# Introduction to PIC Programming

## Baseline Architecture and Assembly Language

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## *Lesson 3: Introducing Modular Code*

Lesson 2 introduced delay loops, which we used in flashing an LED.

Delay loops are an example of useful code that could be re-used in other applications; you don't want to have to re-invent the wheel (or delay loop!) every time. Or, in a larger application, you may need to use delays in several parts of the program. It would be wasteful to have to include multiple copies of the same code in the one program. And if you wanted to make a change to your delay code, it would be not only more convenient, but less likely to introduce errors, if you only have to change it in one place.

Code that is made up of pieces that can be easily re-used, either within the same program, or in other programs, is called modular. You'll save yourself a lot of time if you learn to write re-usable, modular code, which is why it's being covered in such an early lesson.

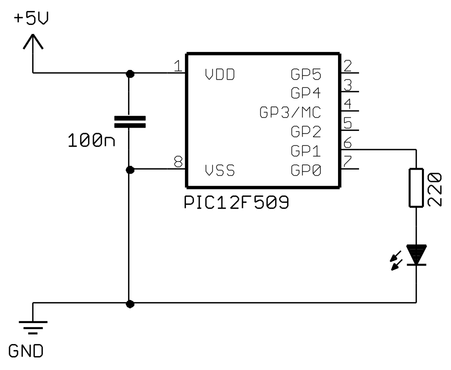
In this lesson, we will learn about:

- Subroutines
- Relocatable code and modules
- Banking and paging

## The Circuit

The development environment and circuit for this is identical to that in lessons 1 and 2.

For reference, here is the circuit again:



Refer back to lesson 1 to see how to build it by either soldering a resistor, LED (and optional isolating jumper) to the demo board, or by making connections on the demo board's 14-pin header.

## Subroutines

Here again is the main code from lesson 2:

```
start
        movlw   b'111101'       ; configure GP1 (only) as an output
        tris    GPIO
        clrf    sGPIO           ; start with shadow GPIO zeroed
flash
        movf    sGPIO,w         ; get shadow copy of GPIO
        xorlw   b'000010'       ; flip bit corresponding to GP1 (bit 1)
        movwf   GPIO            ; write to GPIO
        movwf   sGPIO           ; and update shadow copy

        ; delay 500 ms
        movlw   .244            ; outer loop: 244 x (1023 + 1023 + 3) + 2
        movwf   dc2             ;   = 499,958 cycles
        clrf    dc1             ; inner loop: 256 x 4 - 1
dly1    nop                     ; inner loop 1 = 1023 cycles
        decfsz  dc1,f
        goto    dly1
dly2    nop                     ; inner loop 2 = 1023 cycles
        decfsz  dc1,f
        goto    dly2
        decfsz  dc2,f
        goto    dly1

        goto    flash           ; repeat forever


        END
```

Suppose that you wanted to include another 500 ms delay in another part of the program. To place the delay code *inline*, as it is above, would mean repeating all 11 lines of the delay routine somewhere else. And you have to be very careful when copying and pasting code – you can't refer to the labels '`dly1`' or '`dly2`' in the copied code, or else it will jump back to the original delay routine – probably not the intended effect!

The usual way to use the same code in a number of places in a program is to place it into a *subroutine*. The main code loop would then look like this:

```
flash
        movf    sGPIO,w         ; get shadow copy of GPIO
        xorlw   b'000010'       ; flip bit corresponding to GP1 (bit 1)
        movwf   GPIO            ; write to GPIO
        movwf   sGPIO           ; and update shadow copy
        call    delay500        ; delay 500ms
        goto    flash           ; repeat forever
```

The '`call`' instruction – "**call** subroutine" – is similar to '`goto`', in that it jumps to another program address. But first, it copies (or *pushes*) the address of the next instruction onto the stack. The *stack* is a set of registers, used to hold the return addresses of subroutines. When a subroutine is finished, the *return address* is copied (*popped*) from the stack to the program counter, and program execution continues with the instruction following the subroutine call.

The baseline PICs only have two stack registers, so a maximum of two return addresses can be stored. This means that you can call a subroutine from within another subroutine, but you can't *nest* the subroutine calls any deeper than that. But for the sort of programs you'll want to write on a baseline PIC, you'll find this isn't a problem. If it is, then it's time to move up to a midrange PIC, or a PIC18…

The instruction to *return* from a subroutine is '`retlw`' – "**ret**urn with **l**iteral in **W**". This instruction places a literal value in the W register, and then pops the return address from the stack, to return execution to the calling code.

Note that the baseline PICs do not have a simple 'return' instruction, only '`retlw`'; you can't avoid returning a literal in W. If you need to preserve the value in W when a subroutine is called, you must first save it in another register.

Here is the 500 ms delay routine, written as a subroutine:

```
delay500                        ; delay 500ms
        movlw   .244            ; outer loop: 244x(1023+1023+3)-1+3+4
        movwf   dc2             ;   = 499,962 cycles
        clrf    dc1
dly1    nop                     ; inner loop 1 = 256x4-1 = 1023 cycles
        decfsz  dc1,f
        goto    dly1
dly2    nop                     ; inner loop 2 = 1023 cycles
        decfsz  dc1,f
        goto    dly2
        decfsz  dc2,f
        goto    dly1

        retlw   0
```

Note that this code returns a '0' in W. It doesn't have to be '0'; any number would do, but it's conventional to return a '0' if you're not returning some specific value.

### *Parameter Passing with W*

A re-usable 500 ms delay routine is all very well, but it's only useful if you need a delay of 500 ms. What if you want a 200 ms delay – write another routine? Have multiple delay subroutines, one for each delay length? It's more useful to have a single routine that can provide a range of delays. The requested delay time would be passed as a *parameter* to the delay subroutine.

If you had a number of parameters to pass (for example, a 'multiply' subroutine would have to be given the two numbers to multiply), you'd need to place the parameters in general purpose registers, accessed by both the calling program and the subroutine. But if there is only one parameter to pass, it's often convenient to simply place it in W.

For example, in the delay routine above, we could simply remove the 'movlw .244' line, and instead pass this number (244) as a parameter:

```
        movlw   .244
        call    delay           ; delay 244x2.049ms = 500ms
```

But passing a value of '244' to specify a delay of 500 ms is a little obscure. It would be better if the delay subroutine worked in multiples of an easier-to-use duration than 2.049 ms.

Ideally, we'd pass the number of milliseconds wanted, directly, i.e. pass a parameter of '500' for a 500 ms delay. But that won't work. The baseline PICs are 8-bit devices; the largest value you can pass in any single register, including W, is 255.

If the delay routine produces a delay which is some multiple of 10 ms, it could be used for any delay from 10 ms to 2.55 s, which is quite useful – you'll find that you commonly want delays in this range.

To implement a W × 10 ms delay, we need an inner set of loops which create a 10 ms (or close enough) delay, and an outer loop which counts the specified number of those 10 ms loops.

