Embedded C Routines for the Micromite

MMBasic for the Micromite allows a BASIC program to load a machine code module and execute the code in that module. Because the module is written in the C language it can run much faster than a BASIC program and can more easily access the special hardware features of the PIC32 microcontroller.

However, it does require that the programmer has experience with programming in C (not an easy subject to learn) and has a good working knowledge of MPLAB X and programming for the PIC32. This guide provides an outline of how to write an embedded C module but it does not explain how to write C programs. For a good introduction to C see: http://microchip.wikidot.com/tls2101:start

CFunctions and CSubs

Two types of embedded modules are supported in MMBasic (ver 5.0 or greater). These are a CSub which is a subroutine (ie, it is used as a command) and a CFunction which is a function (ie, it can be used in expressions and returns a value). Both are similar and will be referred to in this tutorial as "embedded C routines".

Learning to Create Embedded C Routines

Peter Mather (matherp on the Back Shed forum) has produced an excellent series of tutorials which describe how to write CFunctions by example. They are recommended reading for anyone new to this subject: http://www.thebackshed.com/forum/forum_posts.asp?TID=7965
http://www.thebackshed.com/forum/forum_posts.asp?TID=7973
and http://www.thebackshed.com/forum/forum_posts.asp?TID=8038

Another good resource is the embedded C routines included with the Micromite firmware (http://geoffg.net/micromite.html#Downloads). Most routines include the C source code and it is recommended that you experiment by recompiling and modifying some these before writing your own routines. That way the compiler and tools can be verified as working correctly.

Writing an Embedded Routine

An embedded C routine can accept up to ten arguments and, in the case of a CFunction, returns a 64-bit integer. All arguments passed to the embedded routine are pointers to the memory allocated to a variable or the result of an expression. They can be pointers to integers, strings or an array of integers or strings. Floating point constants and variables can also be passed but they need to be handled carefully within the embedded C routine as the C compiler will generate invalid code for normal floating point operations.

There are a few points to note:

- A CFunction returns a value which is a 64-bit integer (a long long int in C). A CSub does not return a value and MMBasic will ignore it if it is provided.
- Because the arguments are pointers to the memory allocated to the variables in MMBasic your C program can modify this memory and this is another way of returning data to MMBasic. If you pass an expression the argument will be a pointer to the result of the expression (integer or string) but changing it will not achieve anything.
- Integers are 64-bit signed numbers (called long long int in C) and occupy 8 bytes. Because the MIPS processor is little endian the pointer actually contains the address of the least significant byte. This means that you can declare the argument as a pointer to a short int (16-bits) or int (32-bits) and it will still work as long as the contents of the variable do not exceed these sizes.
- Strings are passed as a pointer to the first byte of the memory allocated to a string (which defaults to 256 bytes). In MMBasic the first byte is the length of the string (in characters) and the 2nd and subsequent bytes are the characters in the string.

- Arrays are passed by using the array name with empty brackets (ie, with no dimensions). For example: `x = CFun(a%, b%(), c%)`. In the embedded C routine the argument will be a pointer to the first element of the array.

An embedded C routine has some important restrictions and issues:

- It cannot call any library functions (eg, toupper(), strcmp(), etc) and it cannot do anything that will cause the compiler to call a library function (eg, manipulate a float). Note that you can call functions defined within the C program module.
- It cannot define data that is const (ie, data that will be stored in flash memory) or static (ie, variables defined outside of a function). This means that you cannot use something like "`const int var`" or "`static int var`" and you cannot create literal strings (ie, "foo").
- It is hard to debug embedded C routines and most programming errors will cause a MIPS processor exception which in turn will force an immediate reboot of the processor.
- MMBasic requires that the embedded routine contain only position independent code (see below for how to specify this) but regardless of the compiler's settings the compiler can sometimes ignore these settings (a good example is when the C language *switch* statement is used). If this happens the embedded routine will cause a MIPS processor exception and force an immediate reboot of the processor.

