Keil C51 Cross Compiler

- ANSI C Compiler
  - Generates fast compact code for the 8051 and it's derivatives
- Advantages of C over Assembler
  - Do not need to know the microcontroller instruction set
  - Register allocation and addressing modes are handled by the compiler
  - Programming time is reduced
  - Code may be ported easily to other microcontrollers
    - (not 100% portable)
- C51 supports a number of C language extensions that have been added to support the 8051 microcontroller architecture e.g.
  - Data types
  - Memory types
  - Pointers
  - Interrupts

C vs Assembly Language

Code efficiency can be defined by 3 factors: -

1. How long does it take to write the code
2. What size is the code? (how many Bytes of code memory required?)
3. How fast does the code run?

- C is much quicker to write and easier to understand and debug than assembler.

- Assembler will normally produce faster and more compact code than C
  - Dependant on C compiler
  - A good knowledge of the micro architecture and addressing modes will allow a programmer to produce very efficient C code

C51 Keywords

Keywords

To facilitate many of the features of the 8051, the **Cx51** compiler adds a number of new keywords to the scope of the C language:

_at_	**far**	**sbit**
alien	**idata**	**sfr**
bdata	**interrupt**	**sfr16**
bit	**large**	**small**
code	**pdata**	**_task_**
compact	**_priority_**	**using**
data	**reentrant**	**xdata**

C51 Data Types

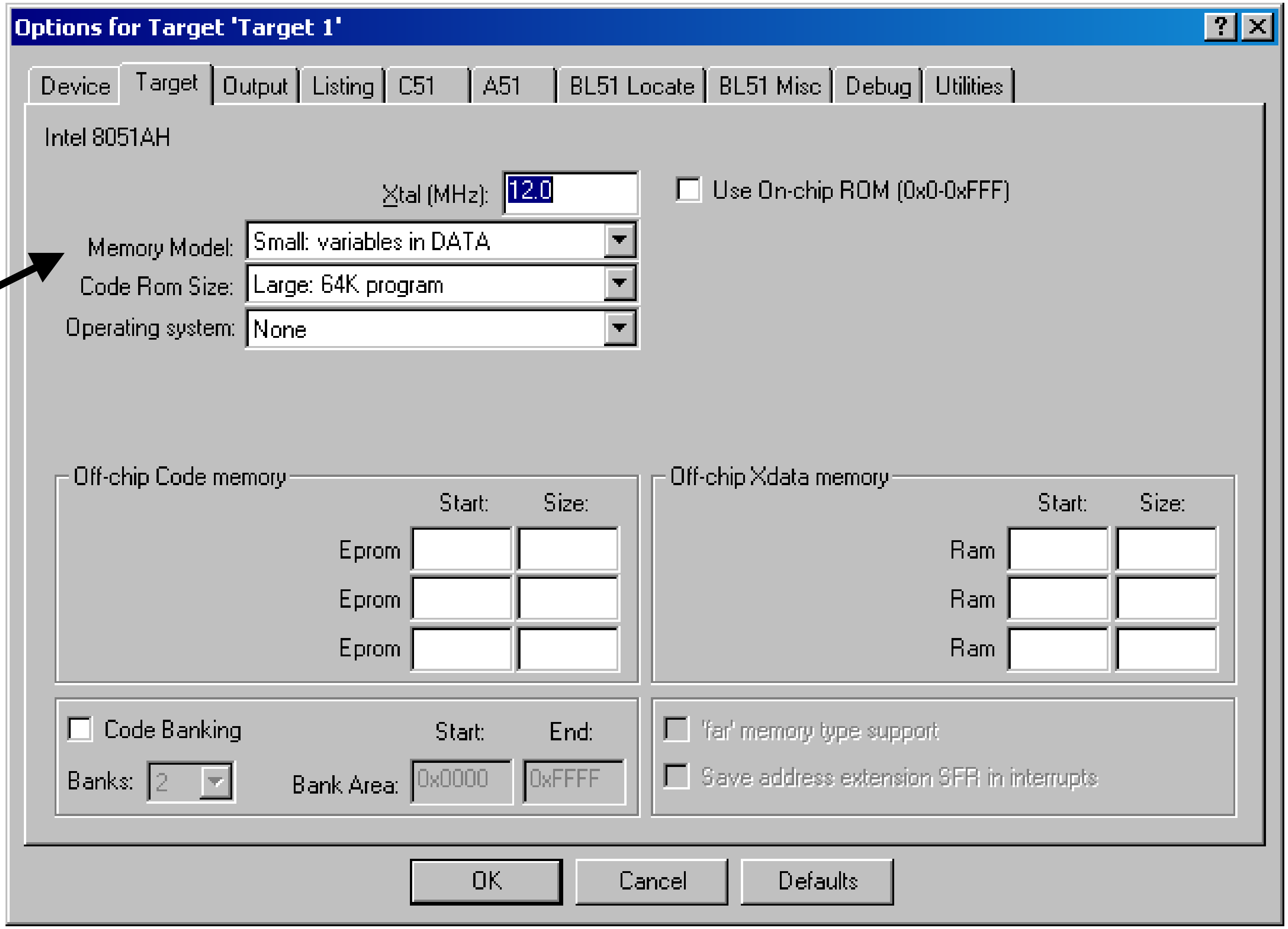
Data Types	Bits	Bytes	Value Range
bit †	1		0 to 1
signed char	8	1	-128 to +127
unsigned char	8	1	0 to 255
enum	8 / 16	1 or 2	-128 to +127 or –32768 to +32767
signed short	16	2	-32768 to +32767
unsigned short	16	2	0 to 65535
signed int	16	2	-32768 to +32767
unsigned int	16	2	0 to 65535
signed long	32	4	-2147483648 to +2147483647
unsigned long	32	4	0 to 4294967295
float	32	4	±1.175494E-38 to ±3.402823E+38
sbit †	1		0 or 1
sfr †	8	1	0 to 255
sfr16 †	16	2	0 to 65535