To count multiples of 10 ms, we need to add a third loop counter, as in the following code:

```
delay10                         ; delay W x 10ms
        movwf   dc3             ; delay = 1+Wx(3+10009+3)-1+4 -> Wx10.015ms

dly2    movlw   .13             ; repeat inner loop 13 times
        movwf   dc2             ; -> 13x(767+3)-1 = 10009 cycles

        clrf    dc1             ; inner loop = 256x3-1 = 767 cycles
dly1    decfsz  dc1,f
        goto    dly1

        decfsz  dc2,f           ; end middle loop
        goto    dly1

        decfsz  dc3,f           ; end outer loop
        goto    dly2

        retlw   0
```

To illustrate where this is useful, suppose that, instead of the LED being on half the time (a 50% *duty cycle*), we want the LED to flash briefly, for say 200 ms, once per second (a 20% duty cycle). That would require a delay of 200 ms while the LED is on, then a delay of 800 ms while it is off.

Here is the complete program to do this, to illustrate how all the above fits together:

```
;************************************************************************
;                                                                       *
;   Description:    Lesson 3, example 1                                 *
;                                                                       *
;   Flashes a LED at approx 1Hz, with 20% duty cycle                    *
;   LED continues to flash until power is removed                      *
;                                                                       *
;************************************************************************
;                                                                       *
;   Pin assignments:                                                    *
;       GP1 - flashing LED                                              *
;                                                                       *
;************************************************************************

    list        p=12F509
    #include    <p12F509.inc>

                ; ext reset, no code protect, no watchdog, 4Mhz int clock
    __CONFIG    _MCLRE_ON & _CP_OFF & _WDT_OFF & _IntRC_OSC


;***** VARIABLE DEFINITIONS
        UDATA
dc1     res 1                   ; delay loop counters
dc2     res 1
dc3     res 1


;************************************************************************
RESET   CODE    0x000           ; effective reset vector
        movwf   OSCCAL          ; update OSCCAL with factory cal value


;***** MAIN PROGRAM

;***** Initialisation
```

```
start
        movlw   b'111101'       ; configure GP1 (only) as an output
        tris    GPIO

;***** Main loop
flash
        movlw   b'000010'       ; set bit corresponding to GP1 (bit 1)
        movwf   GPIO            ; write to GPIO to turn on LED
        movlw   .20             ; stay on for 0.2s:
        call    delay10         ;   delay 20 x 10ms = 200ms
        clrf    GPIO            ; clear GPIO to turn off LED
        movlw   .80             ; stay off for 0.8s:
        call    delay10         ;   delay 80 x 10ms = 800ms
        goto    flash           ; repeat forever


;***** Subroutines
delay10                         ; delay W x 10ms
        movwf   dc3             ; delay = 1+Wx(3+10009+3)-1+4 -> Wx10.015ms

dly2    movlw   .13             ; repeat inner loop 13 times
        movwf   dc2             ; -> 13x(767+3)-1 = 10009 cycles

        clrf    dc1             ; inner loop = 256x3-1 = 767 cycles
dly1    decfsz  dc1,f
        goto    dly1
        decfsz  dc2,f           ; end middle loop
        goto    dly1
        decfsz  dc3,f           ; end outer loop
        goto    dly2

        retlw   0


        END
```

By using a variable delay subroutine, the main loop (starting at the label '`flash`') is much shorter and simpler than it would otherwise be.

Note that this code does not use a shadow register. It's no longer necessary, because the GP1 bit is being directly set/cleared. It's not being flipped; there's no dependency on its previous value. At no time does the GPIO register have to be read. It's only being written to. So "read-modify-write" is not a consideration here. If that's unclear, go back to the description in lesson 2, and think about why an 'xor' operation on an I/O register is different to simply writing a new value directly to the I/O register. It's important to understand this point, but if you're ever in doubt about whether the "read-modify-write" problem may apply, it's best to be safe and use a shadow register.

### *`CALL` Instruction Address Limitation*

Before moving on from subroutines, it is important that you be aware of a limitation in the baseline PIC architecture, regarding the addressing of subroutines.

At the lowest level, PIC instructions consist of bits. In the baseline PICs, the instruction words are 12 bits wide. Some of the bits designate which instruction it is; this set of bits is called the *opcode*.

For example, the opcode for `movlw` is 1100.

The remaining bits in the 12-bit word are used to specify whatever value is associated with the instruction, such as a literal value, a register, or an address. In the case of `movlw`, the opcode is only 4 bits long, leaving the other 8 bits to hold the literal value that will be moved into W.

For example, the 12-bit instruction word for ‘`movlw 1`’ is 1100 00000001 (the last 8 bits being the binary for ‘1’).

The opcode for `goto` is 101. That’s only 3 bits, leaving 9 bits to specify the address to jump to. 9 bits are enough to specify any value from 0 to 511. That’s 512 addresses in all.

The program memory on the 12F508 is 512 words. Since the `goto` instruction can specify any of these 512 addresses, it is able to jump anywhere in the 12F508’s memory.

However, the opcode for the `call` instruction is 1001. That’s 4 bits, leaving only 8 bits to specify the address of the subroutine being called.

8 bits can hold a value from 0 to 255. There’s no problem if your subroutine is in the first 256 words of memory. But what if it’s at an address above 255? With only 8 bits available for the address in the `call` instruction, how can you specify an address higher than 255? The answer is that, on the baseline PICs, you can’t.

*In the baseline PIC architecture,* ***subroutine calls are limited to the first 256 locations of any program memory page.***

What’s a program memory page? Paging is discussed below, but, briefly, on the baseline PICs, program memory is split into pages 512 words long (it’s no coincidence that that matches the number of locations that `goto` can address). The 12F508 only has 512 words of program memory, forming a single page. So for the 12F508, we can say that subroutine calls are limited to the first 256 words of program memory. It’s possible for a subroutine to use goto to jump to somewhere in the second 256 words of a memory on a 12F508, but the entry point for every subroutine has to be within that first 256 words.

That can be an awkward limitation to work around; if your main code is more than 256 instructions long and (as in the program above) you place your subroutines after the main code, you’ll have a problem. The MPASM assembler will warn you if you try to call a subroutine past the 256-word boundary. The only way to fix it is to re-arrange your code.

One approach would be to place the subroutines toward the beginning of the main code section, which we know is located at address 0x000 (the start of the first page), with a `goto` instruction immediately before the subroutines, to jump around them to the start of the main program code. A problem with that approach is that all the subroutines plus the main code may be too big to fit into a single page (i.e. more than 512 words in total), but each code section has to fit within a single page. The solution to that is simple – place the subroutines in the section located at 0x000 (so we know they are toward the start of a page), but put the main code into its own code section, which the linker can place anywhere in program memory – wherever it fits.

A more significant problem is that placing all the subroutines toward the start of page doesn’t mean that they will all start within the first 256 addresses in the page; if the subroutines together total more than 256 words, there could still be problems.

