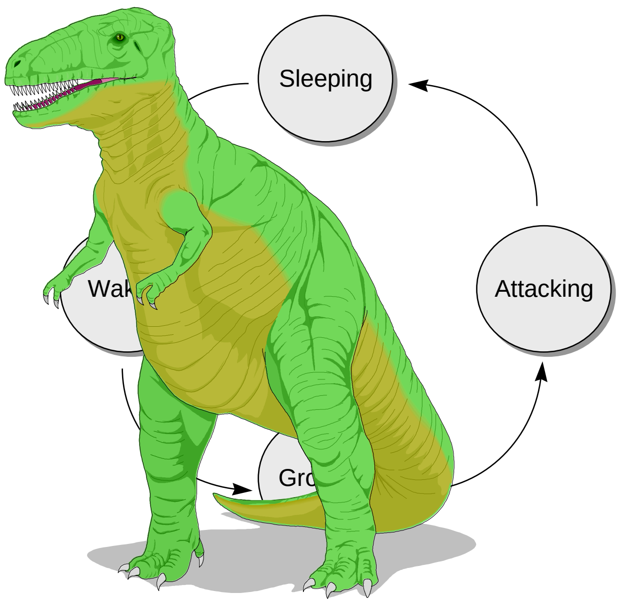
Perhaps the most important side-effect of this form of simple OS is that - unlike a traditional 'real-time operating system' - it becomes part of the application itself, rather than forming a separate code layer.

Preparation for the next seminar



Please read **Chapter 8**
before the next seminar

Seminar 7:
Multi-State Systems and Function Sequences



Introduction

Two broad categories of multi-state systems:

- **Multi-State (Timed)**
  In a multi-state (timed) system, the transition between states will depend **only** on the passage of time.

  For example, the system might begin in State A, repeatedly executing `FunctionA()`, for ten seconds. It might then move into State B and remain there for 5 seconds, repeatedly executing `FunctionB()`. It might then move back into State A, *ad infinituum*.

  A basic traffic-light control system might follow this pattern.

- **Multi-State (Input / Timed)**
  This is a more common form of system, in which the transition between states (and behaviour in each state) will depend both on the passage of time **and** on system inputs.

  For example, the system might only move between State A and State B if a particular input is received within X seconds of a system output being generated.

  The autopilot system discussed at the start of this seminar might follow this pattern, as might a control system for a washing machine, or an intruder alarm system.

For completeness, we will mention on further possibility:

- **Multi-State (Input)**
  This is a comparatively rare form of system, in which the transition between states (and behaviour in each state) depends **only** on the system inputs.

  For example, the system might only move between State A and State B if a particular input is received. It will remain indefinitely in State A if this input is not received.

  Such systems have no concept of time, and - therefore - no way of implementing timeout or similar behaviours. We will not consider such systems in this course.

In this seminar, we will consider how the Multi-State (Time) and Multi-State (Input / Time) architectures can be implemented in C.

Implementing a Multi-State (Timed) system

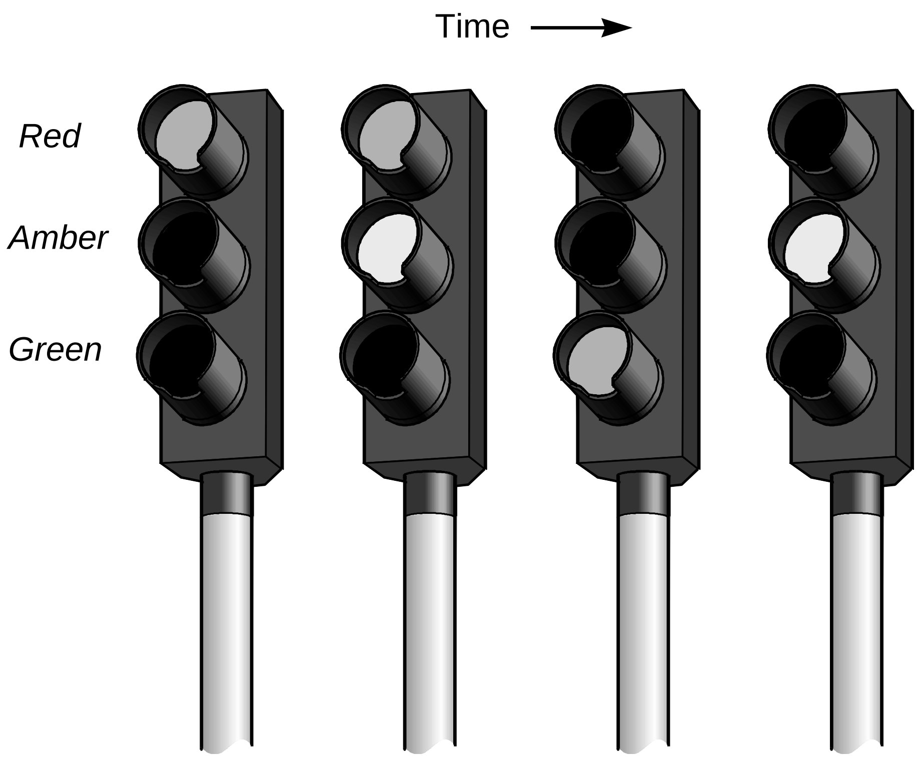
We can describe the time-driven, multi-state architecture as follows:

- The system will operate in two or more states.
- Each state may be associated with one or more function calls.
- Transitions between states will be controlled by the passage of time.
- Transitions between states may also involve function calls.

Please note that, in order to ease subsequent maintenance tasks, the system states should not be arbitrarily named, but should - where possible - reflect a physical state observable by the user and / or developer.

Please also note that the system states will usually be represented by means of a `switch` statement in the operating system ISR.

Example: Traffic light sequencing



Note:
European sequence!

In this case, the various states are easily identified:

- **Red**
- **Red-Amber**
- **Green**
- **Amber**

In the code, we will represent these states as follows:

```
/* Possible system states */
typedef enum {RED, RED_AND_AMBER, GREEN, AMBER} eLight_State;
```

We will store the time to be spent in each state as follows:

```
/* (Times are in seconds) */
#define RED_DURATION  20
#define RED_AND_AMBER_DURATION  5
#define GREEN_DURATION 30
#define AMBER_DURATION 5
```

In this simple case, we do not require function calls from (or between) system states: the required behaviour will be implemented directly through control of the (three) port pins which – in the final system – would be connected to appropriate bulbs.

For example:

```
case RED:
     {
     Red_light = ON;
     Amber_light = OFF;
     Green_light = OFF;

  ...
```

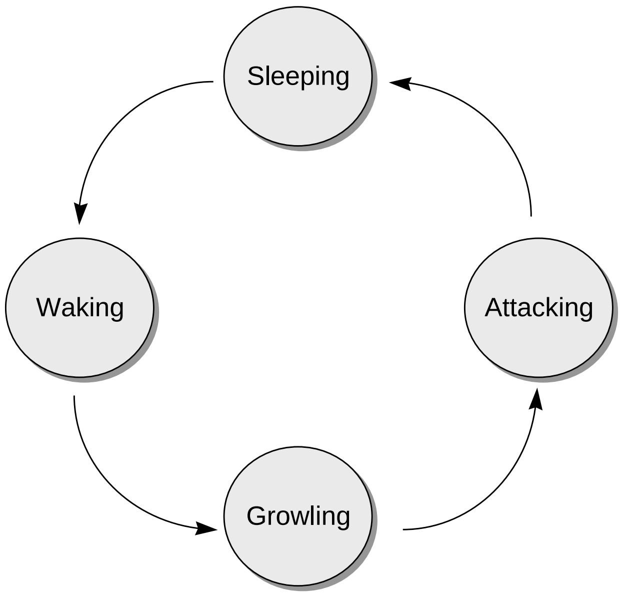
```
/*------------------------------------------------------------------*-

   Main.c (v1.00)

  ------------------------------------------------------------------

   Traffic light example.

-*------------------------------------------------------------------*/

#include "Main.H"
#include "Port.H"
#include "Simple_EOS.H"

#include "T_Lights.H"

/* ------------------------------------------------------------------ */

void main(void)
   {
   /* Prepare to run traffic sequence */
   TRAFFIC_LIGHTS_Init(RED);

   /* Set up simple EOS (50 ms ticks) */
   sEOS_Init_Timer2(50);

   while(1) /* Super Loop */
      {
      /* Enter idle mode to save power */
      sEOS_Go_To_Sleep();
      }
   }

/*------------------------------------------------------------------*-
  ---- END OF FILE -------------------------------------------------
-*------------------------------------------------------------------*/
```

```
/*------------------------------------------------------------------*-

   T_Lights.H (v1.00)

  ------------------------------------------------------------------

   - See T_Lights.C for details.

-*------------------------------------------------------------------*/

#ifndef _T_LIGHTS_H
#define _T_LIGHTS_H

/* ------ Public data type declarations ----------------------- */

/* Possible system states */
typedef enum {RED, RED_AND_AMBER, GREEN, AMBER} eLight_State;

/* ------ Public function prototypes -------------------------- */

void TRAFFIC_LIGHTS_Init(const eLight_State);
void TRAFFIC_LIGHTS_Update(void);

#endif

/*------------------------------------------------------------------*-
  ---- END OF FILE -------------------------------------------------
-*------------------------------------------------------------------*/
```

```
/*------------------------------------------------------------------*-

   T_lights.C (v1.00)

-*------------------------------------------------------------------*/

#include "Main.H"
#include "Port.H"

#include "T_lights.H"

/* ------ Private constants ----------------------------------- */

/* Easy to change logic here */
#define ON  0
#define OFF 1

/* Times in each of the (four) possible light states
   (Times are in seconds) */
#define RED_DURATION  20
#define RED_AND_AMBER_DURATION  5
#define GREEN_DURATION 30
#define AMBER_DURATION 5


/* ------ Private variables ----------------------------------- */

/* The state of the system */
static eLight_State Light_state_G;

/* The time in that state */
static tLong Time_in_state;

/* Used by sEOS */
static tByte Call_count_G = 0;

/*------------------------------------------------------------------*-

  TRAFFIC_LIGHTS_Init()

  Prepare for traffic light activity.

-*------------------------------------------------------------------*/
void TRAFFIC_LIGHTS_Init(const eLight_State START_STATE)
   {
   Light_state_G = START_STATE;  /* Decide on initial state */
   }
```

```
/*------------------------------------------------------------------*-

  TRAFFIC_LIGHTS_Update()

  Must be called once per second.

-*------------------------------------------------------------------*/
void TRAFFIC_LIGHTS_Update(void)
   {
   switch (Light_state_G)
      {
      case RED:
         {
         Red_light = ON;
         Amber_light = OFF;
         Green_light = OFF;

         if (++Time_in_state == RED_DURATION)
            {
            Light_state_G = RED_AND_AMBER;
            Time_in_state = 0;
            }

         break;
         }

      case RED_AND_AMBER:
         {
         Red_light = ON;
         Amber_light = ON;
         Green_light = OFF;

         if (++Time_in_state == RED_AND_AMBER_DURATION)
            {
            Light_state_G = GREEN;
            Time_in_state = 0;
            }

         break;
         }
      case GREEN:
         {
         Red_light = OFF;
         Amber_light = OFF;
         Green_light = ON;

         if (++Time_in_state == GREEN_DURATION)
            {
            Light_state_G = AMBER;
            Time_in_state = 0;
            }

         break;
         }

      case AMBER:
         {
         Red_light = OFF;
         Amber_light = ON;
         Green_light = OFF;

         if (++Time_in_state == AMBER_DURATION)
            {
            Light_state_G = RED;
            Time_in_state = 0;
            }

         break;
         }
      }
   }

/*------------------------------------------------------------------*-
  ---- END OF FILE -------------------------------------------------
-*------------------------------------------------------------------*/
```

Example: Animatronic dinosaur



The system states

- **Sleeping**:
  The dinosaur will be largely motionless, but will be obviously 'breathing'. Irregular snoring noises, or slight movements during this time will add interest for the audience.