† = extension to ANSI C

C51 Memory Models

- Small
  - All variables stored in internal data memory
    - Be careful – stack is placed here too
  - Generates the fastest, most efficient code
  - Default model for Keil uVision Projects
- Compact
  - All variables stored in 1 page (256 bytes) of external data memory
  - Accessed using MOVX @R0
  - Slower than small model, faster than large model
- Large
  - All variables stored in external data memory (up to 64KByte)
  - Accessed using MOVX @DPTR
  - Generates more code than small or compact models

C51 Memory Models



Select Model

C51 Memory Types

- Memory type extensions allow access to all 8051 memory types.
  - A variable may be assigned to a specific memory space
  - The memory type may be explicitly declared in a variable declaration
    - *variable_type <memory_type> variable_name;*
    - *e.g. int data x;*

- Program Memory
  - CODE memory type
  - Up to 64Kbytes (some or all may be located on 8051 chip)

- Data Memory
  - 8051 derivatives have up to 256 bytes of internal data memory
  - Lower 128 bytes can be directly or indirectly addressed
  - Upper 128 bytes shares the same address space as the SFR registers and can only be indirectly addressed
  - Can be expanded to 64KBytes off-chip

C51 Memory Types

- **code**
  - Program memory (internal or external).
  - *unsigned char code const1 = 0x55;* *//define a constant*
  - *char code string1[] = “hello”;* *//define a string*

- **data**
  - Lower 128 bytes of internal data memory
  - Accessed by direct addressing (fastest variable access)
  - *unsigned int data x;* *//16-bit variable x*

- **idata**
  - All 256 bytes of internal data memory (8052 micro)
  - Accessed by indirect addressing (slower)

C51 Memory Types

- **bdata**
  - Bit addressable area of internal data memory (addresses 20H to 2FH)
  - Allows data types that can be accessed at the bit level
  - *unsigned char bdata status;*
  - *sbit flag1 = status^0;*