The solution is to use a jump table, or *subroutine vectors* (or *long calls*). The idea is that only the entry points for each subroutine are placed at the start of a page. Each entry point consists of a ‘`goto`’ instruction, jumping to the main body of the subroutine, which could be anywhere in memory – preferably in another `CODE` section so that the linker is free to place it wherever it fits best.

The above program could be restructured to use a subroutine vector, as follows:

```
RESET   CODE    0x000           ; effective reset vector
        movwf   OSCCAL          ; update OSCCAL with factory cal value
        goto    start           ; jump to main code

;***** Subroutine vectors
delay10 goto    delay10_R       ; delay W x 10ms
```

```
;***** Main program
MAIN    CODE
start ; Initialisation
        movlw   b'111101'       ; configure GP1 (only) as an output
        tris    GPIO

;***** Main loop
flash
        movlw   b'000010'       ; set bit corresponding to GP1 (bit 1)
        movwf   GPIO            ; write to GPIO to turn on LED
        movlw   .20             ; stay on for 0.2s:
        call    delay10         ;   delay 20 x 10ms = 200ms
        clrf    GPIO            ; clear GPIO to turn off LED
        movlw   .80             ; stay off for 0.8s:
        call    delay10         ;   delay 80 x 10ms = 800ms
        goto    flash           ; repeat forever


;***** Subroutines
SUBS    CODE

delay10_R                       ; delay W x 10ms
        movwf   dc3             ; -> 1+Wx(3+10009+3)-1+4 = Wx10.015ms
dly2    movlw   .13             ; repeat inner loop 13 times
        movwf   dc2             ; -> 13x(767+3)-1 = 10009 cycles
        clrf    dc1             ; inner loop = 256x3-1 = 767 cycles
dly1    decfsz  dc1,f
        goto    dly1
        decfsz  dc2,f           ; end middle loop
        goto    dly1
        decfsz  dc3,f           ; end outer loop
        goto    dly2

        retlw   0
```

Dividing the program into so many `CODE` sections is of course overkill for such a small program, but if you adopt this approach you will avoid problems as your programs grow larger.

The entry point for the 'delay10' subroutine is guaranteed to be within the first 256 words of the program memory page, while the subroutine proper, renamed to 'delay10_R' (R for routine) is in a separate code section which could be anywhere in memory – perhaps on a separate page. And therein lies a problem; as written, this code is not guaranteed to work. The following section explains why.

## Paging

As discussed above, the `goto` instruction word only has 9 bits to specify the program location to jump to; enough to address up to a single *page* of 512 program words

That's fine for the 12F508, which only has 512 words of program memory, but it's a problem for a device such as the 12F509, with 1024 words.

The solution is to use a bit in the STATUS register, PA0, to select which page is to be accessed:

| | Bit 7 | Bit 6 | Bit 5 | Bit 4 | Bit 3 | Bit 2 | Bit 1 | Bit 0 |
|---|---|---|---|---|---|---|---|---|
| STATUS | GPWUF | - | PA0 | $\overline{\text{TO}}$ | $\overline{\text{PD}}$ | Z | DC | C |

The *program counter* (PC) holds the full 12-bit address of the next instruction to be executed. Whenever a `goto` instruction is executed, the lower 9 bits of the program counter (PC<8:0>) are taken from the `goto` instruction word, but the 10th bit (PC<9>) is provided by the current value to PA0.

This is also true for the `call` instruction, except that, as explained earlier, only the lower 8 bits of the program counter come from the `call` instruction word, and PC<8> is always set to 0.

(In fact, this is true for any instruction which modifies the program counter; a point we will come back to when we cover lookup tables in lesson 8.)

Therefore, to `goto` or `call` an address in the first 512 words of program memory (page 0), you must first clear PA0. To access a routine in page 1, you must first set PA0 to '1'.

If you don't update PA0, but then try to `goto` or `call` an address in a different page, you will instead jump the corresponding address in the current page – not the location you were trying to access, and your program will almost certainly fail.

For baseline devices with 2048 words of program memory, such as the 16F59, this paging scheme is extended, with bit 6 of the STATUS register, referred to as PA1, providing PC<10>. Given two page selection bits (PA0 and PA1), up to four 512-word pages can be selected, allowing a total of 2048 words.

### *Using the `PAGESEL` directive*

If your program includes multiple code sections, you can't know beforehand where the linker will place them in memory, so you can't know how to set the page selection bits when jumping to locations in other sections.

The solution is to use the '`pagesel`' directive, which instructs the assembler and linker to generate code to select the correct page for the given program address.

To ensure that the program above will work correctly, regardless of which pages the main code and subroutines are on, `pagesel` directives should be added to the start-up and subroutine vector code, as follows:

```
RESET   CODE    0x000           ; effective reset vector
        movwf   OSCCAL          ; update OSCCAL with factory cal value
        pagesel start
        goto    start           ; jump to main code

;***** Subroutine vectors
delay10                         ; delay W x 10ms
        pagesel delay10_R
        goto    delay10_R
```

And, then, since the delay10 subroutine entry point may be in a different page from the main code, `pagesel` directives should be added to the main loop, as follows:

```
flash
        movlw   b'000010'       ; set bit corresponding to GP1 (bit 1)
        movwf   GPIO            ; write to GPIO to turn on LED
        movlw   .20             ; stay on for 0.2s:
        pagesel delay10
        call    delay10         ;   delay 20 x 10ms = 200ms
        clrf    GPIO            ; clear GPIO to turn off LED
        movlw   .80             ; stay off for 0.8s:
        call    delay10         ;   delay 80 x 10ms = 800ms
        pagesel flash
        goto    flash           ; repeat forever
```

Note that there is no '`pagesel`' before the second call to '`delay10`'. It's unnecessary, because the first '`pagesel`' has already set the page selection bits for calls to '`delay10`'. If you're going to successively call subroutines in a single section, there is no need to add a '`pagesel`' for each; the first is enough.

Finally, note the '`pagesel`' before the '`goto`' at the end of the loop. This is necessary because, at that point, the page selection bits will still be set for whatever page the '`delay10`' entry point is on, not necessarily the current page.

An alternative is to place a ‘`pagesel $`’ directive (“select page for current address”) after each `call` instruction, to ensure that the current page is selected after returning from a subroutine.

You do not, however, need to use `pagesel` before every `goto` or `call`, or after every `call`. Remember that, provided you use the default linker scripts, a single code section is guaranteed to be wholly contained within a single page. So, once you know that you’ve selected the correct page, subsequent `goto`s or `call`s to the same section will work correctly. But be careful!

If in doubt, using `pagesel` before every `goto` and `call` is a safe approach that will always work.

## Banking

A limitation, similar to that for program memory access, also exists with data memory.

As discussed earlier, the opcodes encoding the PIC instructions use a limited number of bits, as part of the instruction word, to represent a register in data memory or a program memory address. In the baseline architecture, only 5 bits are allocated to register addressing. That’s enough to allow up to 32 registers to be directly addressed, corresponding to the size of a *register bank*: 32 registers.