- **Waking:**
  The dinosaur will begin to wake up. Eyelids will begin to flicker. Breathing will become more rapid.

- **Growling:**
  Eyes will suddenly open, and the dinosaur will emit a very loud growl. Some further movement and growling will follow.

- **Attacking:**
  Rapid 'random' movements towards the audience. Lots of noise (you should be able to hear this from the next floor in the museum).

```
typedef enum {SLEEPING, WAKING, GROWLING, ATTACKING} eDinosaur_State;

/* Times in each of the (four) possible states */
/* (Times are in seconds) */
#define SLEEPING_DURATION 255
#define WAKING_DURATION 60
#define GROWLING_DURATION 40
#define ATTACKING_DURATION 120
```

```
/*------------------------------------------------------------------*-

   Dinosaur.C (v1.00)

  --------------------------------------------------------

   Demonstration of multi-state (timed) architecture:
   Dinosaur control system.

 -*------------------------------------------------------------------*/

#include "Main.h"
#include "Port.h"

#include "Dinosaur.h"

/* ------ Private data type declarations ---------------------- */
/* Possible system states */
typedef
enum {SLEEPING, WAKING, GROWLING, ATTACKING} eDinosaur_State;

/* ------ Private function prototypes ------------------------- */
void DINOSAUR_Perform_Sleep_Movements(void);
void DINOSAUR_Perform_Waking_Movements(void);
void DINOSAUR_Growl(void);
void DINOSAUR_Perform_Attack_Movements(void);

/* ------ Private constants ----------------------------------- */
/* Times in each of the (four) possible states
   (Times are in seconds) */
#define SLEEPING_DURATION 255
#define WAKING_DURATION 60
#define GROWLING_DURATION 40
#define ATTACKING_DURATION 120

/* ------ Private variables ----------------------------------- */
/* The current state of the system */
static eDinosaur_State Dinosaur_state_G;

/* The time in the state */
static tByte Time_in_state_G;

/* Used by sEOS */
static tByte Call_count_G = 0;
```

```
/*------------------------------------------------------------------*-
  DINOSAUR_Init()
-*------------------------------------------------------------------*/
void DINOSAUR_Init(void)
   {
   /* Initial dinosaur state */
   Dinosaur_state_G = SLEEPING;
   }

/*------------------------------------------------------------------*-

  DINOSAUR_Update()

  Must be scheduled once per second (from the sEOS ISR).

-*------------------------------------------------------------------*/
void DINOSAUR_Update(void)
   {
   switch (Dinosaur_state_G)
      {
      case SLEEPING:
         {
         /* Call relevant function */
         DINOSAUR_Perform_Sleep_Movements();

         if (++Time_in_state_G == SLEEPING_DURATION)
            {
            Dinosaur_state_G = WAKING;
            Time_in_state_G = 0;
            }

         break;
         }

      case WAKING:
         {
         DINOSAUR_Perform_Waking_Movements();

         if (++Time_in_state_G == WAKING_DURATION)
            {
            Dinosaur_state_G = GROWLING;
            Time_in_state_G = 0;
            }

         break;
         }
      case GROWLING:
         {
          /* Call relevant function */
          DINOSAUR_Growl();

         if (++Time_in_state_G == GROWLING_DURATION)
            {
            Dinosaur_state_G = ATTACKING;
            Time_in_state_G = 0;
            }

         break;
         }

      case ATTACKING:
         {
          /* Call relevant function */
          DINOSAUR_Perform_Attack_Movements();

         if (++Time_in_state_G == ATTACKING_DURATION)
            {
            Dinosaur_state_G = SLEEPING;
            Time_in_state_G = 0;
            }

         break;
         }
      }
   }
```

```
/*------------------------------------------------------------------*/
void DINOSAUR_Perform_Sleep_Movements(void)
   {
   /* Demo only... */
   P1 = (tByte) Dinosaur_state_G;
   P2 = Time_in_state_G;
   }

/*------------------------------------------------------------------*/
void DINOSAUR_Perform_Waking_Movements(void)
   {
   /* Demo only... */
   P1 = (tByte) Dinosaur_state_G;
   P2 = Time_in_state_G;
   }

/*------------------------------------------------------------------*/
void DINOSAUR_Growl(void)
   {
   /* Demo only... */
   P1 = (tByte) Dinosaur_state_G;
   P2 = Time_in_state_G;
   }

/*------------------------------------------------------------------*/
void DINOSAUR_Perform_Attack_Movements(void)
   {
   /* Demo only... */
   P1 = (tByte) Dinosaur_state_G;
   P2 = Time_in_state_G;
   }

/*------------------------------------------------------------------*-
  ---- END OF FILE -------------------------------------------
-*------------------------------------------------------------------*/
```

Implementing a Multi-State (Input/Timed) system

- The system will operate in two or more states.
- Each state may be associated with one or more function calls.
- Transitions between states may be controlled by the passage of time, by system inputs or a combination of time and inputs.
- Transitions between states may also involve function calls.

Implementing state timeouts

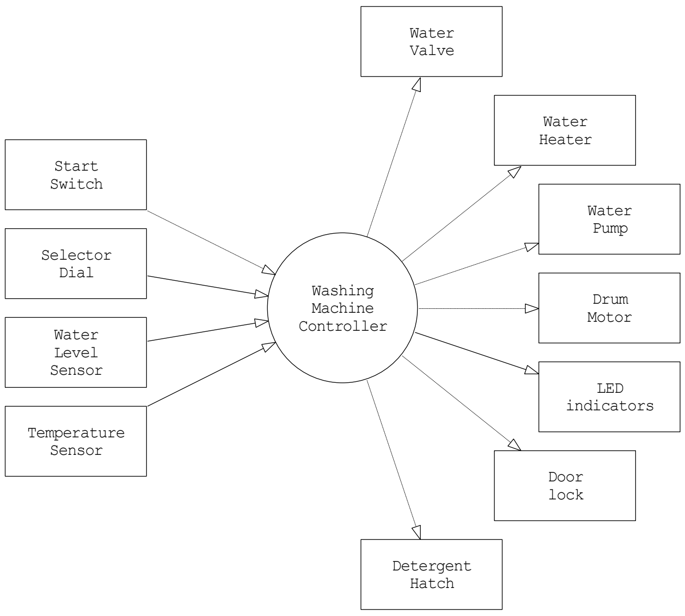
Consider the following - informal - system requirements:

- The pump should be run for 10 seconds. If, during this time, no liquid is detected in the outflow tank, then the pump should be switched off and 'low water' warning should be sounded. If liquid is detected, the pump should be run for a further 45 seconds, or until the 'high water' sensor is activated (whichever is first).
- After the front door is opened, the correct password must be entered on the control panel within 30 seconds or the alarm will sound.
- The 'down flap' signal will be issued. If, after 50 ms, no flap movement is detected, it should be concluded that the flap hydraulics are damaged. The system should then alert the user and enter manual mode.

To meet this type of requirement, we can do two things:

- Keep track of the time in each system state;
- If the time exceeds a pre-determined error value, then we should move to a different state.

Example: Controller for a washing machine



Here is a brief description of the way in which we expect the system to operate:

1. The user selects a wash program (e.g. ‘Wool’, ‘Cotton’) on the selector dial.
2. The user presses the ‘Start’ switch.
3. The door lock is engaged.
4. The water valve is opened to allow water into the wash drum.
5. If the wash program involves detergent, the detergent hatch is opened. When the detergent has been released, the detergent hatch is closed.
6. When the ‘full water level’ is sensed, the water valve is closed.
7. If the wash program involves warm water, the water heater is switched on. When the water reaches the correct temperature, the water heater is switched off.
8. The washer motor is turned on to rotate the drum. The motor then goes through a series of movements, both forward and reverse (at various speeds) to wash the clothes. (The precise set of movements carried out depends on the wash program that the user has selected.) At the end of the wash cycle, the motor is stopped.
9. The pump is switched on to drain the drum. When the drum is empty, the pump is switched off.

The Input / Timed architecture discussed here is by no means unique to 'white goods' (such as washing machines).

- For example, the sequence of events used to raise the landing gear in a passenger aircraft will be controlled in a similar manner. In this case, basic tests (such as 'WoW' - 'Weight on Wheels') will be used to determine whether the aircraft is on the ground or in the air: these tests will be completed before the operation begins.

- Feedback from various door and landing-gear sensors will then be used to ensure that each phase of the manoeuvre completes correctly.

```
/*------------------------------------------------------------------*-

   Washer.C (v1.01)

  --------------------------------------------------------

   Multi-state framework for washing-machine controller.

-*------------------------------------------------------------------*/

#include "Main.H"
#include "Port.H"

#include "Washer.H"

/* ------ Private data type declarations ----------------------- */

/* Possible system states */
typedef enum {INIT, START, FILL_DRUM, HEAT_WATER,
              WASH_01, WASH_02, ERROR} eSystem_state;

/* ------ Private function prototypes ------------------------- */

tByte WASHER_Read_Selector_Dial(void);
bit   WASHER_Read_Start_Switch(void);
bit   WASHER_Read_Water_Level(void);
bit   WASHER_Read_Water_Temperature(void);

void  WASHER_Control_Detergent_Hatch(bit);
void  WASHER_Control_Door_Lock(bit);
void  WASHER_Control_Motor(bit);
void  WASHER_Control_Pump(bit);
void  WASHER_Control_Water_Heater(bit);
void  WASHER_Control_Water_Valve(bit);

/* ------ Private constants ----------------------------------- */

#define OFF 0
#define ON 1

#define MAX_FILL_DURATION (tLong) 1000
#define MAX_WATER_HEAT_DURATION (tLong) 1000

#define WASH_01_DURATION 30000
```

```
/* ------ Private variables ----------------------------------- */

static eSystem_state System_state_G;

static tWord Time_in_state_G;

static tByte Program_G;

/* Ten different programs are supported
   Each one may or may not use detergent */
static tByte Detergent_G[10] = {1,1,1,0,0,1,0,1,1,0};

/* Each one may or may not use hot water */
static tByte Hot_Water_G[10] = {1,1,1,0,0,1,0,1,1,0};

/* --------------------------------------------------------------- */
void WASHER_Init(void)
   {
   System_state_G = INIT;
   }
```

```
/* ------------------------------------------------------------ */
void WASHER_Update(void)
   {
   /* Call once per second */
   switch (System_state_G)
      {
      case INIT:
         {
         /* For demo purposes only */
         Debug_port = (tByte) System_state_G;

         /* Set up initial state */
         /* Motor is off */
         WASHER_Control_Motor(OFF);

         /* Pump is off */
         WASHER_Control_Pump(OFF);

         /* Heater is off */
         WASHER_Control_Water_Heater(OFF);

         /* Valve is closed */
         WASHER_Control_Water_Valve(OFF);

         /* Wait (indefinitely) until START is pressed */
         if (WASHER_Read_Start_Switch() != 1)
             {
             return;
             }

         /* Start switch pressed
            -> read the selector dial */
         Program_G = WASHER_Read_Selector_Dial();

          /* Change state */
         System_state_G = START;
          break;
         }
      case START:
         {
         /* For demo purposes only */
         Debug_port = (tByte) System_state_G;

         /* Lock the door */
         WASHER_Control_Door_Lock(ON);

         /* Start filling the drum */
         WASHER_Control_Water_Valve(ON);

         /* Release the detergent (if any) */
         if (Detergent_G[Program_G] == 1)
            {
            WASHER_Control_Detergent_Hatch(ON);
            }

         /* Ready to go to next state */
         System_state_G = FILL_DRUM;
         Time_in_state_G = 0;

         break;
         }
```

```
case FILL_DRUM:
   {
   /* For demo purposes only */
   Debug_port = (tByte) System_state_G;

   /* Remain in this state until drum is full
      NOTE: Timeout facility included here */
   if (++Time_in_state_G >= MAX_FILL_DURATION)
      {
      /* Should have filled the drum by now... */
      System_state_G = ERROR;
      }

   /* Check the water level */
   if (WASHER_Read_Water_Level() == 1)
      {
      /* Drum is full */

      /* Does the program require hot water? */
      if (Hot_Water_G[Program_G] == 1)
         {
         WASHER_Control_Water_Heater(ON);

         /* Ready to go to next state */
         System_state_G = HEAT_WATER;
         Time_in_state_G = 0;
         }
      else
         {
         /* Using cold water only */
         /* Ready to go to next state */
         System_state_G = WASH_01;
         Time_in_state_G = 0;
         }
      }
   break;
   }
```