- **xdata**
  - External data memory
  - Slower access than internal data memory
  - *unsigned char xdata var1;*

8051 Memory Usage

- In a single chip 8051 application data memory is scarce
  - 128 or 256 bytes on most 8051 derivatives
- Always declare variables as the smallest possible data type
  - Declare flags to be of type bit
  - Use chars instead of ints when a variable’s magnitude can be stored as 8 bits
- Use code memory to store constants and strings

Example Code (1)

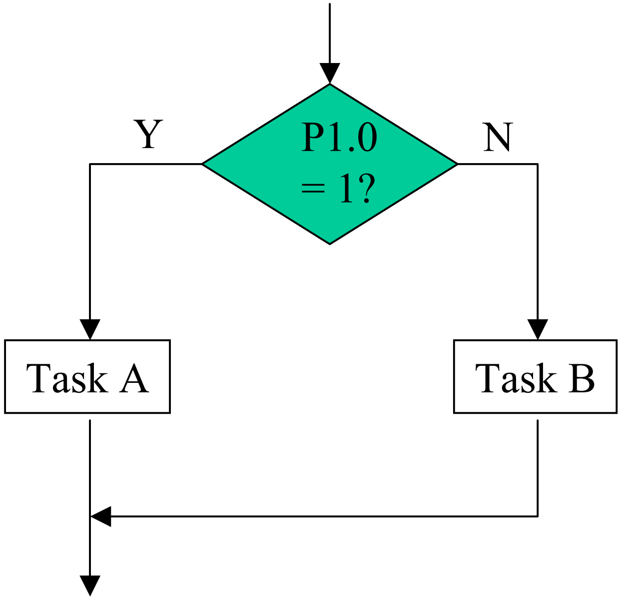
```
sbit input = P1^0;
void main()
{
    unsigned char status;
    int x;

    for(x=0;x<10;x++)
    {
        status = input;
    }
}
```

- How can the variable declarations be improved?

Program Branching

- Most embedded programs need to make some decisions
  - e.g. perform a certain task only if a switch input is high
- An if-else statement is the most common method of coding a decision box of a flowchart.




```
if (P1^0 == 1)
{
    //task A
}
else
{
    //task B
}
```

  - Note that the brackets are only required if the if or else statement contains more then 1 line of code

Wait Loops

- In some applications the program must wait until a certain condition is true before progressing to the next program task (wait loop)
  - e.g. in a washing machine wait for the water to heat before starting the wash cycle

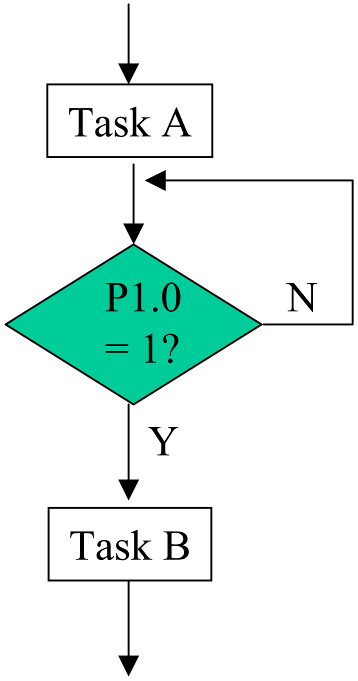
- A while statement is often used here

//task A

while(P1^0 == 0);   //will stay here while P1.0 is low

//can also write as while(P1^0 == 0) {}

//task B



Continuous Loops

- An embedded program never ends
  - It must contain a main loop than loops continuously
  - e.g. a washing machine program continually tests the switch inputs

- A continuous loop is programmed using a loop with no condition
  - *while(1){ }*
  - *while(1);*
  - *for(;;){ }*
  - *for(;;);*