The PIC12F508 has 7 special function registers and 25 general purpose registers; 32 registers in total. They are arranged as a single bank, as described in lesson 1.

### PIC12F509 Registers

| Address | *Bank 0* | Address | *Bank 1* |
|---|---|---|---|
| 00h | INDF | 20h | INDF |
| 01h | TMR0 | 21h | TMR0 |
| 02h | PCL | 22h | PCL |
| 03h | STATUS | 23h | STATUS |
| 04h | FSR | 24h | FSR |
| 05h | OSCCAL | 25h | OSCCAL |
| 06h | GPIO | 26h | GPIO |
| 07h – 0Fh | General Purpose Registers | 27h – 2Fh | Map to Bank 0 07h – 0Fh |
| 10h – 1Fh | General Purpose Registers | 30h – 3Fh | General Purpose Registers |

The 12F509 has 41 general purpose registers, in addition to the 7 special function registers; 48 in total. That’s too many to fit into a single bank.

To allow these additional registers to be addressed, they are arranged into two banks, as shown at the left.

The bank to be accessed is selected by bit 5 in the FSR register (FSR<5>). If it is cleared to ‘0’, bank 0 is selected, and any instructions which reference a register will address a register in bank 0. If FSR<5> is set to ‘1’, bank 1 is selected, and subsequent instructions will reference registers in bank 1.

The special function registers appear in both banks. Regardless of which bank is selected, you can refer directly to any special function register, such as GPIO. That’s not true in the midrange devices, where you have to be very careful to select the correct bank before accessing special function registers. But on the baseline PICs, you don’t have to worry about banking when working with special function registers.

The first set of 9 general purpose registers (07h – 0Fh) are mapped into both banks. Whichever bank is selected, these same registers will be addressed. Registers like this, which appear at the same location across all banks, are referred to as *shared*. They are very useful for storing data or variables which you want to access often, regardless of which bank is selected, without having to include bank selection instructions. If you address a register as 07h or 27h, it will contain the same data; it’s the same physical register.

The next 16 general purpose registers (10h – 1Fh) are accessed through bank 0 only. If you set FSR<5> to select bank 1, you'll access an entirely separate set of 16 general purpose registers (30h – 3Fh).

Note that, when referring to numeric register addresses, FSR<5> is considered to be bit 5 of the register address (bits 0 to 4 of the address coming from the instruction word).

So the 12F509 has 9 shared general purpose registers, and 32 banked general purpose registers (16 in each of two banks), for a total of 41 bytes of data memory.

Taking this banking scheme further, the 16F505 has 72 bytes of data memory, arranged into four banks: 8 shared registers and 64 banked registers (16 in each bank). As for the other baseline devices, the special function registers are mapped into each bank.

The four data banks in the 16F505 are selected by bits 5 and 6 of the FSR register (FSR<6:5>): '00' selects bank 0, '01' for bank 1, '10' for bank 2, and '11' selects bank 3.

Similarly, the 16F59 has 134 general purpose registers: 6 shared and 16 in each of 8 banks. To specify which of the eight banks is selected, three bits are needed: FSR<7:5>. Since FSR has no 8th bit, this scheme can't be extended any further, so eight is the maximum number of data banks possible in the midrange architecture.

### *Using the BANKSEL directive*

Typically, when you use the UDATA and RES directives to declare and allocate space in a section of data memory, you don't specify an address, allowing the linker to locate the section anywhere in data memory, fitting it around other sections. The potential problem with this is that "anywhere in data memory" also means "in any bank".

When you refer to registers allocated within relocatable data sections, you can't know what bank they will be in, so you can't know how to set the bank selection bits in FSR.

The solution is similar to that for paging: use the banksel directive to instruct the assembler and linker to generate appropriate code to select the correct bank for the given variable (or data address label).

To ensure that the 'delay10' routine accesses the register bank containing the delay loop counter variables, a banksel directive should be added, as follows:

```
delay10_R                       ; delay W x 10ms
        banksel dc3             ; -> ?+1+Wx(3+10009+3)-1+4 = Wx10.015ms
        movwf   dc3
dly2    movlw   .13             ; repeat inner loop 13 times
        movwf   dc2             ; -> 13x(767+3)-1 = 10009 cycles
        clrf    dc1             ; inner loop = 256x3-1 = 767 cycles
dly1    decfsz  dc1,f
        goto    dly1
        decfsz  dc2,f           ; end middle loop
        goto    dly1
        decfsz  dc3,f           ; end outer loop
        goto    dly2

        retlw   0
```

banksel is used the first time a group of variables is accessed, but not subsequently – unless another bank has been selected (for example, after calling a subroutine which may have selected a different bank).

We know that all three variables will be in the same bank, since they are all declared as part of the same data section. As long as you use the default, Microchip-supplied, linker scripts, that's guaranteed. If you select the bank for one variable in a data section, then it will also be the correct bank for every other variable in that section, so we only need to use banksel once. You only need another banksel if you're going to access a variable in a different data section.

Note that the code could have been started with '`banksel dc1`', instead of '`banksel dc3`'; it would make no difference, because `dc1` and `dc3` are in the same section and therefore the same bank. But it seems clearer, and more maintainable, to have `banksel` refer to the variable you're about to access, and to place it immediately before that access.

### *Declaring a Shared Data Section*

As discussed above, not all data memory is banked. The special function registers and some of the general purpose registers are mapped into every bank. These shared registers are useful for storing variables that are used throughout a program, without having to worry about setting bank selection bits to access them.

The `UDATA_SHR` directive is used to declare a section of shared data memory.

It's used in the same way as `UDATA`; the only difference is that registers reserved in a `UDATA_SHR` section won't be banked.

Since there is less shared memory available than banked memory, it should be used sparingly. However, it can make sense to allocate shadow registers in shared memory, as they are likely to be used often.

To summarise:

- The first time you access a variable declared in a `UDATA` section, use `banksel`.
- To access subsequent variables in the same `UDATA` section, you don't need to use `banksel`.
  (unless you had selected another bank between variable accesses)
- Following a call to a subroutine or external module (see below), which may have selected a different bank, use `banksel` for the first variable accessed after the call.
- To access variables in a `UDATA_SHR` section, there is never any need to use `banksel`.

## Relocatable Modules

If you wanted to take a subroutine you had written as part of one program, and re-use it in another, you could simply copy and paste the source code into the new program.

There are a few potential problems with this approach:

- Address labels, such as '`dly1`', may already be in use in the new program, or in other pieces of code that you're copying.
- You need to know which variables are needed by the subroutine, and remember to copy their definitions to the new program.
- Variable names have the same problem as address labels – they may already be used in new program, in which case you'd need to identify and rename all references to them.