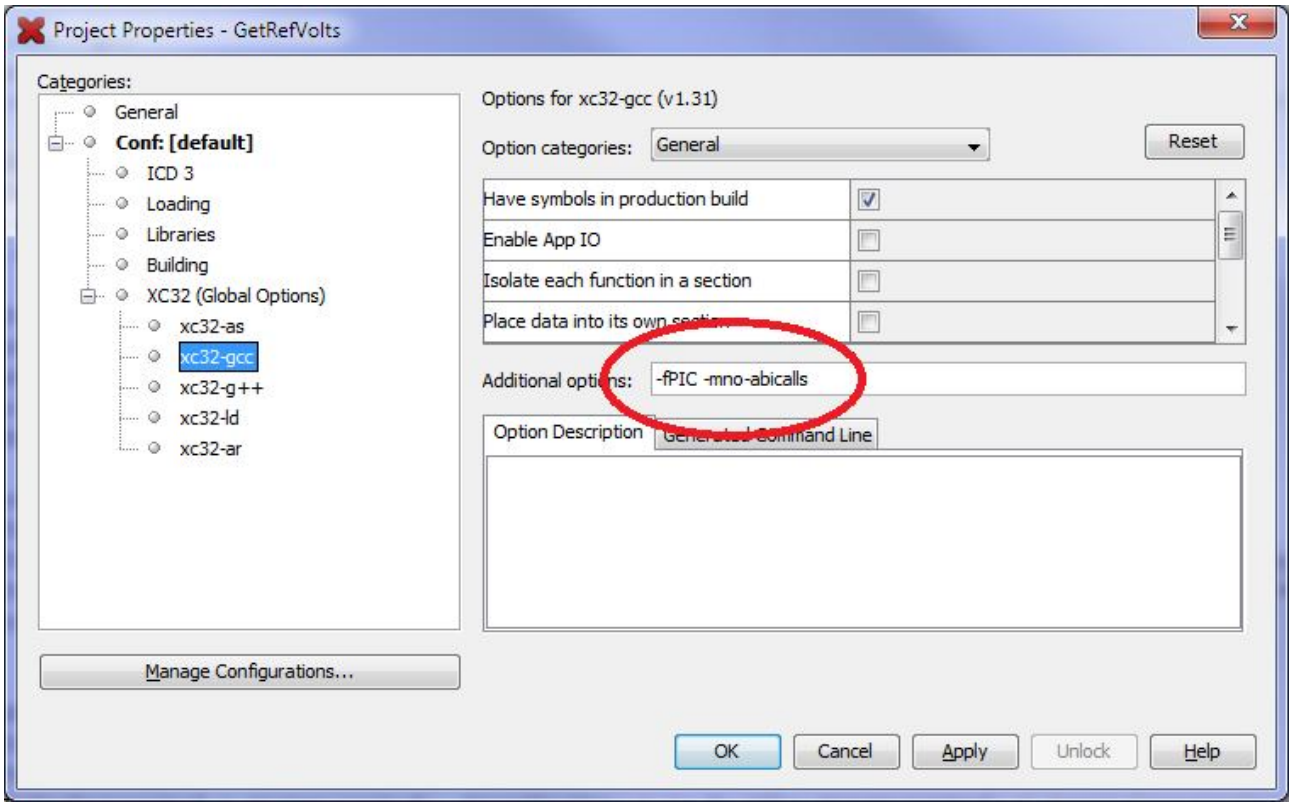
Setting Up the Compiler

The embedded C routine should be compiled using the Microchip MPLAB X and XC32 compiler (both available for free from http://microchip.com). It must be compiled using position independent code and that is done by setting the following options in MPLAB X:

```
-fPIC –mno-abicalls
```

This is done by going into the project's properties (in MPLAB X), selecting the compiler (X32-gcc) and entering these options into the "Additional options" field.

This is illustrated below:



Building the Embedded Module

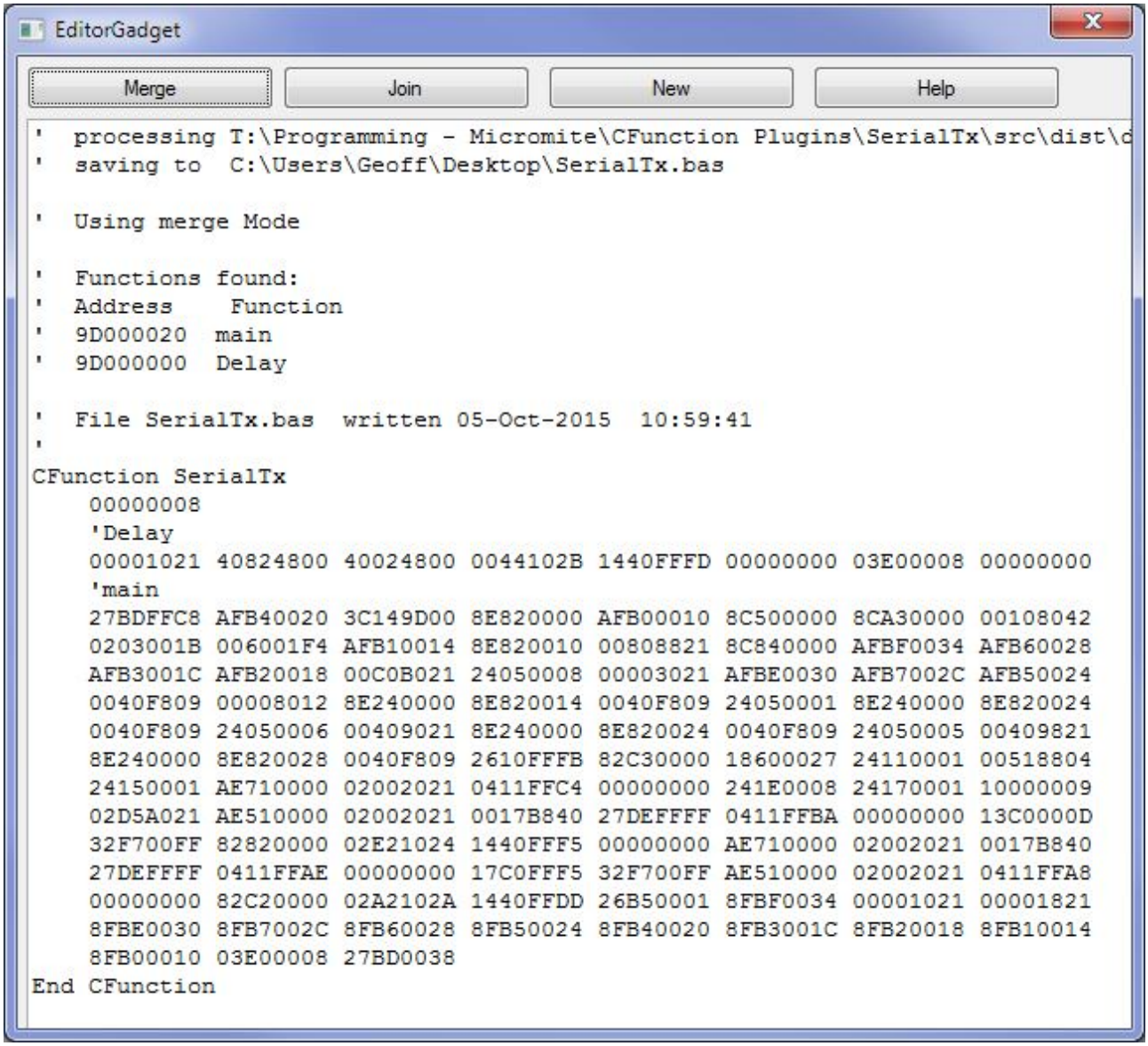
The C program should be compiled as normal (ie, not in debug mode). The compiler will create a file with the extension .ELF within the project directory structure. Starting with the project directory (typically ending with .X) the .ELF file can normally be found in: \dist\default\production

To create the MMBasic code for the C module you should use the Windows program CFGEN.EXE which is included in the normal Micromite firmware distribution. CFGEN was written by Jim Hiley (TassyJim on the Back Shed forum) and it does not need installation (ie, it can be run from within its ZIP file).

When CFGEN is run it will immediately pop up a dialog box requesting the file name of the .ELF file (described above). It will then request a file name for the output BASIC program file. Finally it will display its main window where you will have four buttons and an empty window.

For most normal embedded C programs you should choose MERGE (the HELP button provides some more information on this). When you click on MERGE the program will read the .ELF file and generate the MMBasic program module that contains the MIPS machine code for your module.

The result should look something like this:



The window of the program shows the data written to the .BAS file. This data is also copied onto the clipboard so that it can be immediately pasted into your main BASIC program.

Note that CFGEN always labels the embedded routine as a CFunction (the most common case) but if you have created a CSub (a subroutine) then all you need to do is change the two occurrences of CFunction to CSub (as shown below).

Using an Embedded C Routine

To use the embedded C routine to MMBasic you must insert the contents of the .BAS file generated by CFGEN somewhere in your BASIC program. The exact spot is not important but at the end of the program is typical.