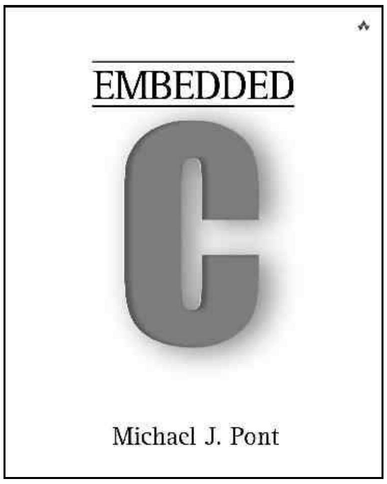
```
      case HEAT_WATER:
         {
         /* For demo purposes only */
         Debug_port = (tByte) System_state_G;

         /* Remain in this state until water is hot
            NOTE: Timeout facility included here */
         if (++Time_in_state_G >= MAX_WATER_HEAT_DURATION)
            {
            /* Should have warmed the water by now... */
            System_state_G = ERROR;
            }

         /* Check the water temperature */
         if (WASHER_Read_Water_Temperature() == 1)
            {
            /* Water is at required temperature */
            /* Ready to go to next state */
            System_state_G = WASH_01;
            Time_in_state_G = 0;
            }

         break;
         }
      case WASH_01:
         {
         /* For demo purposes only */
         Debug_port = (tByte) System_state_G;

         /* All wash program involve WASH_01
            Drum is slowly rotated to ensure clothes are fully wet */
         WASHER_Control_Motor(ON);

         if (++Time_in_state_G >= WASH_01_DURATION)
            {
            System_state_G = WASH_02;
            Time_in_state_G = 0;
            }

         break;
         }

      /* REMAINING WASH PHASES OMITTED HERE ... */

      case WASH_02:
         {
         /* For demo purposes only */
         Debug_port = (tByte) System_state_G;

         break;
         }

      case ERROR:
         {
         /* For demo purposes only */
         Debug_port = (tByte) System_state_G;

         break;
         }
      }
   }
```

```
/* ------------------------------------------------------------------ */
tByte WASHER_Read_Selector_Dial(void)
   {
   /* User code here... */

   return 0;
   }

/* ------------------------------------------------------------------ */
bit WASHER_Read_Start_Switch(void)
   {
   /* Simplified for demo ... */

   if (Start_pin == 0)
      {
      /* Start switch pressed */
      return 1;
      }
   else
      {
      return 0;
      }
   }

/* ------------------------------------------------------------------ */
bit WASHER_Read_Water_Level(void)
   {
   /* User code here... */

   return 1;
   }

/* ------------------------------------------------------------------ */
bit WASHER_Read_Water_Temperature(void)
   {
   /* User code here... */

   return 1;
   }

/* ------------------------------------------------------------------ */
void WASHER_Control_Detergent_Hatch(bit State)
   {
   bit Tmp = State;
   /* User code here... */
   }
```

Conclusions

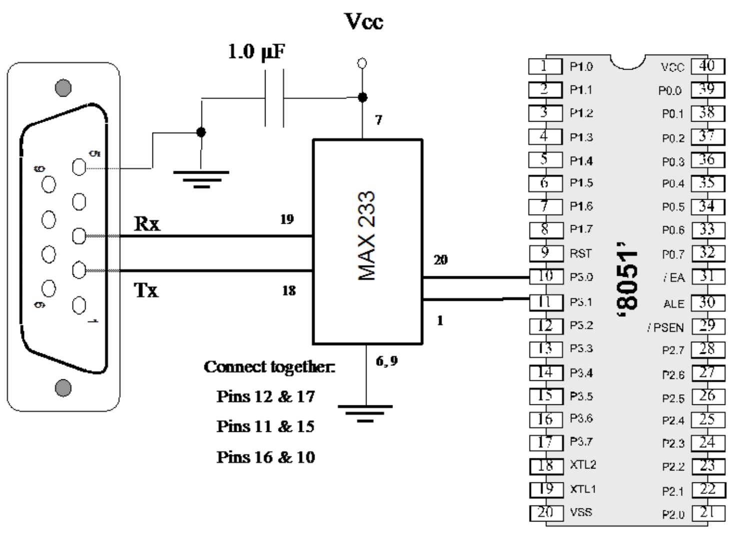
This seminar has discussed the implementation of multi-state (timed) and multi-state (input / timed) systems. Used in conjunction with an operating system like that presented in "Embedded C" Chapter 7, this flexible system architecture is in widespread use in embedded applications.

Preparation for the next seminar



Please read **Chapter 9**
before the next seminar

Seminar 8: Using the Serial Interface



Overview of this seminar

This seminar will:

- Discuss the RS-232 data communication standard
- Consider how we can use RS-232 to transfer data to and from deskbound PCs (and similar devices).

This can be useful, for example:

- In data acquisition applications.
- In control applications (sending controller parameters).
- For general debugging.

What is 'RS-232'?

In 1997 the Telecommunications Industry Association released what is formally known as TIA-232 Version F, a serial communication protocol which has been universally referred to as 'RS-232' since its first 'Recommended Standard' appeared in the 1960s. Similar standards (V.28) are published by the International Telecommunications Union (ITU) and by CCITT (The Consultative Committee International Telegraph and Telephone).

The 'RS-232' standard includes details of:

- The protocol to be used for data transmission.
- The voltages to be used on the signal lines.
- The connectors to be used to link equipment together.

Overall, the standard is comprehensive and widely used, at data transfer rates of up to around 115 or 330 kbits / second (115 / 330 k baud). Data transfer can be over distances of 15 metres or more.

Note that RS-232 is a peer-to-peer communication standard.

Basic RS-232 Protocol

RS-232 is a character-oriented protocol. That is, it is intended to be used to send single 8-bit blocks of data. To transmit a byte of data over an RS-232 link, we generally encode the information as follows:

- We send a ‘Start’ bit.
- We send the data (8 bits).
- We send a ‘Stop’ bit (or bits).
-

NOTE: The UART takes care of these details!

Asynchronous data transmission and baud rates

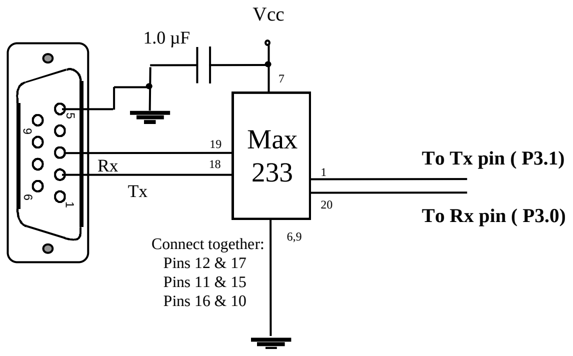
- RS-232 uses an asynchronous protocol.
- Both ends of the communication link have an internal clock, running at the same rate. The data (in the case of RS-232, the 'Start' bit) is then used to synchronise the clocks, if necessary, to ensure successful data transfer.

- RS-232 generally operates at one of a (restricted) range of baud rates.
- Typically these are: 75, 110, 300, 1200, 2400, 4800, 9600, 14400, 19200, 28800, 33600, 56000, 115000 and (rarely) 330000 baud.
- 9600 baud is a very 'safe' choice, as it is very widely supported.

RS-232 voltage levels

- The threshold levels used by the receiver are +3 V and -3 V and the lines are inverted.
- The maximum voltage allowed is +/- 15V.

- Note that these voltages cannot be obtained directly from the naked microcontroller port pins: some form of interface hardware is required.
- For example, the Maxim Max232 and Max233 are popular and widely-used line driver chips.



Using a Max 233 as an RS-232 tranceiver.

The software architecture

- Suppose we wish to transfer data to a PC at a standard 9600 baud rate; that is, 9600 bits per second. Transmitting each byte of data, plus stop and start bits, involves the transmission of 10 bits of information (assuming a single stop bit is used). As a result, each byte takes approximately 1 ms to transmit.

- Suppose, for example, we wish to send this information to the PC:

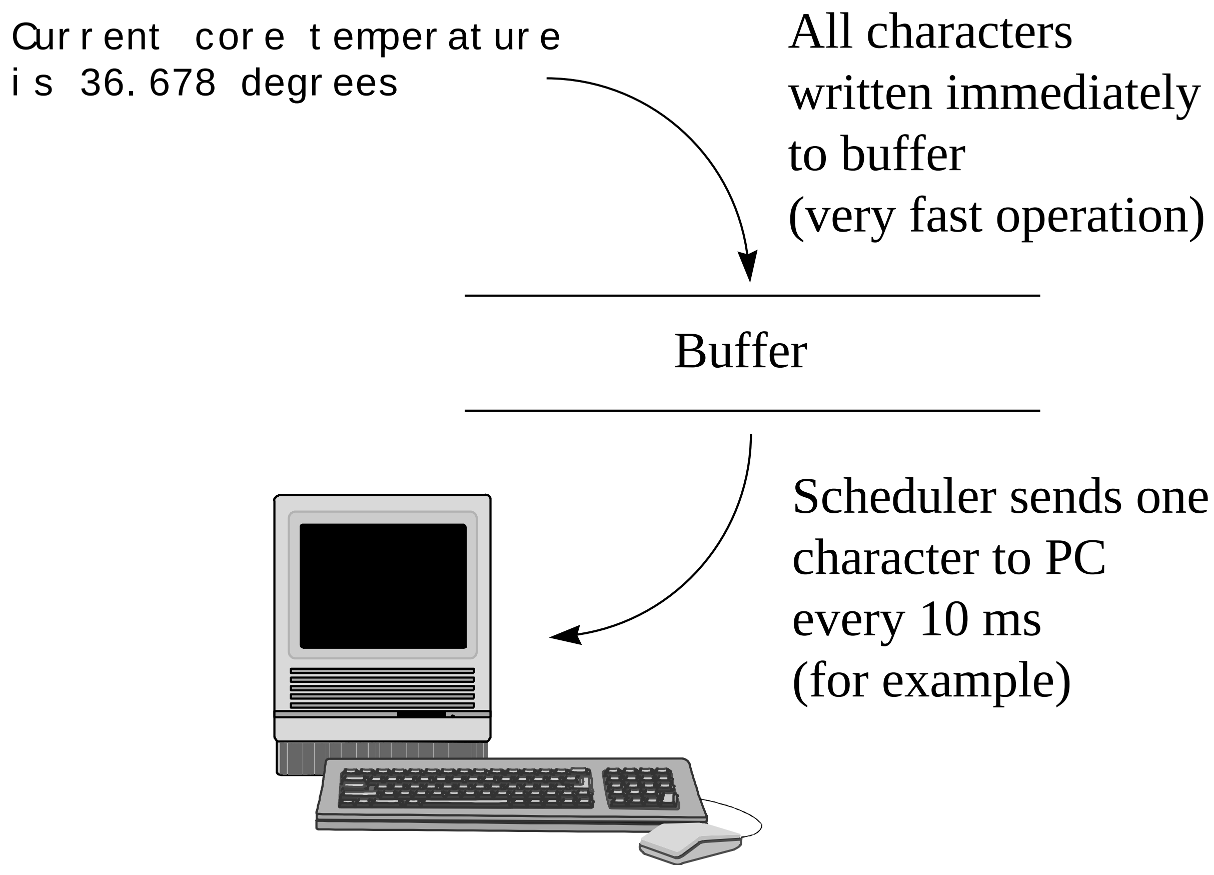
```
Current core temperature is 36.678 degrees
```

…then the task sending these 42 characters will take more than 40 milliseconds to complete. This will - frequently be an unacceptably long duration.