These problems can be avoided by keeping the subroutine code in a separate source file, where it is assembled into an object file, called an *object module*. The main code is assembled into a separate object file. These object files – one for the main code, plus one for each module, are then linked together to create the final executable code, which is output as a .hex file to be programmed into the PIC. This assembly/link (or *build*) process sounds complicated, but MPLAB takes care of the details, as we'll see.

### *Creating a multiple-file project*

Let's set up a project with the following files:

- delay10.asm - containing the W × 10 ms delay routine
- L3-Flash_LED-main.asm - the main code (calling the delay routine)

These can be based on parts of the programs developed above.

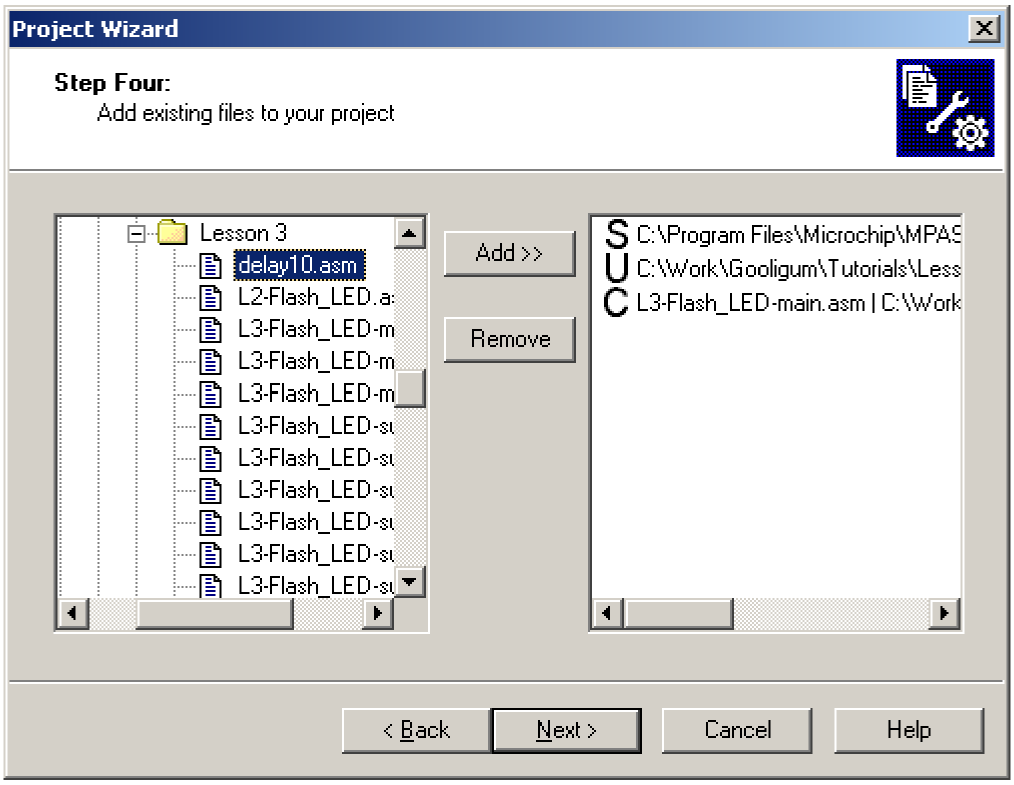
To create the multiple-file project, open an existing project and then save it with a new name, such as "L3-Flash_LED-mod", in the same way as you did when creating new project in lesson 2.

Open the assembler source containing the main loop and the 'delay10' subroutine (e.g. from example 1, above) and save it, using "File → Save As…" as "delay10.asm".

Next close the editor window and run the project wizard as before, to reconfigure the active project.

When you reach "Step Four: Add existing files to your project" window, rename the source file to "L3-Flash_LED-main", in the same way as was done in lesson 2 (changing the "U" next to the filename to "C").

Now find the "delay10.asm" file you saved before in the left hand pane, and click on "Add>>" to add it to your project. The filename is already correct, but you should click on the "A" next to the filename to change it to a "U" to indicate that this is a user file, as shown:

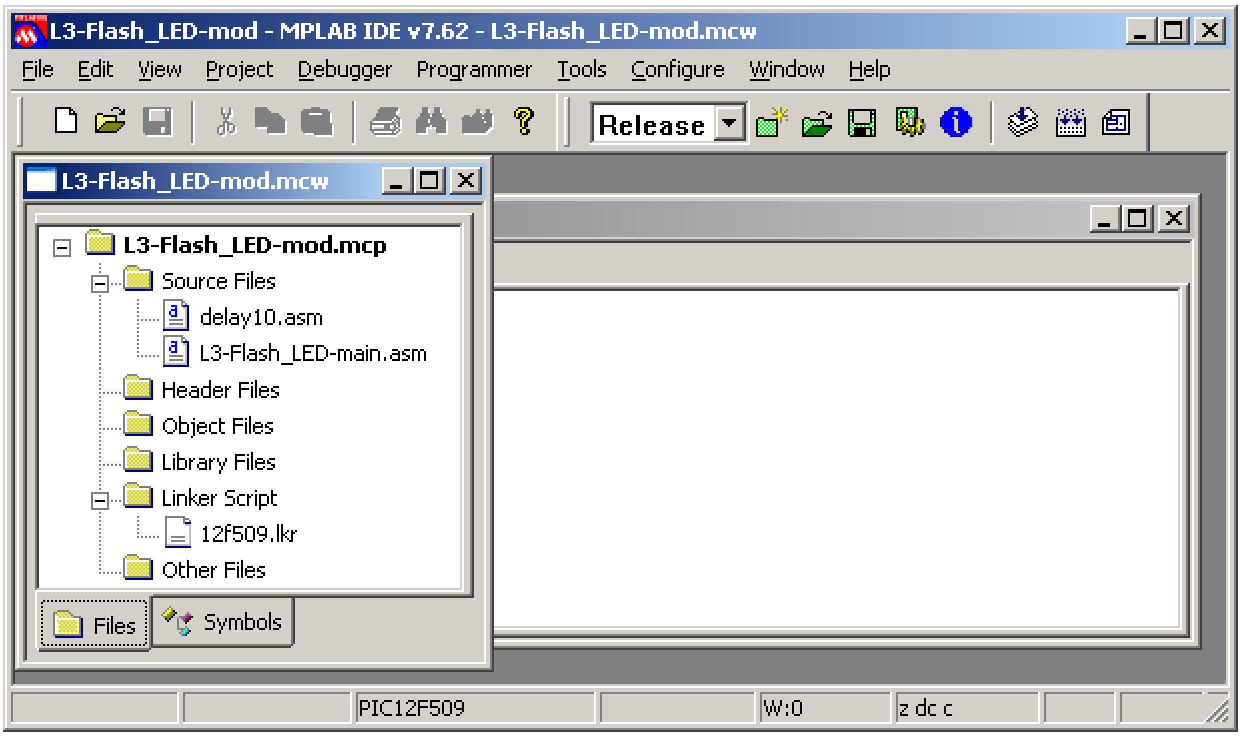

Project Wizard

Step Four:
Add existing files to your project

Lesson 3
delay10.asm
L2-Flash_LED.a
L3-Flash_LED-m
L3-Flash_LED-m
L3-Flash_LED-m
L3-Flash_LED-su
L3-Flash_LED-su
L3-Flash_LED-su
L3-Flash_LED-su
L3-Flash_LED-su
L3-Flash_LED-su