C Bitwise Operators

- NOT ~
  char data x = 0x05;
  x = ~x; //x=0xFA
- AND &
  char data x = 0x45;
  x &= 0x0F; //x = 0x05
  - Useful for clearing specific bits within a variable (masking)
- OR |
  char data x = 0x40;
  x |= 0x01; //x = 0x41
  - Useful for setting individual bits within a variable
- EXCLUSIVE OR ^
  char data x = 0x45;
  x ^= 0x0F; //x = 0x4A
  - Useful for inverting individual bits within a variable

Question

- What is the value of variable x after the following code executes?

```
unsigned char data x;
x = 21;
x &= 0xF0;
x |= 0x03;
```

- Write C code to set the upper 4 bits of a char to “1100”.

C Logical Operators

- Bitwise operators will change certain bits within a variable

- Logical operators produce a true or false answer
  - They are used for looping and branching conditions

- C Logical Operators
  - AND &&
  - OR ||
  - Equals = =
  - Not Equal !=
  - Less <
  - Less or Equal <=
  - Greater >
  - Greater or Equal >=

Example Code (2)

```
//program to add 2 8-bit variables
//a flag should be set if the result exceeds 100
void main()
{
    unsigned char data num1, num2;
    unsigned int data result;
    bit overflow;

    num1 = 10;
    num2 = 25;
    result = num1 + num2;
    if (result >100)
        overflow = 1;
}
```

Accessing Port Pins

- Writing to an entire port

```
P2 = 0x12;          //Port 2 = 12H (00010010 binary)
P2 &= 0xF0;         //clear lower 4 bits of Port 2
P2 |= 0x03;         //set P2.0 and P2.1
```

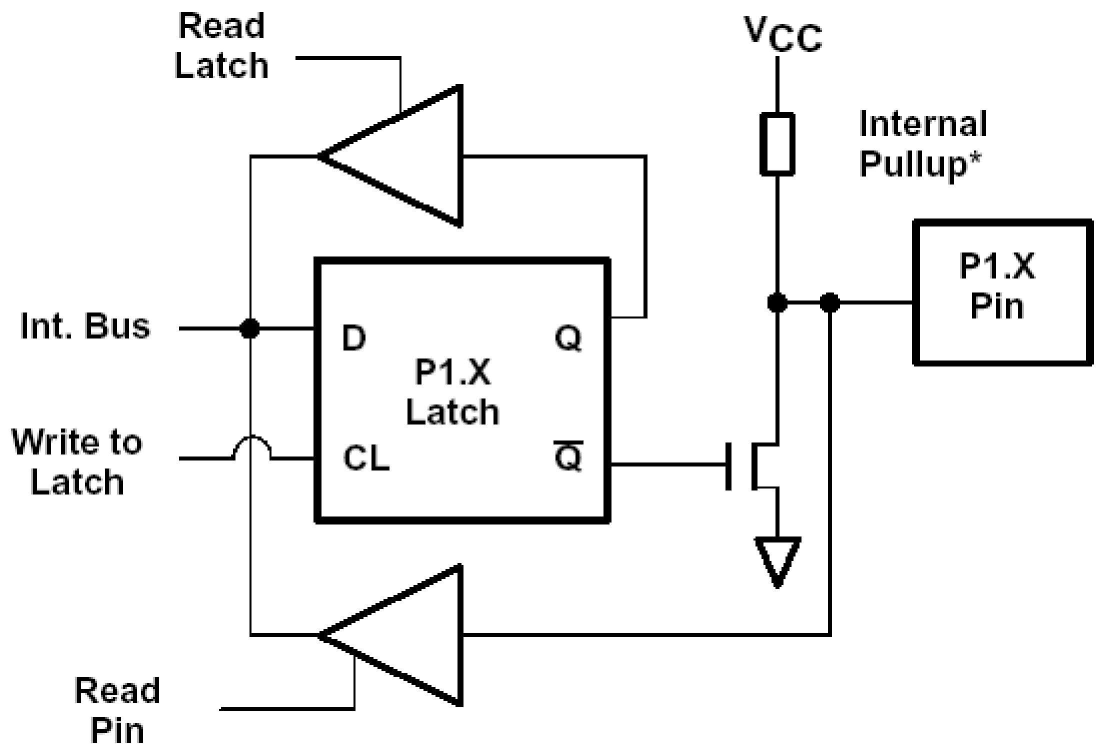
- Reading from a port

```
unsigned char data status;
status = P1;        //read from Port 1
```