- The most obvious way of solving this problem is to increase the baud rate; however, this is not always possible (and it does not really solve the underlying problem).

A better solution is to write all data to a buffer in the microcontroller. The contents of this buffer will then be sent - usually one byte at a time - to the PC, using a regular, scheduled, task.

Overview


Current core temperature is 36.678 degrees
All characters written immediately to buffer (very fast operation)
Buffer
Scheduler sends one character to PC every 10 ms (for example)

Using the on-chip U(S)ART for RS-232 communications

- The UART is full duplex, meaning it can transmit and receive simultaneously.
- It is also receive-buffered, meaning it can commence reception of a second byte before a previously received byte has been read from the receive register.

- The serial port can operate in 4 modes (one synchronous mode, three asynchronous modes).

- We are primarily interested in Mode 1.
- In this mode, 10 bits are transmitted (through TxD) or received (through RxD): a start bit (0), 8 data bits (lsb first), and a stop bit (1).

Serial port registers

The serial port control and status register is the special function register SCON. This register contains the mode selection bits (and the serial port interrupt bits, TI and RI: not used here).

SBUF is the receive and transmit buffer of serial interface.

Writing to SBUF loads the transmit register and initiates transmission.

```
SBUF = 0x0D;  /* Output CR */
```

Reading out SBUF accesses a physically separate receive register.

```
/* Read the data from UART     */
Data = SBUF;
```

Baud rate generation

- We are primarily concerned here with the use of the serial port in Mode 1.
- In this mode the baud rate is determined by the overflow rate of Timer 1 or Timer 2.
- We focus on the use of Timer 1 for baud rate generation.

The baud rate is determined by the Timer 1 overflow rate and the value of SMOD follows:

Baud rate (Mode 1) =

Where:

SMOD	…is the 'double baud rate' bit in the PCON register;
	…is the oscillator / resonator frequency;
	…is the number of machine instructions per oscillator cycle (e.g. 12 or 6)
*TH*1	…is the reload value for Timer 1

Note that Timer is used in 8-bit auto-reload mode and that interrupt generation should be disabled.

Why use 11.0592 MHz crystals?

It is very important to appreciate that it is not generally possible to produce standard baud rates (e.g. 9600) using Timer 1 (or Timer 2), unless you use an 11.0592 MHz crystal oscillator.

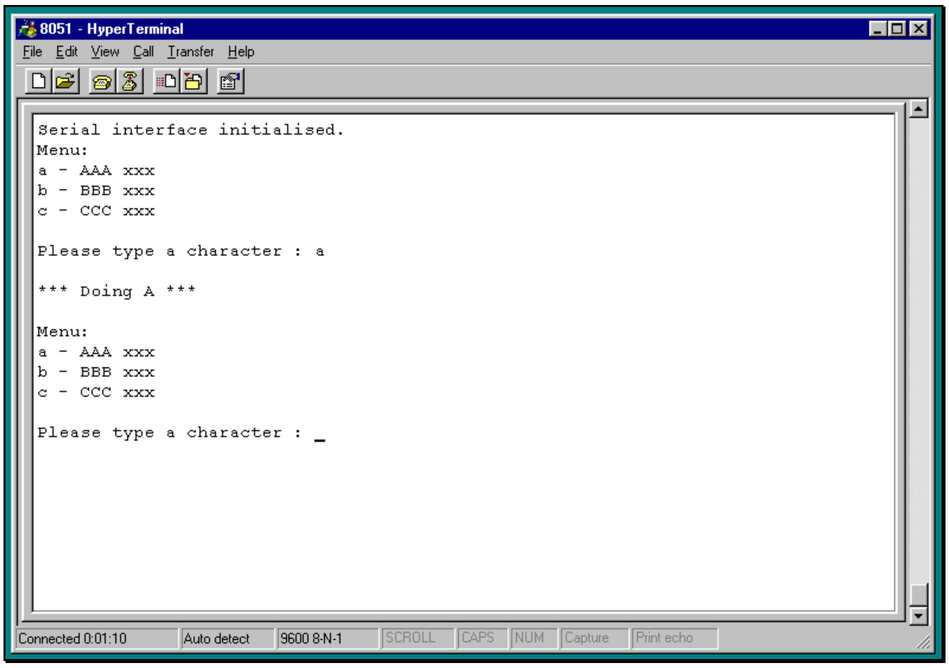
Remember: this is an asynchronous protocol, and **relies for correct operation on the fact that both ends of the connection are working at the same baud rate**. In practice, you can generally work with a difference in baud rates at both ends of the connection **by up to 5%**, but no more.

Despite the possible 5% margin, it is always good policy to get the baud rate as close as possible to the standard value because, **in the field**, there may be significant temperature variations between the oscillator in the PC and that in the embedded system.

Note also that it is generally **essential** to use some form of crystal oscillator (rather than a ceramic resonator) when working with asynchronous serial links (such as RS-232, RS-485, or CAN): the ceramic resonator is not sufficiently stable for this purpose.

PC Software

If your desktop computer is running Windows (95, 98, NT, 2000), then a simple but effective option is the 'Hyperterminal' application which is included with all of these operating systems.



```
Serial interface initialised.
Menu:
a - AAA xxx
b - BBB xxx
c - CCC xxx

Please type a character : a

*** Doing A ***

Menu:
a - AAA xxx
b - BBB xxx
c - CCC xxx

Please type a character : _
```

Connected 0:01:10 | Auto detect | 9600 8-N-1 | SCROLL | CAPS | NUM | Capture | Print echo

What about `printf()`?

We do not generally recommend the use of standard library function "`printf()`", because:

- this function sends data immediately to the UART. As a result, the duration of the transmission is often too long to be safely handled in a co-operatively scheduled application, and,
- most implementations of `printf()` do not incorporate timeouts, making it possible that use of this functions can 'hang' the whole application if errors occur.

RS-232 and 8051: Overall strengths and weaknesses

☺ RS-232 support is part of the 8051 core: applications based on RS-232 are very portable.

☺ At the PC end too, RS-232 is ubiquitous: every PC has one or more RS-232 ports.

☺ Links can - with modern tranceiver chips - be up to 30 m (100 ft) in length.

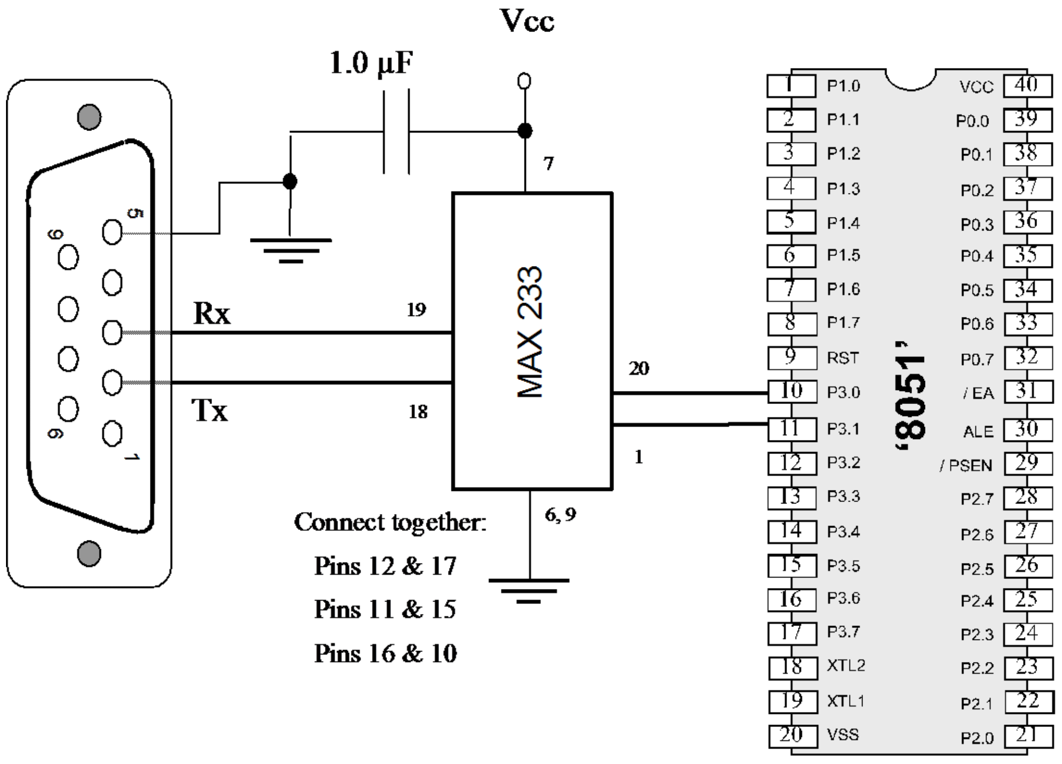
☺ Because of the hardware support, RS-232 generally imposes a low software load.

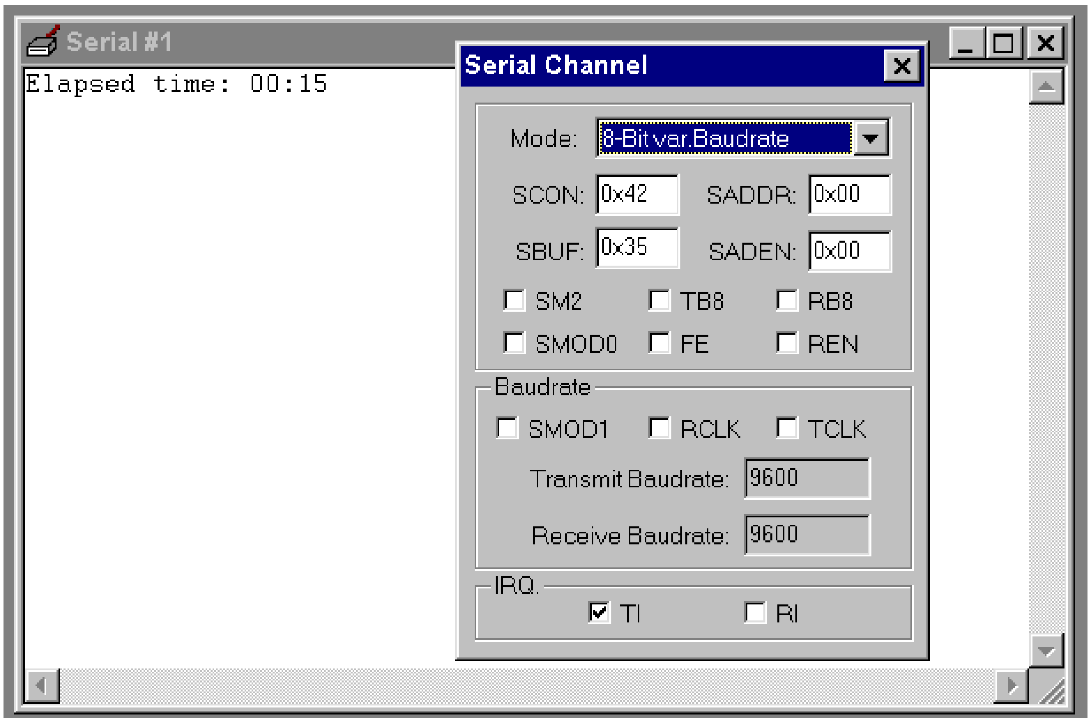
BUT:

☹ RS-232 is a peer-to-peer protocol (unlike, for example, RS-485): you can only connect one microcontroller directly (simultaneously) to each PC.

☹ RS-232 has little or no error checking at the hardware level (unlike, for example, CAN): if you want to be sure that the data you received at the PC is valid, you need to carry out checks in software.