S C:\Program Files\Microchip\MPAS
U C:\Work\Gooligum\Tutorials\Less
C L3-Flash_LED-main.asm | C:\Work

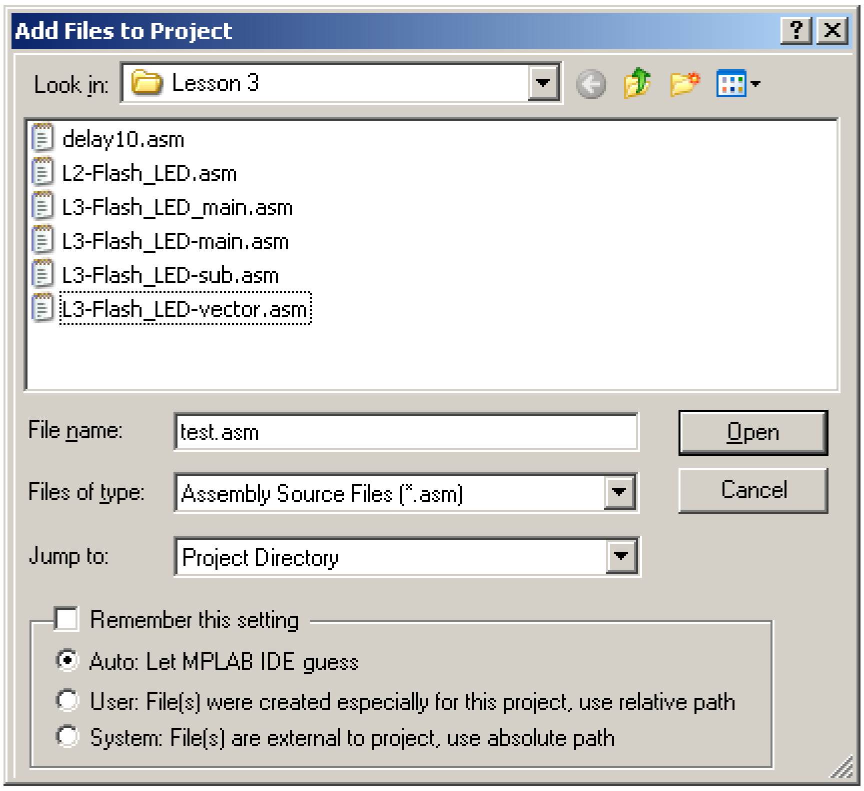
After clicking on “Next >” and then “Finish”, you will see that your project now contains both source files:


L3-Flash_LED-mod - MPLAB IDE v7.62 - L3-Flash_LED-mod.mcw
File Edit View Project Debugger Programmer Tools Configure Window Help
Release
L3-Flash_LED-mod.mcw
Files
Symbols
PIC12F509
W:0
z dc c

- L3-Flash_LED-mod.mcp
  - Source Files
    - delay10.asm
    - L3-Flash_LED-main.asm
  - Header Files
  - Object Files
  - Library Files
  - Linker Script
    - 12f509.lkr
  - Other Files

Of course there are a number of ways to create a multiple-file project.

If you simply want to add an existing file (or files) to a project, you can right-click on “Source Files” in the project window, then select “Add Files” from the context menu, or else select the “Project → Add Files to Project…” menu item. Either way, you will be presented with the window shown on the right. As you can see, it gives you the option, for each file, to specify whether it is a user (relative path) or system (absolute path) file.



delay10.asm
L2-Flash_LED.asm
L3-Flash_LED_main.asm
L3-Flash_LED-main.asm
L3-Flash_LED-sub.asm
L3-Flash_LED-vector.asm

File name: test.asm
Files of type: Assembly Source Files (*.asm)
Jump to: Project Directory

Remember this setting
- [✓ Auto: Let MPLAB IDE guess]
- User: File(s) were created especially for this project, use relative path
- System: File(s) are external to project, use absolute path

Or if you want to create a new file from scratch, instead of using an existing one, use the “Project → Add New File to Project…” menu item (also available under the File menu). You’ll be presented with a blank editor window, into which you can copy text from other files (or simply start typing!).

However you created them, now that you have a project which includes the two source files, we can consider their content…

### *Creating a Relocatable Module*

Converting an existing subroutine, such as our ‘delay10’ routine, into a standalone, relocatable module is easy. All you need to do is to declare any symbols (address labels or variables) that need to be accessible from other modules, using the `GLOBAL` directive.

For example:

```
    #include    <p12F509.inc>   ; any baseline device will do

    GLOBAL      delay10_R


;***** VARIABLE DEFINITIONS
        UDATA
dc1     res 1                   ; delay loop counters
dc2     res 1
dc3     res 1


;************************************************************************
        CODE

delay10_R                       ; delay W x 10ms
        banksel dc3             ; -> ?+1+Wx(3+10009+3)-1+4 = Wx10.015ms
        movwf   dc3
dly2    movlw   .13             ; repeat inner loop 13 times
        movwf   dc2             ; -> 13x(767+3)-1 = 10009 cycles
        clrf    dc1             ; inner loop = 256x3-1 = 767 cycles
dly1    decfsz  dc1,f
        goto    dly1
        decfsz  dc2,f           ; end middle loop
        goto    dly1
        decfsz  dc3,f           ; end outer loop
        goto    dly2

        retlw   0


        END
```

This is the subroutine from the earlier example, with a `CODE` directive at the beginning of it, and the `UDATA` directive to reserve the data memory it needs. And toward the start, a `GLOBAL` directive has been added, declaring that the ‘`delay10_R`’ label is to be made available (*exported*) to other modules, so that they can call this subroutine.

You should also include (pardon the pun) a ‘`#include`’ directive, to define any “standard” symbols used in the code, such as the instruction destinations ‘`w`’ and ‘`f`’. This delay routine will work on any baseline PIC; it’s not specific to any, so you can use the include file for any of the baseline PICs, such as the 12F509. Note that there is no `list` directive; this avoids the processor mismatch errors that would be reported if you specify more than one processor in the modules comprising a single project.

Of course it’s also important to add a block of comments at the start; they should describe what this module is for, how it is used, any effects it has (including side effects, such as returning ‘0’ in the W register), and any assumptions that have been made. In this case, it is assumed that the processor is clocked at exactly 4 MHz.

### *Calling Relocatable Modules*

Having created an *external* relocatable module (i.e. one in a separate file), we need to declare, in the main (or *calling*) file any labels we want to use from the module being called , so that the linker knows that these labels are defined in another module.  That's done with the `EXTERN` directive.