  – Before reading from a port pin, always write a ‘1’ to the pin first.

Reading 8051 Port Pins

- We can only read the proper logic value of a pin if the latch contains a ‘1’.
  - If the latch contains a ‘0’ the FET is on and a ‘0’ will always be read.



Example Code (3)

```
//Program to read from 8 switches connected to Port 1. The status of the switches
//is written to 8 LEDs connected to Port 2.
#include <reg51.h>                          //SFR address definitions
void main()
{
    unsigned char data status;              //variable to hold switch status

    //continuous loop to read switches and display the status
    while(1)
    {
        status = P1;
        P2 = status;
    }
}
```

Accessing Individual Port Pins

- Writing to a port pin

  //write a logic 1 to port 0 pin 1

  P0^1 = 1;

- In a program using lots of individual port pins it is better coding practice to name the pins according to their function

  sbit power_led = P0^1;

  power_led = 1;

- Reading from a port pin

  //Turn on LED if switch is active

  sbit switch_input = P2^0;

  if (switch_input)

  power_led = 1;

  else

  power_led = 0;

Example Code (4)

```
//program to flash an LED connected to Port 2 pin 0 every 0.2 seconds
#include <reg51.h>
sbit LED = P2^0;
void delay();
void main()
{
    while (1)
    {
        LED = 0;    //LED off
        delay();
        LED = 1;    //LED on
        delay();
    }
}

//Delay function
void delay()
{
…….
}
```

Generating Delays

- Software Delays
  - Uses looping mechanisms in C or assembly
  - Does not use any microcontroller hardware resources
  - Ties up the CPU while the delay is running
  - Delay produced depends on the compiler

- Hardware Delays
  - Uses a microcontroller timer
  - Uses very little CPU resources (runs in background)

Software Delay

- Use a for loop
  - Does not use any timer resources
  - Uses CPU resources while running
    - i.e. no other task can be performed during delay loop
  - Can result in large amounts of machine code being generated
  - Results may be different for different compilers
- The following code results in a 204 usecond delay for the 8051 operating off the 12MHz oscillator
- For loops can be nested to produce longer delays

```
void delay()
{
    unsigned char x;
    for (x=100; i > 0; x--);
}
```

Software Delay

```
line level    source

   1          #include <REG51.H>
   2          sbit OUTPUT = P1^0;
   3          void main()
   4          {
   5   1              unsigned char x;
   6   1              while(1)
   7   1              {
   8   2                      OUTPUT = ~OUTPUT;
   9   2                      for(x=100;x>0;x--);
  10   2              }
  11   1      }
  12
C51 COMPILER V7.10   DELAY_FOR_LOOP

ASSEMBLY LISTING OF GENERATED OBJECT CODE


             ; FUNCTION main (BEGIN)
                                                      ; SOURCE LINE # 3
                                                      ; SOURCE LINE # 4
0000         ?C0001:
                                                      ; SOURCE LINE # 6
                                                      ; SOURCE LINE # 7
                                                      ; SOURCE LINE # 8
0000 B290              CPL     OUTPUT
                                                      ; SOURCE LINE # 9
;---- Variable 'x' assigned to Register 'R7' ----
0002 7F64              MOV     R7,#064H
0004         ?C0003:
0004 DFFE              DJNZ    R7,?C0003
0006 80F8              SJMP    ?C0001
             ; FUNCTION main (END)
```