Example: Displaying elapsed time on a PC




Serial #1

```
Elapsed time: 00:15
```

Serial Channel

Mode: 8-Bit var.Baudrate

SCON: 0x42 SADDR: 0x00

SBUF: 0x35 SADEN: 0x00

☐ SM2 ☐ TB8 ☐ RB8

☐ SMOD0 ☐ FE ☐ REN

Baudrate

☐ SMOD1 ☐ RCLK ☐ TCLK

Transmit Baudrate: 9600

Receive Baudrate: 9600

IRQ

☑ TI ☐ RI

```c
/*------------------------------------------------------------------*-

   Main.c (v1.00)

  ------------------------------------------------------------------

   RS-232 (Elapsed Time) example - sEOS.

-*------------------------------------------------------------------*/

#include "Main.H"
#include "Port.H"
#include "Simple_EOS.H"

#include "PC_O_T1.h"
#include "Elap_232.h"

/* ------------------------------------------------------------------ */

void main(void)
   {
   /* Set baud rate to 9600 */
   PC_LINK_O_Init_T1(9600);

   /* Prepare for elapsed time measurement */
   Elapsed_Time_RS232_Init();

   /* Set up simple EOS (5ms tick) */
   sEOS_Init_Timer2(5);

   while(1) /* Super Loop */
      {
      sEOS_Go_To_Sleep();  /* Enter idle mode to save power */
      }
   }

/*------------------------------------------------------------------*-
  ---- END OF FILE -------------------------------------------------
-*------------------------------------------------------------------*/
```

```
/*------------------------------------------------------------------*-

   Elap_232.C (v1.00)

  --------------------------------------------------------

   Simple library function for keeping track of elapsed time
   Demo version to display time on PC screen via RS232 link.

-*------------------------------------------------------------------*/

#include "Main.h"
#include "Elap_232.h"
#include "PC_O.h"

/* ------ Public variable definitions ------------------------- */

tByte Hou_G;
tByte Min_G;
tByte Sec_G;

/* ------ Public variable declarations ------------------------ */

/* See Char_Map.c */
extern const char code CHAR_MAP_G[10];

/*------------------------------------------------------------------*-

  Elapsed_Time_RS232_Init()

  Init function for simple library displaying elapsed time on PC
  via RS-232 link.

-*------------------------------------------------------------------*/
void Elapsed_Time_RS232_Init(void)
   {
   Hou_G = 0;
   Min_G = 0;
   Sec_G = 0;
   }
```

```
/*------------------------------------------------------------------*/

void Elapsed_Time_RS232_Update(void)
   {
   char Time_Str[30] = "\rElapsed time:               ";

   if (++Sec_G == 60)
      {
      Sec_G = 0;

      if (++Min_G == 60)
         {
         Min_G = 0;

         if (++Hou_G == 24)
            {
            Hou_G = 0;
            }
         }
      }

   Time_Str[15] = CHAR_MAP_G[Hou_G / 10];
   Time_Str[16] = CHAR_MAP_G[Hou_G % 10];

   Time_Str[18] = CHAR_MAP_G[Min_G / 10];
   Time_Str[19] = CHAR_MAP_G[Min_G % 10];

   Time_Str[21] = CHAR_MAP_G[Sec_G / 10];
   Time_Str[22] = CHAR_MAP_G[Sec_G % 10];

   /* We use the "seconds" data to turn on and off the colon
      (between hours and minutes) */
   if ((Sec_G % 2) == 0)
      {
      Time_Str[17] = ':';
      Time_Str[20] = ':';
      }
   else
      {
      Time_Str[17] = ' ';
      Time_Str[20] = ' ';
      }

   PC_LINK_O_Write_String_To_Buffer(Time_Str);
   }
```

```
/*------------------------------------------------------------------*-

  PC_LINK_O_Init_T1()

  This version uses T1 for baud rate generation.

  Uses 8051 (internal) UART hardware

-*------------------------------------------------------------------*/
void PC_LINK_O_Init_T1(const tWord BAUD_RATE)
   {
   PCON &= 0x7F;   /* Set SMOD bit to 0 (don't double baud rates) */

   /*  Receiver disabled
       8-bit data, 1 start bit, 1 stop bit, variable baud */
   SCON = 0x42;

   TMOD |= 0x20;   /* T1 in mode 2, 8-bit auto reload */

   TH1 = (256 - (tByte)((((tLong)OSC_FREQ / 100) * 3125)
            / ((tLong) BAUD_RATE * OSC_PER_INST * 1000)));

   TL1 = TH1;
   TR1 = 1;  /* Run the timer */
   TI = 1;   /* Send first character (dummy) */

   /* Set up the buffers for reading and writing */
   Out_written_index_G = 0;
   Out_waiting_index_G = 0;

   /* Interrupt *NOT* enabled */
   ES = 0;
   }
```

```
/*------------------------------------------------------------*/

void PC_LINK_O_Update(void)
   {
   /* Deal with transmit bytes here.
      Are there any data ready to send? */
   if (Out_written_index_G < Out_waiting_index_G)
      {
      PC_LINK_O_Send_Char(Tran_buffer[Out_written_index_G]);

      Out_written_index_G++;
      }
   else
      {
      /* No data to send - just reset the buffer index */
      Out_waiting_index_G = 0;
      Out_written_index_G = 0;
      }
   }

/*------------------------------------------------------------*/

void PC_LINK_O_Write_String_To_Buffer(const char* const STR_PTR)
   {
   tByte i = 0;

   while (STR_PTR[i] != '\0')
      {
      PC_LINK_O_Write_Char_To_Buffer(STR_PTR[i]);
      i++;
      }
   }
```

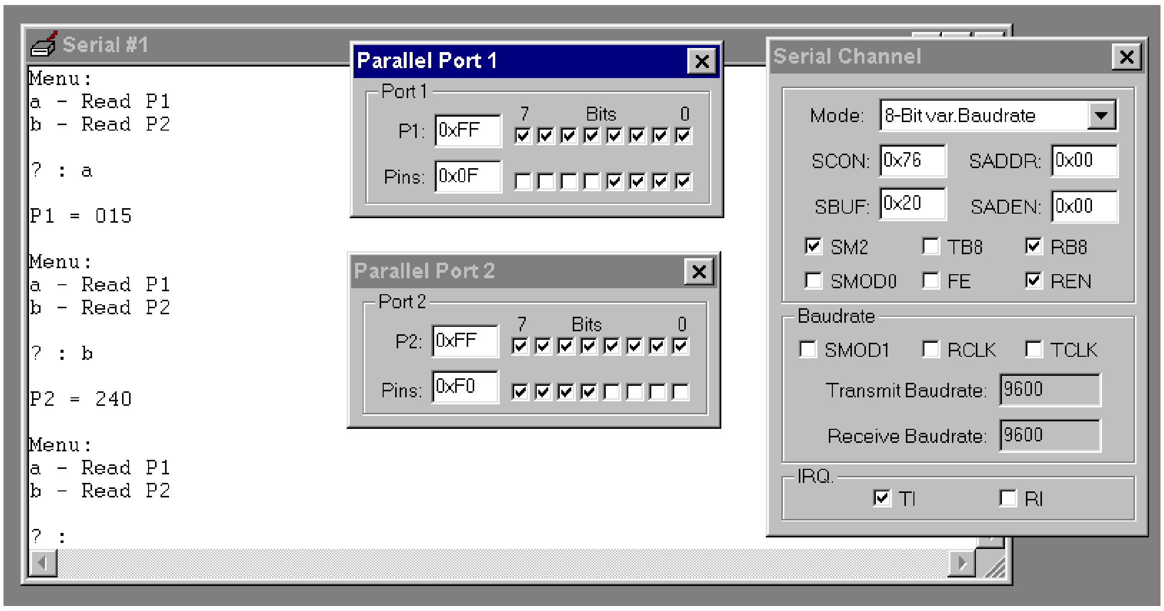
```
/*------------------------------------------------------------------*/
void PC_LINK_O_Write_Char_To_Buffer(const char CHARACTER)
   {
   /* Write to the buffer *only* if there is space
      (No error reporting in this simple library...) */
   if (Out_waiting_index_G < TRAN_BUFFER_LENGTH)
      {
      Tran_buffer[Out_waiting_index_G] = CHARACTER;
      Out_waiting_index_G++;
      }
   }

/*------------------------------------------------------------------*/
void PC_LINK_O_Send_Char(const char CHARACTER)
   {
   tLong Timeout1 = 0;

   if (CHARACTER == '\n')
      {
      Timeout1 = 0;
      while ((++Timeout1) && (TI == 0));

      if (Timeout1 == 0)
         {
         /* UART did not respond - error
            No error reporting in this simple library... */
         return;
         }

      TI = 0;
      SBUF = 0x0d;  /* Output CR   */
      }

   Timeout1 = 0;
   while ((++Timeout1) && (TI == 0));

   if (Timeout1 == 0)
      {
      /* UART did not respond - error
         No error reporting in this simple library... */
      return;
      }

   TI = 0;

   SBUF = CHARACTER;
   }
```

```
sEOS_ISR() interrupt INTERRUPT_Timer_2_Overflow
   {
   TF2 = 0;  /* Must manually reset the T2 flag    */

   /*===== USER CODE - Begin ================================== */
   /* Call RS-232 update function every 5ms */
   PC_LINK_O_Update();

   /* This ISR is called every 5 ms
      - only want to update time every second */
   if (++Call_count_G == 200)
      {
      /* Time to update time */
      Call_count_G = 0;

      /* Call time update function */
      Elapsed_Time_RS232_Update();
      }
   /*===== USER CODE - End ==================================== */
   }
```

Example: Data acquisition

In this section, we give an example of a simple data acquisition system with a **serial-menu** architecture.

In this case, using the menu, the user can determine the state of the input pins on Port 1 or Port 2:



```
Menu:
a - Read P1
b - Read P2

? : a

P1 = 015

Menu:
a - Read P1
b - Read P2

? : b

P2 = 240

Menu:
a - Read P1
b - Read P2

? :
```

Port 1

P1: 0xFF — Bits 7…0: ✓ ✓ ✓ ✓ ✓ ✓ ✓ ✓

Pins: 0x0F — ☐ ☐ ☐ ☐ ✓ ✓ ✓ ✓

Port 2

P2: 0xFF — Bits 7…0: ✓ ✓ ✓ ✓ ✓ ✓ ✓ ✓

Pins: 0xF0 — ✓ ✓ ✓ ✓ ☐ ☐ ☐ ☐

Mode: 8-Bit var.Baudrate

SCON: 0x76 SADDR: 0x00

SBUF: 0x20 SADEN: 0x00

✓ SM2 ☐ TB8 ✓ RB8

☐ SMOD0 ☐ FE ✓ REN

Baudrate

☐ SMOD1 ☐ RCLK ☐ TCLK

Transmit Baudrate: 9600

Receive Baudrate: 9600

IRQ

✓ TI ☐ RI

```
void MENU_Command_Processor(void)
   {
   char Ch;

   if (First_time_only_G == 0)
      {
      First_time_only_G = 1;
      MENU_Show_Menu();
      }

   /* Check for user inputs */
   PC_LINK_IO_Update();

   Ch = PC_LINK_IO_Get_Char_From_Buffer();

   if (Ch != PC_LINK_IO_NO_CHAR)
      {
      MENU_Perform_Task(Ch);
      MENU_Show_Menu();
      }
   }


void MENU_Show_Menu(void)
   {
   PC_LINK_IO_Write_String_To_Buffer("Menu:\n");
   PC_LINK_IO_Write_String_To_Buffer("a - Read P1\n");
   PC_LINK_IO_Write_String_To_Buffer("b - Read P2\n\n");
   PC_LINK_IO_Write_String_To_Buffer("? : ");
   }
```

```
void MENU_Perform_Task(char c)
   {
   PC_LINK_IO_Write_Char_To_Buffer(c);  /* Echo the menu option */
   PC_LINK_IO_Write_Char_To_Buffer('\n');

   /* Perform the task */
   switch (c)
      {
      case 'a':
      case 'A':
         {
         Get_Data_From_Port1();
         break;
         }

      case 'b':
      case 'B':
         {
         Get_Data_From_Port2();
         break;
         }
      }
   }

void Get_Data_From_Port1(void)
   {
   tByte Port1 = Data_Port1;
   char String[11] = "\nP1 = XXX\n\n";

   String[6] = CHAR_MAP_G[Port1 / 100];
   String[7] = CHAR_MAP_G[(Port1 / 10) % 10];
   String[8] = CHAR_MAP_G[Port1 % 10];

   PC_LINK_IO_Write_String_To_Buffer(String);
   }

void Get_Data_From_Port2(void)
   {
   tByte Port2 = Data_Port2;
   char String[11] = "\nP2 = XXX\n\n";

   String[6] = CHAR_MAP_G[Port2 / 100];
   String[7] = CHAR_MAP_G[(Port2 / 10) % 10];
   String[8] = CHAR_MAP_G[Port2 % 10];

   PC_LINK_IO_Write_String_To_Buffer(String);
   }
```