For example:

```
    list        p=12F509
    #include    <p12F509.inc>

    EXTERN      delay10_R       ; W x 10ms delay


;***** CONFIGURATION
                ; ext reset, no code protect, no watchdog, 4Mhz int clock
    __CONFIG    _MCLRE_ON & _CP_OFF & _WDT_OFF & _IntRC_OSC


;***** VARIABLE DEFINITIONS
        UDATA_SHR
sGPIO   res 1                   ; shadow copy of GPIO


;************************************************************************
RESET   CODE    0x000           ; effective reset vector
        movwf   OSCCAL          ; update OSCCAL with factory cal value
        pagesel start
        goto    start           ; jump to main code

;***** Subroutine vectors
delay10                         ; delay W x 10ms
        pagesel delay10_R
        goto    delay10_R


;***** MAIN PROGRAM
MAIN    CODE

;***** Initialisation
start
        movlw   b'111101'       ; configure GP1 (only) as an output
        tris    GPIO

        clrf    sGPIO           ; start with shadow GPIO zeroed

;***** Main loop
flash
        movf    sGPIO,w         ; get shadow copy of GPIO
        xorlw   b'000010'       ; flip bit corresponding to GP1 (bit 1)
        movwf   GPIO            ; write to GPIO
        movwf   sGPIO           ; and update shadow copy
        movlw   .50
        pagesel delay10
        call    delay10         ; delay 500ms -> 1Hz at 50% duty cycle

        pagesel flash
        goto    flash           ; repeat forever

        END
```

This is the main loop from the "Flash an LED" program from lesson 2, with the inline delay routine replaced with a call to the "delay10" routine, and the variables used by the delay routine removed. And toward the start of the program, an `EXTERN` directive has been added, to declare that the '`delay10_R`' label is a reference to another module. Note that a subroutine vector is still used, as it is not possible to know where in program memory the linker will place the subroutine.

Also note that the shadow register is declared as a shared variable in a `UDATA_SHR` segment, so there is no need to use `banksel` before accessing it.

To summarise:

- The `GLOBAL` and `EXTERN` directives work as a pair.
- `GLOBAL` is used in the file that defines a module, to export a symbol for use by other modules.
- `EXTERN` is used when calling external modules. It declares that a symbol has been defined elsewhere.

### *Complete programs*

Here are the modular delay and main flash routines, illustrating the use of external modules, banked and shared registers and page selection:

#### delay10.asm

```
;************************************************************************
;                                                                       *
;   Filename:      delay10.asm                                          *
;   Date:          22/9/07                                              *
;   File Version:  1.1                                                  *
;                                                                       *
;   Author:        David Meiklejohn                                     *
;   Company:       Gooligum Electronics                                 *
;                                                                       *
;************************************************************************
;                                                                       *
;   Architecture:  Baseline PIC                                         *
;   Processor:     any                                                  *
;                                                                       *
;************************************************************************
;                                                                       *
;   Files required: none                                                *
;                                                                       *
;************************************************************************
;                                                                       *
;   Description:    Variable Delay : N x 10ms (10ms - 2.55s)            *
;                                                                       *
;       N passed as parameter in W reg                                  *
;       exact delay = W x 10.015ms                                      *
;                                                                       *
;   Returns: W = 0                                                      *
;   Assumes: 4MHz clock                                                 *
;                                                                       *
;************************************************************************

    #include    <p12F509.inc>   ; any baseline device will do

    GLOBAL      delay10_R
```

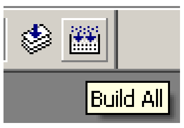
```
;***** VARIABLE DEFINITIONS
        UDATA
dc1     res 1                   ; delay loop counters
dc2     res 1
dc3     res 1


;************************************************************************
        CODE

delay10_R                       ; delay W x 10ms
        banksel dc3             ; -> ?+1+Wx(3+10009+3)-1+4 = Wx10.015ms
        movwf   dc3
dly2    movlw   .13             ; repeat inner loop 13 times
        movwf   dc2             ; -> 13x(767+3)-1 = 10009 cycles
        clrf    dc1             ; inner loop = 256x3-1 = 767 cycles
dly1    decfsz  dc1,f
        goto    dly1
        decfsz  dc2,f           ; end middle loop
        goto    dly1
        decfsz  dc3,f           ; end outer loop
        goto    dly2

        retlw   0

        END
```

### L3-Flash_LED-main.asm

```
;************************************************************************
;   Filename:      L3-Flash_LED-main.asm                                *
;   Date:          22/9/07                                              *
;   File Version:  1.1                                                  *
;                                                                       *
;   Author:        David Meiklejohn                                     *
;   Company:       Gooligum Electronics                                 *
;                                                                       *
;************************************************************************
;   Architecture:  Baseline PIC                                         *
;   Processor:     12F508/509                                           *
;                                                                       *
;************************************************************************
;                                                                       *
;   Files required: delay10.asm     (provides W x 10ms delay)           *
;                                                                       *
;************************************************************************
;                                                                       *
;   Description:    Lesson 3, example 3                                 *
;                                                                       *
;   Demonstrates how to call external modules                           *
;                                                                       *
;   Flashes a LED at approx 1Hz.                                        *
;   LED continues to flash until power is removed.                      *
;                                                                       *
;************************************************************************
;                                                                       *
;   Pin assignments:                                                    *
;       GP1 - flashing LED                                              *
;                                                                       *
;************************************************************************
```

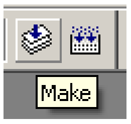
```
    list        p=12F509
    #include    <p12F509.inc>

    EXTERN      delay10_R       ; W x 10ms delay


;***** CONFIGURATION
                ; ext reset, no code protect, no watchdog, 4Mhz int clock
    __CONFIG    _MCLRE_ON & _CP_OFF & _WDT_OFF & _IntRC_OSC


;***** VARIABLE DEFINITIONS
        UDATA_SHR
sGPIO   res 1                   ; shadow copy of GPIO


;************************************************************************
RESET   CODE    0x000           ; effective reset vector
        movwf   OSCCAL          ; update OSCCAL with factory cal value
        pagesel start
        goto    start           ; jump to main code

;***** Subroutine vectors
delay10                         ; delay W x 10ms
        pagesel delay10_R
        goto    delay10_R


;***** MAIN PROGRAM
MAIN    CODE

;***** Initialisation
start
        movlw   b'111101'       ; configure GP1 (only) as an output
        tris    GPIO

        clrf    sGPIO           ; start with shadow GPIO zeroed

;***** Main loop
flash
        movf    sGPIO,w         ; get shadow copy of GPIO
        xorlw   b'000010'       ; flip bit corresponding to GP1 (bit 1)
        movwf   GPIO            ; write to GPIO
        movwf   sGPIO           ; and update shadow copy
        movlw   .50
        pagesel delay10
        call    delay10         ; delay 500ms -> 1Hz at 50% duty cycle

        pagesel flash
        goto    flash           ; repeat forever


        END
```

## The Build Process (Revisited)



In a multiple-file project, when you select the "Project → Build All" menu item, or click on the "Build All" toolbar icon, the assembler will assemble all the source files, producing a new '.o' *object file* for each. The linker then combines these '.o' files to build a single '.hex' file, containing an image of the executable code to be programmed into the PIC.