Having done that you can refer to the CSub or CFunction as a normal subroutine or function. For example, the following is a program that uses the above generated CSub (note that because this is a subroutine any occurrences of CFunction have been changed to CSub):

```
SerialTx 2, 19200, "Hello World"

CSub SerialTx
    00000008
    'Delay
    00001021 40824800 40024800 0044102B 1440FFFD 00000000 03E00008 00000000
    'main
    27BDFFC8 AFB40020 3C149D00 8E820000 AFB00010 8C500000 8CA30000 00108042
    0203001B 006001F4 AFB10014 8E820010 00808821 8C840000 AFBF0034 AFB60028
    AFB3001C AFB20018 00C0B021 24050008 00003021 AFBE0030 AFB7002C AFB50024
    0040F809 00008012 8E240000 8E820014 0040F809 24050001 8E240000 8E820024
    0040F809 24050006 00409021 8E240000 8E820024 0040F809 24050005 00409821
    8E240000 8E820028 0040F809 2610FFFB 82C30000 18600027 24110001 00518804
    24150001 AE710000 02002021 0411FFC4 00000000 241E0008 24170001 10000009
    02D5A021 AE510000 02002021 0017B840 27DEFFFF 0411FFBA 00000000 13C0000D
    32F700FF 82820000 02E21024 1440FFF5 00000000 AE710000 02002021 0017B840
    27DEFFFF 0411FFAE 00000000 17C0FFF5 32F700FF AE510000 02002021 0411FFA8
    00000000 82C20000 02A2102A 1440FFDD 26B50001 8FBF0034 00001021 00001821
    8FBE0030 8FB7002C 8FB60028 8FB50024 8FB40020 8FB3001C 8FB20018 8FB10014
    8FB00010 03E00008 27BD0038
End CSub
```

When run, this program will send the string "Hello World" as a serial stream out of the Micromite's pin 2 at 19200 baud. Note that this embedded C routine is the same as SerialTx which is included and described in the normal Micromite firmware distribution.

More Details

The .ELF file generated by the compiler contains the MIPS machine code representing the original C program in a ready to run format. All that CFGEN does is read through that file and extract the machine code into a format that MMBasic can use.

An embedded routine in MMBasic must start with the keyword "CSub" or "CFunction" followed by its name and a sequence of 8-digit hex words. It is terminated by an "End CSub" or "End CFunction" keyword. The name is used to identify the routine to BASIC programs and must follow the rules for a variable name in MMBasic.

The data within the routine is a sequence of 8-digit hex words. Each word must be separated by one or more spaces or a new line.

The first word is the offset (in 32 bit words) to the entry point for the embedded routine. The above CSub is a good example of this, the first word contains the number 8 because the main routine starts eight words into the routine (the linker often places smaller functions before the main routine).

Each of the following data words represents each 32-bit instruction in MIPS machine code. The number of instructions that can be included is limited only by the amount of available memory. The routine is terminated by an "End CSub" or "End CFunction" keyword.

When a BASIC program is saved to flash MMBasic will search through it looking for any CFunction or CSub commands. The machine code specified will then be extracted and programmed into flash memory. This code becomes part of MMBasic and will be called whenever the specified CFunction or CSub name is encountered (it is erased when a new program is saved).

Multiple CFunction and CSub commands can be used if multiple embedded C routines are required. During execution MMBasic will skip over the CFunction and CSub commands and the data specified. This means they can be placed anywhere in the program.

Accessing MMBasic Functions

MMBasic V4.7 and later contains a table of handy functions that can be accessed from within an embedded C routine. These functions include getting and sending characters from and to the console, functions to manipulate I/O pins, functions to draw on an attached LCD panel, etc.

To access these functions the file CFunction.h should be included at the start of your program. Eg:

```
#include "CFunction.h"
```

You can then use the functions that it defines in your embedded C routine as you would use a normal function. At this time there is little documentation on the functions defined in CFunction.h so you should request a copy of the source code for MMBasic (from http://mmbasic.com) and use that as your reference. The source to SerialTx and SerialRx also provide examples.

Using the Library Feature

Some embedded C routines can get very large and as a result a lot of program memory can be wasted by holding the hex codes for the routine in the program (this is needed so the whole program can be edited using the built in MMBasic editor). It is also tedious inserting the code into each program that may run.

Using the LIBRARY feature it is possible to add embedded C routines (and normal BASIC code) to MMBasic and make them permanent and part of the language. Routines saved in the library area will not show when LIST is used and will not be deleted when a new program is loaded or NEW is used. However they can be called from within the main program and can even be run at the command prompt (just like a built in command or function).

When the routines are transferred to the library space MMBasic will compress them by removing comments, extra spaces, blank lines and the hex codes in CSubs and CFunctions. This recovers a lot of program memory when used on large embedded C routines.

Refer to the "Micromite User Manual" for more details.