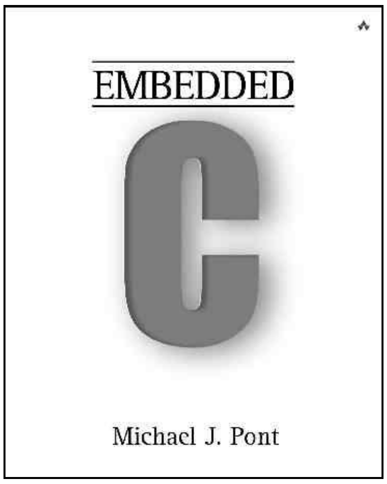
```
sEOS_ISR() interrupt INTERRUPT_Timer_2_Overflow
   {
   TF2 = 0;  /* Must manually reset the T2 flag    */

   /*===== USER CODE - Begin ================================== */
   /* Call MENU_Command_Processor every 5ms */
   MENU_Command_Processor();

   /*===== USER CODE - End ==================================== */
   }
```

Conclusions

In this seminar, we have illustrated how the serial interface on the 8051 microcontroller may be used.

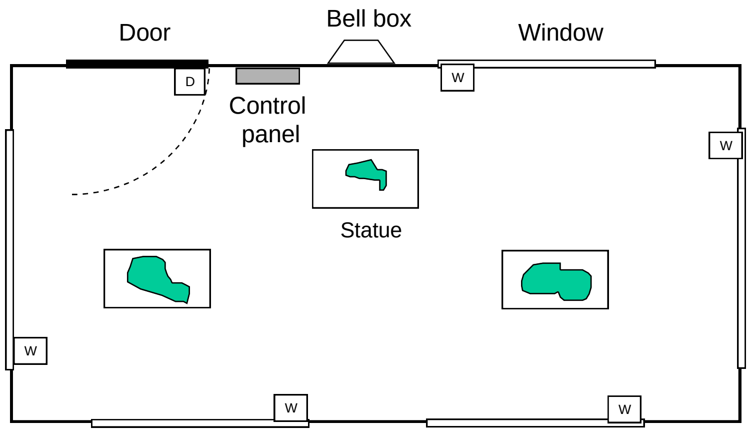
In the next seminar, we will use a case study to illustrate how the various techniques discussed in this can be used in practical applications.

Preparation for the next seminar

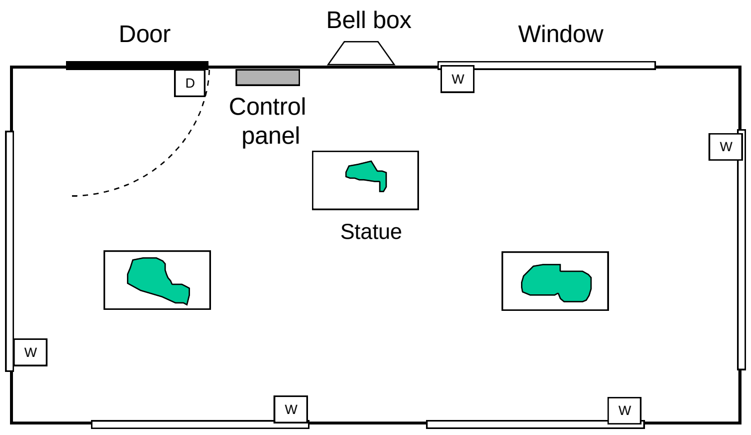


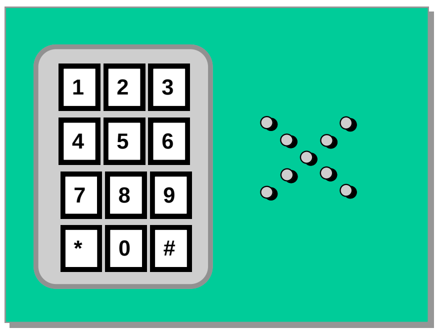
Please read **Chapter 10**
before the next seminar

Seminar 9:
Case Study:
Intruder Alarm System



Introduction





System Operation

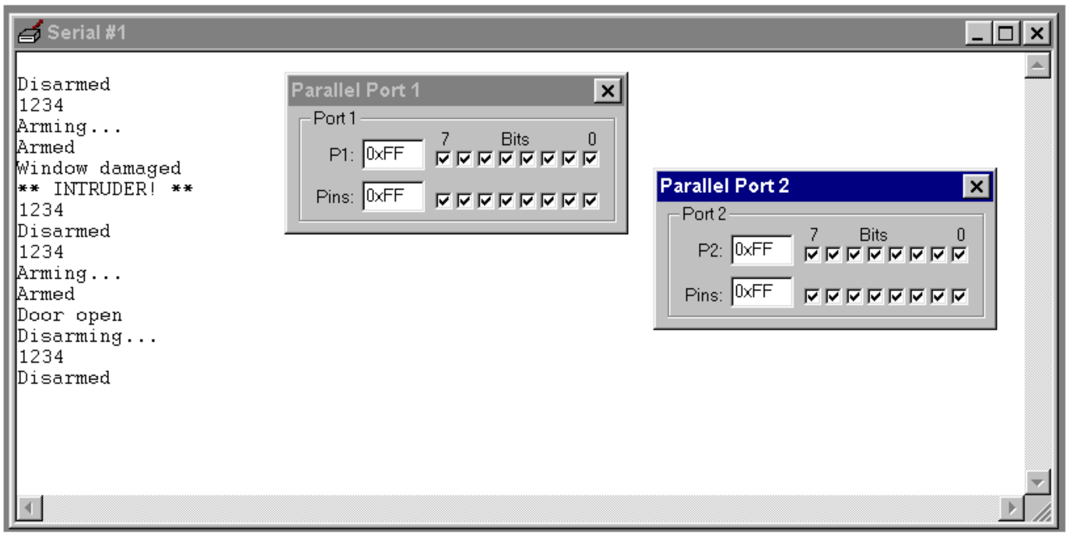
- When initially activated, the system is in ‘Disarmed’ state.
- In **Disarmed** state, the sensors are ignored. The alarm does not sound. The system remains in this state until the user enters a valid password via the keypad (in our demonstration system, the password is “1234”). When a valid password is entered, the systems enters ‘Arming’ state.
- In **Arming** state, the system waits for 60 seconds, to allow the user to leave the area before the monitoring process begins. After 60 seconds, the system enters ‘Armed’ state.
- In **Armed** state, the status of the various system sensors is monitored. If a window sensor is tripped, the system enters ‘Intruder’ state. If the door sensor is tripped, the system enters ‘Disarming’ state. The keypad activity is also monitored: if a correct password is typed in, the system enters ‘Disarmed’ state.
- In **Disarming** state, we assume that the door has been opened by someone who *may* be an authorised system user. The system remains in this state for up to 60 seconds, after which - by default - it enters Intruder state. If, during the 60-second period, the user enters the correct password, the system enters ‘Disarmed’ state.
- In **Intruder** state, an alarm will sound. The alarm will keep sounding (indefinitely), until the correct password is entered.

Key software components used in this example

This case study uses the following software components:

- Software to control external port pins (to activate the external bell), as introduced in "Embedded C" Chapter 3.
- Switch reading, as discussed in "Embedded C" Chapter 4, to process the inputs from the door and window sensors. Note that - in this simple example (intended for use in the simulator) - no switch debouncing is carried out. This feature can be added, if required, without difficulty.
- The embedded operating system, sEOS, introduced in "Embedded C" Chapter 7.
- A simple 'keypad' library, based on a bank of switches. Note that - to simplify the use of the keypad library in the simulator - we have assumed the presence of only eight keys in the example program (0 - 7). This final system would probably use at least 10 keys: support for additional keys can be easily added if required.
- The RS-232 library (from "Embedded C" Chapter 9) is used to illustrate the operation of the program. This library would not be necessary in the final system (but it might be useful to retain it, to support system maintenance).

Running the program



```
Disarmed
1234
Arming...
Armed
Window damaged
** INTRUDER! **
1234
Disarmed
1234
Arming...
Armed
Door open
Disarming...
1234
Disarmed
```