If, however, you've been developing a multi-file project, and you've already built it, and then go back and alter just one of the source files, there's no need to re-assemble all the other source files, if they haven't changed. The object files corresponding to those unchanged source files will still be there, and they'll still be valid.



That's what the "Project → Make" menu item (and the "Make" toolbar icon) does, as was discussed briefly in lesson 1. Like "Build All", it builds your project, but it only assembles source files which have a newer date stamp than the corresponding object file. This is what you normally want, to save unnecessary assembly time (not that it makes much difference with such a small project!), so MPLAB includes a handy shortcut for "Make" – just press 'F10'.

After you build (or make) the project, you'll see a number of new files in the project directory. In addition to your '.asm' source files and the '.o' object files and the '.hex' output file we've already discussed, you'll find a '.lst' file corresponding to each of the source files, and '.lst' and '.map' files corresponding to the project name.

I won't describe these in detail, but they are worth looking at if you are curious about the build process. And they can be valuable to refer to if you when debugging, as they show exactly what the assembler and linker are doing.

The '.lst' *list files* show the output of the assembler; you can see the opcodes corresponding to each instruction. They also show the value of every label. But you'll see that, for the list files belonging to the source files (e.g. 'delay10.lst'), they contain a large number of question marks. For example:

```
0000                 00047 delay10_R               ; delay W x 10ms
0000   ???? ????     00048         banksel dc3     ; -> ?+1+Wx(3+10009+3)-1+4 = Wx10.015ms
0002   00??          00049         movwf   dc3
0003   0C0D          00050 dly2    movlw   .13     ; repeat inner loop 13 times

0004   00??          00051         movwf   dc2     ; -> 13x(767+3)-1 = 10009 cycles
0005   00??          00052         clrf    dc1     ; inner loop = 256x3-1 = 767 cycles
0006   02??          00053 dly1    decfsz  dc1,f
0007   0A??          00054         goto    dly1
0008   02??          00055         decfsz  dc2,f   ; end middle loop
0009   0A??          00056         goto    dly1
000A   02??          00057         decfsz  dc3,f   ; end outer loop
000B   0A??          00058         goto    dly2
                     00059
000C   0800          00060         retlw   0
```

The `banksel` directive is completely undefined at this point; even the instruction hasn't been decided, so it's shown as '`???? ????`'. It can't be defined, because the location of '`dc3`' is unknown.

Similarly, many of the instruction opcodes are only partially complete. The question marks can't be filled in, until the location of all the data and program labels is known.

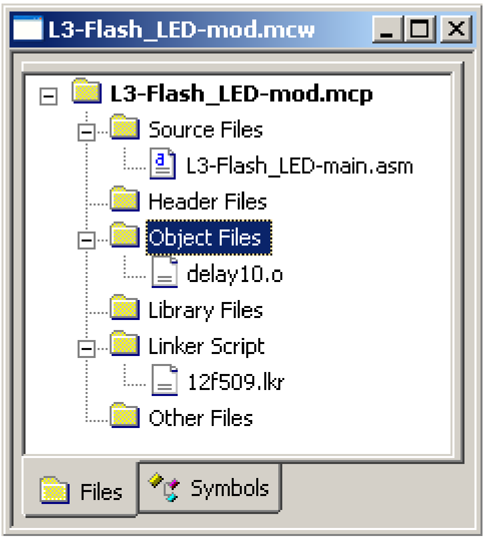
Assigning locations to the various objects is the linker's job, and you can see the choices it has made by looking at the '.map' *map file*. It shows where each section will be placed, and what the final data and program addresses are. For example:

```
                              Section Info
                  Section       Type    Address   Location Size(Bytes)
                --------- --------- --------- --------- ---------
                    RESET      code   0x000000   program   0x00000a
                   .cinit   romdata   0x000005   program   0x000004
```

```
            .code       code    0x000007    program    0x00001a
             MAIN       code    0x000014    program    0x000018
            RCCAL       code    0x0003ff    program    0x000002
          .config       code    0x000fff    program    0x000002
      .udata_shr      udata    0x000007       data    0x000001
           .udata      udata    0x000010       data    0x000003

                   Program Memory Usage
                    Start          End
                 ----------   ----------
                  0x000000     0x00001f
                  0x0003ff     0x0003ff
                  0x000fff     0x000fff
   34 out of 1029 program addresses used, program memory utilization is 3%

                   Symbols - Sorted by Name
             Name    Address    Location    Storage File
        ---------- ---------- ---------- ---------- ---------
          delay10   0x000003    program     static C:\...\L3-Flash_LED-main.asm
        delay10_R   0x000007    program     extern C:\...\delay10.asm
             dly1   0x00000d    program     static C:\...\delay10.asm
```

These addresses are then reflected in the project '.lst' file, which shows the final assembled code, with all the actual instruction opcodes, with fully resolved addresses, that will be loaded into the PIC.

### *Including Object Files*



When a module has been assembled, it's not necessary to have the source code to be able to use that module in a project. Instead you can include the object file directly.

To see how that is done, right-click on 'delay10.asm' in the workspace window, then select "Remove" to remove it from the project.

Then right-click on "Object Files" and select "Add Files…". This will open a dialog box where you can select the 'delay10.o' file and add it to your project. You should end up with a workspace window similar to that shown at right, with one source file and one object file included in the project.

If you now do a "Build All", only the 'Flash_main.asm' source file will be assembled. The 'delay10.o' object file is used as-is.

However, object modules are less flexible than source modules because an object file is only valid for the specific processor that it was built for. You couldn't for example link the 'delay10.o' file assembled for the PIC12F509 into a project being built for another processor, such as the PIC16F505. You'd have to include the assembler source file ('delay10.asm') instead.

*Note: the processor types of all files included in a project must match.*

*An object file can only be linked into a project if it was assembled for the same type of processor as the device selected for the project.*

When you have collected a number of modules for various functions, you can use the MPLIB librarian program to build a *library*, containing the object code for these modules. You can then include the library in your project, instead of the individual object file. That can be very useful when you have a suite of related modules, such as floating point maths functions. The linker will only include the objects that your code references, not the whole library, so there is no penalty for using a library file. We won't go into any detail on building a library here, but you to be aware that they exist, in case you want to look up the details for yourself later.

That’s enough for now. We’ve been flashing LEDs for a while; it’s time to move on.

In the next lesson we’ll look at reading and responding to switches, such as pushbuttons. And since real switches “bounce”, and that can be a problem for microcontroller applications, we’ll look at ways to “debounce” them.