Using a decrementing for loop will generate a DJNZ loop.
Loop execution time =
204 machine cycles
[1 + 1 + (100 *2) + 2]
= 204usec for a 12MHz crystal.
Change starting value to 98 to get a 200usec delay

Hardware Delay

- Use timer 0 or timer 1
  - Very efficient mechanism of producing accurate delays
  - Timer mode, control and counter registers must be configured
  - Timer run bit is used to start/stop the timer
  - The timer flag can be polled to determine when required time delay has elapsed
  - Using timer in interrupt mode uses very little CPU resources

- See timer notes for more details

C51 Functions

- Can specify
  - Register bank used
  - Memory Model
  - Function as an interrupt
  - Re-entrancy
- *[return_type] func_name([args]) [model] [re-entrant] [interrupt n] [using n]*

```
int square(int x)
{
        return(x * x);
}
```

Re-entrant Functions

- A re-entrant function is a function that can be called while it is still running.
  - e.g. an interrupt occurs while the function is running and the service routine calls the same function.

- Keil compiler supports re-entrant functions.
  - Beware of stack limitations

Scope of Variables

- A variable defined within a function will default to an **automatic** variable
  - An automatic variable may be overlaid i.e. the linker may use the variable's memory space for a variable in another function call.
  - This will cause the variable to lose it's value between function calls.

- If you want a variable to maintain it's value between function calls, declare it as a **static** variable.
  - *static int x;*
  - Static variables cannot be overlaid by the linker

- Declare a variable as **volatile** if you want it's value to be read each time it is used

Function Parameter Passing

- Up to 3 arguments may be passed in registers
  - This improves system performance as no memory accesses are required
  - If no registers are available fixed memory locations are used

Argument Number	char, 1-byte ptr	int, 2-byte ptr	long, float	generic ptr
1	R7	R6 & R7	R4—R7	R1—R3
2	R5	R4 & R5	R4—R7	R1—R3
3	R3	R2 & R3		R1—R3

Function Return Values

- Function return values are always passed in registers

Return Type	Register	Description
bit	Carry Flag	
char, unsigned char, 1-byte ptr	R7	
int, unsigned int, 2-byte ptr	R6 & R7	MSB in R6, LSB in R7
long, unsigned long	R4-R7	MSB in R4, LSB in R7
float	R4-R7	32-Bit IEEE format
generic ptr	R1-R3	Memory type in R3, MSB R2, LSB R1

Interrupt Functions

- Interrupt vector number is provided in the function declaration
  - *void timer0_int() interrupt 1 using 2*
    {
    ....
    }
- *Contents of A, B, DPTR and PSW are saved on stack when required*
- *All working registers used in the ISR are stored on the stack if the using attribute is not used to specify a register bank*
- *All registers are restored before exiting the ISR*

Interrupt Number	Interrupt Description	Address
0	EXTERNAL INT 0	0003h
1	TIMER/COUNTER 0	000Bh
2	EXTERNAL INT 1	0013h
3	TIMER/COUNTER 1	001Bh
4	SERIAL PORT	0023h

Absolute Variable Location

- The _at_ keyword is used to assign an absolute memory address to a variable
  - Useful for accessing memory mapped peripherals or specific memory locations
  - Syntax
    - type [memory_space] variable_name _at_ constant
    - *unsigned char xdata lcd _at_ 0x8000*
  - Absolute variables may not be initialised

C51 Pointers

- Generic pointers
  - Same as ANSI C pointers
  - *char *ptr;*
  - Stored using 3 bytes
  - Can be used to access any memory space
  - Code generated executes more slowly than memory specific pointers
- Memory Specific Pointers
  - Specify the memory area pointed to
  - *char data *ptr1; //pointer to char in data memory*
  - Stored as 1 (data, idata) or 2 bytes (code or xdata)
  - Can also specify where pointer is stored
    - *char data * xdata ptr2; //pointer to data stored in xdata*