The software

```
/*------------------------------------------------------------------*-

   Port.H (v1.00)

  ----------------------------------------------------------

  'Port Header' (see Chap 5) for project INTRUDER (see Chap 10)

-*------------------------------------------------------------------*/

/* ------ Keypad.C -------------------------------------------- */

#define KEYPAD_PORT P2

sbit K0 = KEYPAD_PORT^0;
sbit K1 = KEYPAD_PORT^1;
sbit K2 = KEYPAD_PORT^2;
sbit K3 = KEYPAD_PORT^3;
sbit K4 = KEYPAD_PORT^4;
sbit K5 = KEYPAD_PORT^5;
sbit K6 = KEYPAD_PORT^6;
sbit K7 = KEYPAD_PORT^7;

/* ------ Intruder.C ------------------------------------------ */
sbit Sensor_pin = P1^0;
sbit Sounder_pin = P1^7;

/* ------ Lnk_O.C --------------------------------------------- */

/* Pins 3.0 and 3.1 used for RS-232 interface */


/*------------------------------------------------------------------*-
  ---- END OF FILE ----------------------------------------
-*------------------------------------------------------------------*/
```

```
/*------------------------------------------------------------------*-

   Main.c (v1.00)

  ------------------------------------------------------------------

   Simple intruder alarm system.

-*------------------------------------------------------------------*/

#include "Main.H"
#include "Port.H"
#include "Simple_EOS.H"

#include "PC_O_T1.h"
#include "Keypad.h"
#include "Intruder.h"

/* ................................................................ */

void main(void)
   {
   /* Set baud rate to 9600 */
   PC_LINK_O_Init_T1(9600);

   /* Prepare the keypad */
   KEYPAD_Init();

   /* Prepare the intruder alarm */
   INTRUDER_Init();

   /* Set up simple EOS (5ms tick) */
   sEOS_Init_Timer2(5);

   while(1) /* Super Loop */
      {
      sEOS_Go_To_Sleep();  /* Enter idle mode to save power */
      }
   }

/*------------------------------------------------------------------*-
  ---- END OF FILE -------------------------------------------------
-*------------------------------------------------------------------*/
```

```
/*------------------------------------------------------------------*-

   Intruder.C (v1.00)

-*------------------------------------------------------------------*/

...

/* ------ Private data type declarations ----------------------- */

/* Possible system states */
typedef enum {DISARMED, ARMING, ARMED, DISARMING, INTRUDER}
             eSystem_state;

/* ------ Private function prototypes ------------------------- */

bit  INTRUDER_Get_Password_G(void);
bit  INTRUDER_Check_Window_Sensors(void);
bit  INTRUDER_Check_Door_Sensor(void);
void INTRUDER_Sound_Alarm(void);

...

/* --------------------------------------------------------------- */
void INTRUDER_Init(void)
   {
   /* Set the initial system state (DISARMED) */
   System_state_G = DISARMED;

   /* Set the 'time in state' variable to 0 */
   State_call_count_G = 0;

   /* Clear the keypad buffer */
   KEYPAD_Clear_Buffer();

   /* Set the 'New state' flag */
   New_state_G = 1;

   /* Set the (two) sensor pins to 'read' mode */
   Window_sensor_pin = 1;
   Sounder_pin = 1;
   }
```

```
void INTRUDER_Update(void)
   {
   /* Incremented every time */
   if (State_call_count_G < 65534)
      {
      State_call_count_G++;
      }

   /* Call every 50 ms */
   switch (System_state_G)
      {
      case DISARMED:
         {
         if (New_state_G)
            {
            PC_LINK_O_Write_String_To_Buffer("\nDisarmed");
            New_state_G = 0;
            }

         /* Make sure alarm is switched off */
         Sounder_pin = 1;

         /* Wait for correct password ... */
         if (INTRUDER_Get_Password_G() == 1)
            {
            System_state_G = ARMING;
            New_state_G = 1;
            State_call_count_G = 0;
            break;
            }

         break;
         }
```

```
case ARMING:
   {
   if (New_state_G)
      {
      PC_LINK_O_Write_String_To_Buffer("\nArming...");
      New_state_G = 0;
      }

   /* Remain here for 60 seconds (50 ms tick assumed) */
   if (++State_call_count_G > 1200)
      {
      System_state_G = ARMED;
      New_state_G = 1;
      State_call_count_G = 0;
      break;
      }

   break;
   }
```

```
case ARMED:
   {
   if (New_state_G)
      {
      PC_LINK_O_Write_String_To_Buffer("\nArmed");
      New_state_G = 0;
      }

   /* First, check the window sensors */
   if (INTRUDER_Check_Window_Sensors() == 1)
      {
      /* An intruder detected */
      System_state_G = INTRUDER;
      New_state_G = 1;
      State_call_count_G = 0;
      break;
      }

   /* Next, check the door sensors */
   if (INTRUDER_Check_Door_Sensor() == 1)
      {
      /* May be authorised user - go to 'Disarming' state */
      System_state_G = DISARMING;
      New_state_G = 1;
      State_call_count_G = 0;
      break;
      }

   /* Finally, check for correct password */
   if (INTRUDER_Get_Password_G() == 1)
      {
      System_state_G = DISARMED;
      New_state_G = 1;
      State_call_count_G = 0;
      break;
      }

   break;
   }
```

```
      case DISARMING:
         {
         if (New_state_G)
            {
            PC_LINK_O_Write_String_To_Buffer("\nDisarming...");
            New_state_G = 0;
            }

         /* Remain here for 60 seconds (50 ms tick assumed)
            to allow user to enter the password
            - after time up, sound alarm. */
         if (++State_call_count_G > 1200)
            {
            System_state_G = INTRUDER;
            New_state_G = 1;
            State_call_count_G = 0;
            break;
            }

         /* Still need to check the window sensors */
         if (INTRUDER_Check_Window_Sensors() == 1)
            {
            /* An intruder detected */
            System_state_G = INTRUDER;
            New_state_G = 1;
            State_call_count_G = 0;
            break;
            }

         /* Finally, check for correct password */
         if (INTRUDER_Get_Password_G() == 1)
            {
            System_state_G = DISARMED;
            New_state_G = 1;
            State_call_count_G = 0;
            break;
            }

         break;
         }
      case INTRUDER:
         {
         if (New_state_G)
            {
            PC_LINK_O_Write_String_To_Buffer("\n** INTRUDER! **");
            New_state_G = 0;
            }

         /* Sound the alarm! */
         INTRUDER_Sound_Alarm();

         /* Keep sounding alarm until we get correct password */
         if (INTRUDER_Get_Password_G() == 1)
            {
            System_state_G = DISARMED;
            New_state_G = 1;
            State_call_count_G = 0;
            }

         break;
         }
      }
   }
```

```
bit INTRUDER_Get_Password_G(void)
   {
   signed char Key;
   tByte Password_G_count = 0;
   tByte i;

   /* Update the keypad buffer */
   KEYPAD_Update();

   /* Are there any new data in the keypad buffer? */
   if (KEYPAD_Get_Data_From_Buffer(&Key) == 0)
      {
      /* No new data - password can't be correct */
      return 0;
      }

   /* If we are here, a key has been pressed */

   /* How long since last key was pressed?
      Must be pressed within 50 seconds (assume 50 ms 'tick') */
   if (State_call_count_G > 1000)
      {
      /* More than 5 seconds since last key
         - restart the input process */
      State_call_count_G = 0;
      Position_G = 0;
      }

   if (Position_G == 0)
      {
      PC_LINK_O_Write_Char_To_Buffer('\n');
      }

   PC_LINK_O_Write_Char_To_Buffer(Key);

   Input_G[Position_G] = Key;
   /* Have we got four numbers? */
   if ((++Position_G) == 4)
      {
      Position_G = 0;
      Password_G_count = 0;

      /* Check the password */
      for (i = 0; i < 4; i++)
          {
          if (Input_G[i] == Password_G[i])
             {
             Password_G_count++;
             }
          }
      }

   if (Password_G_count == 4)
      {
      /* Password correct */
      return 1;
      }
   else
      {
      /* Password NOT correct */
      return 0;
      }
   }
```

```
bit INTRUDER_Check_Window_Sensors(void)
   {
   /* Just a single window 'sensor' here
      - easily extended. */
   if (Window_sensor_pin == 0)
      {
      /* Intruder detected... */
      PC_LINK_O_Write_String_To_Buffer("\nWindow damaged");
      return 1;
      }

   /* Default */
   return 0;
   }

/* ------------------------------------------------------------------ */
bit INTRUDER_Check_Door_Sensor(void)
   {
   /* Single door sensor (access route) */
   if (Door_sensor_pin == 0)
      {
      /* Someone has opened the door... */
      PC_LINK_O_Write_String_To_Buffer("\nDoor open");
      return 1;
      }

   /* Default */
   return 0;
   }

/* ------------------------------------------------------------------ */
void INTRUDER_Sound_Alarm(void)
   {
   if (Alarm_bit)
      {
      /* Alarm connected to this pin */
      Sounder_pin = 0;
      Alarm_bit = 0;
      }
   else
      {
      Sounder_pin = 1;
      Alarm_bit = 1;
      }
   }
```

```
void KEYPAD_Update(void)
   {
   char Key;

   /* Scan keypad here... */
   if (KEYPAD_Scan(&Key) == 0)
      {
      /* No new key data - just return */
      return;
      }

   /* Want to read into index 0, if old data has been read
      (simple ~circular buffer). */
   if (KEYPAD_in_waiting_index == KEYPAD_in_read_index)
      {
      KEYPAD_in_waiting_index = 0;
      KEYPAD_in_read_index = 0;
      }

   /* Load keypad data into buffer */
   KEYPAD_recv_buffer[KEYPAD_in_waiting_index] = Key;

   if (KEYPAD_in_waiting_index < KEYPAD_RECV_BUFFER_LENGTH)
      {
      /* Increment without overflowing buffer */
      KEYPAD_in_waiting_index++;
      }
   }


bit KEYPAD_Get_Data_From_Buffer(char* const pKey)
   {
   /* If there is new data in the buffer */
   if (KEYPAD_in_read_index < KEYPAD_in_waiting_index)
      {
      *pKey = KEYPAD_recv_buffer[KEYPAD_in_read_index];

      KEYPAD_in_read_index++;

      return 1;
      }

   return 0;
   }
```

```
bit KEYPAD_Scan(char* const pKey)
   {
   char Key = KEYPAD_NO_NEW_DATA;

   if (K0 == 0) { Key = '0'; }
   if (K1 == 0) { Key = '1'; }
   if (K2 == 0) { Key = '2'; }
   if (K3 == 0) { Key = '3'; }
   if (K4 == 0) { Key = '4'; }
   if (K5 == 0) { Key = '5'; }
   if (K6 == 0) { Key = '6'; }
   if (K7 == 0) { Key = '7'; }

   if (Key == KEYPAD_NO_NEW_DATA)
      {
      /* No key pressed  */
      Old_key_G = KEYPAD_NO_NEW_DATA;
      Last_valid_key_G = KEYPAD_NO_NEW_DATA;

      return 0;  /* No new data */
      }

   /* A key has been pressed: debounce by checking twice */
   if (Key == Old_key_G)
      {
      /* A valid (debounced) key press has been detected */

      /* Must be a new key to be valid - no 'auto repeat' */
      if (Key != Last_valid_key_G)
         {
         /* New key! */
         *pKey = Key;
         Last_valid_key_G = Key;

         return 1;
         }
      }

   /* No new data */
   Old_key_G = Key;
   return 0;
   }
```

```
sEOS_ISR() interrupt INTERRUPT_Timer_2_Overflow
   {
   TF2 = 0;  /* Must manually reset the T2 flag    */

   /*===== USER CODE - Begin ================================== */
   /* Call RS-232 update function every 5ms */
   PC_LINK_O_Update();

   /* This ISR is called every 5 ms
      - only want to update intruder every 50 ms. */
   if (++Call_count_G == 10)
      {
      /* Time to update intruder alarm */
      Call_count_G = 0;

      /* Call intruder update function */
      INTRUDER_Update();
      }
   /*===== USER CODE - End ==================================== */
   }
```

Extending and modifying the system

- How would you add a “real” keypad?

(See “Patterns for Time-Triggered Embedded Systems, Chap. 20)

- How would you add an LCD display?

(See “Patterns for Time-Triggered Embedded Systems, Chap. 22)

- How would you add additional nodes?

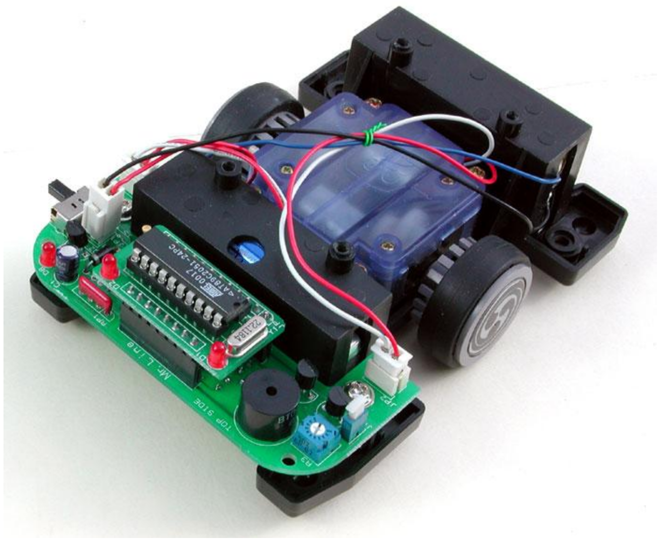
(See “Patterns for Time-Triggered Embedded Systems, Part F)

Conclusions

This case study has illustrated most of the key features of embedded C, as discussed throughout the earlier sessions in this course.

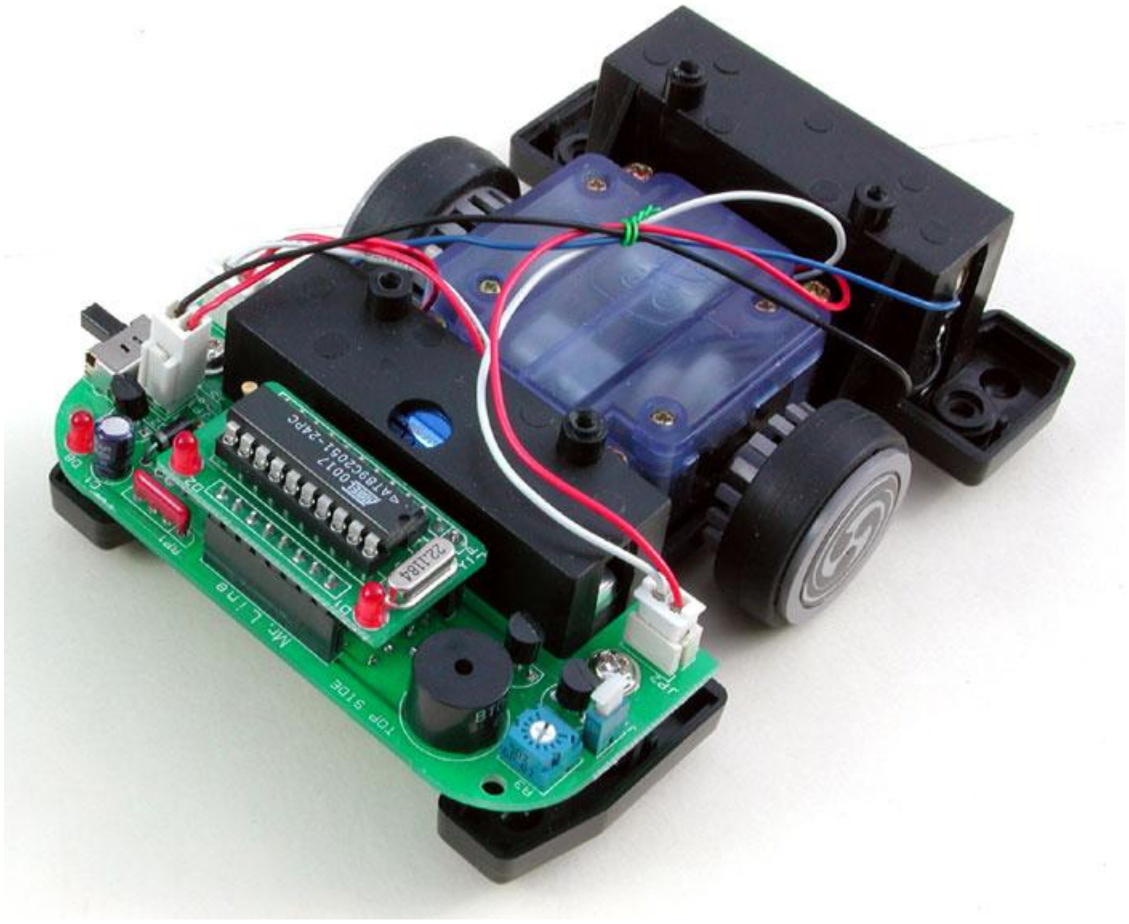
We'll consider a final case study in the next seminar.

Seminar 10:
Case Study:
Controlling a Mobile Robot



Overview

In this session, we will discuss the design of software to control a small mobile robot.



The robot is “Mr Line”

He is produced by “Microrobot NA”

`http://www.microrobotna.com`

What can the robot do?

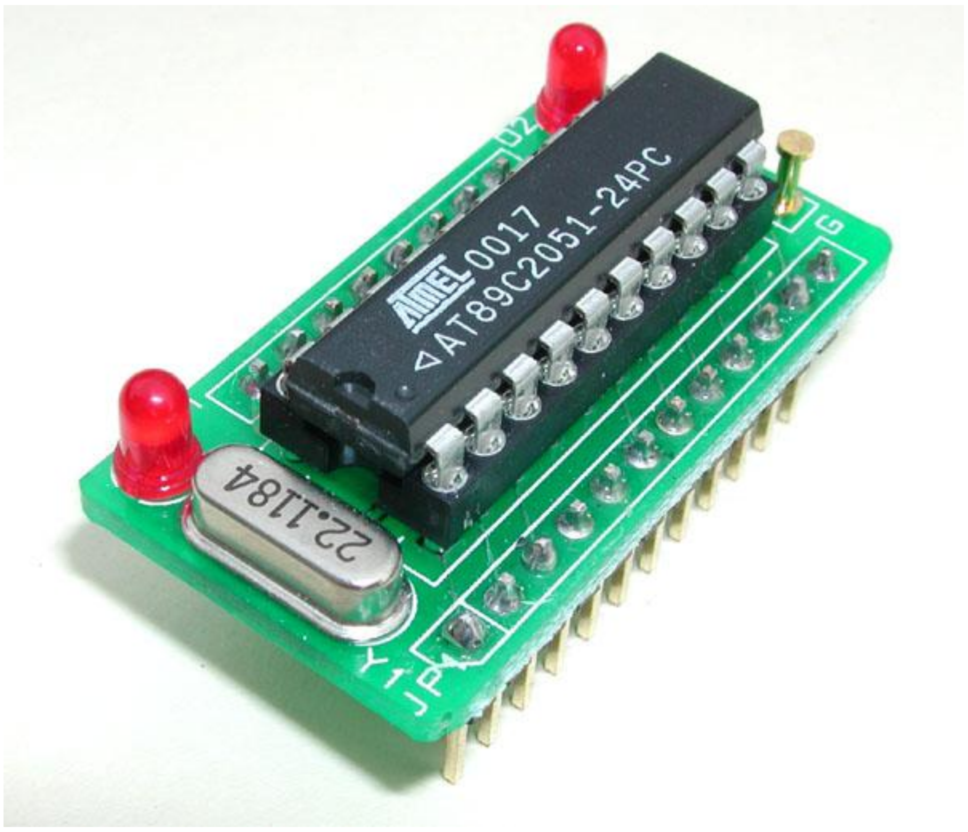
The robot has IR sensors and transmitters that allow him to detect a black line on a white surface - and follow it.

http://www.microrobotna.com

The robot brain

Mr Line is controlled by an 8051 microcontroller (an AT89C2051).

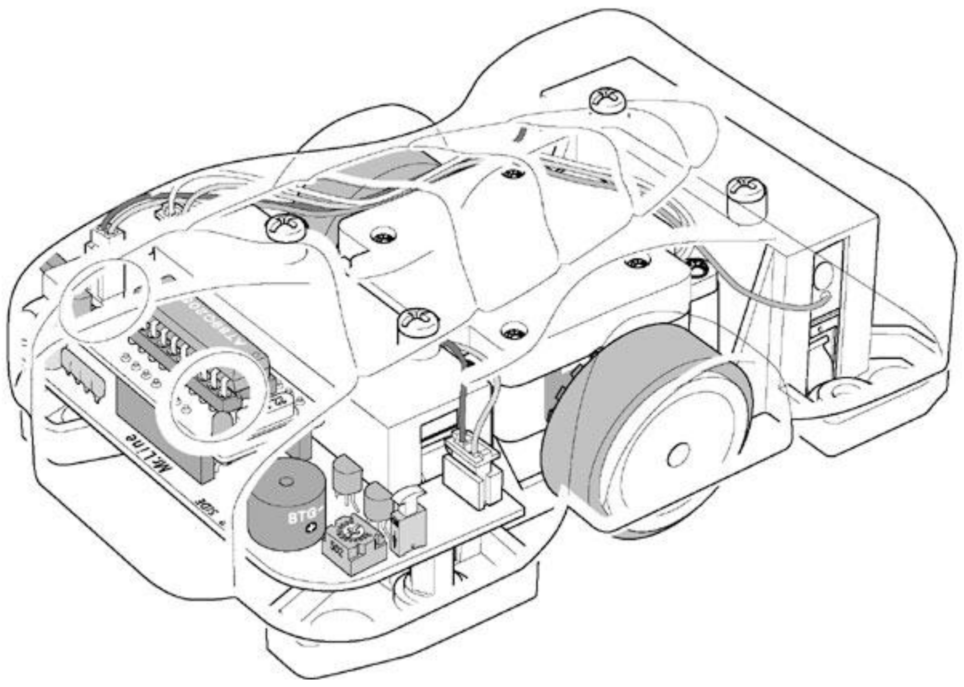
We'll use a pin-compatible AT89C4051 in this study.



http://www.microrobotna.com

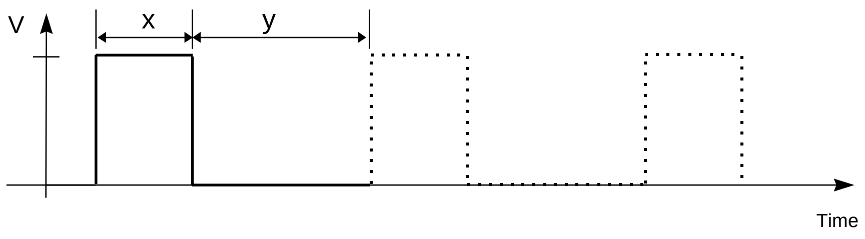
How does the robot move?

Mr Line has two DC motors: by controlling the relative speed of these motors, we can control the speed and direction in which he will move.



http://www.microrobotna.com

Pulse-width modulation



Duty cycle (%) = $\boxed{}$

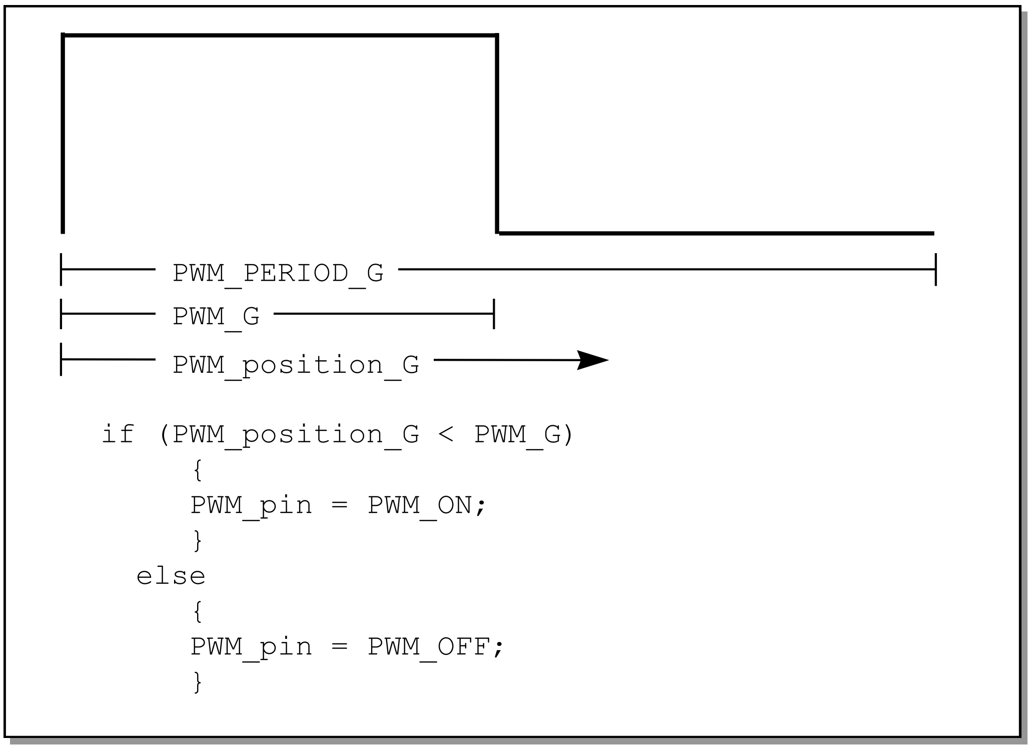
Period = *x* + *y*, where *x* and *y* are in seconds.

Frequency = $\boxed{}$, where *x* and *y* are in seconds.

The key point to note is that the average voltage seen by the load is given by the duty cycle multiplied by the load voltage.

See: **"Patterns for Time-Triggered Embedded Systems"**, Chapter 33

Software PWM



```
if (PWM_position_G < PWM_G)
       {
       PWM_pin = PWM_ON;
       }
   else
       {
       PWM_pin = PWM_OFF;
       }
```

See: **"Patterns for Time-Triggered Embedded Systems"**, Chapter 33

The resulting code

< We'll discuss the resulting code in the lecture … >

More about the robot

Please see:

`http://www.le.ac.uk/engineering/mjp9/robot.htm`

Conclusions

That brings us to the end of this course!