The Tile Hill Style Guide

–

C Style Guide for embedded systems

By

Chris Hills

First Edition 1.1
23 June 2002

Part of the QuEST series:- QA2

Hitex (UK) Ltd.
Warwick Uni Science Park
Coventry, CV4 7EZ
http://www.hitex.co.uk/
chills@hitex.co.uk

Quest@phaedsys.org
http://quest.phaedsys.org/

The Tile Hill Style Guide

–

C Style Guide
for embedded systems

First Edition 1.1
23 June 2002
By
Eur. Ing. **Chris Hills** BSc, C. Eng., MIEE, MIEEE, FRGS

The slides and copies of this paper (and subsequent versions) the templates, any source code and the power point slides will be available at www.hitex.co.uk or at http://quest.phaedsys.org/, the author's personal web site.
quest@phaedsys.org

Many thanks to **Paul Baker** of **Thames Valley Controls Ltd** for proof reading and the many helpful suggestions. **www.tvcl.co.uk**

The ART in Embedded Engineering comes through Engineering discipline.

Quality Embedded Software Techniques

QuEST is a series of papers based around the theme of Quality embedded systems. Not for a specific industry or type of work but for all embedded C. It is usually faster, more efficient and surprisingly a lot more fun when things work well.

QuEST Series

QuEST 0	Introduction & SCIL-Level
QuEST 1	Embedded C Traps and Pitfalls
QuEST 2	Embedded Debuggers
QuEST 3	Advanced Embedded Testing For Fun

Additional Information

QA1	SCIL-Level
QA2	Tile Hill Style Guide
QA3	QuEST-C
QA4	PC-Lint MISRA-C Compliance Matrix

Contents

The Tile Hill Style Guide

–

C Style Guide
for embedded systems

1. Introduction

When writing C there are two types of guide available and programmers often confuse them. Firstly the style guide which will be described here. Style dictates source code layout and should ensure a uniform and more *readable* format. A uniform style makes errors and non-conformance stand out. It is this word that causes the problems "conformance"…. Free thinking programmers hate it. However for Engineers it is a cornerstone. This Guide is for Software *Engineers.* Many in embedded engineering come from a disciplined electronic engineering background and are used to working to strict regulations for many things. They understand that:-

The ART in Embedded Engineering
comes through
engineering discipline.

This style guide is not about safe use of C as such. The other type of guide covers the safe use of C, normally via a [safer] subset of C. This will restrict which parts of C can and cannot be used. In some cases it lays down very strict lines about how a particular feature is to be used. This type of guide usually has less resistance to being used because there is a clear reason for the rule. Style guides are just that. They have no solid engineering reason to do it this way instead of another way. The problem occurs when everyone has his or her own system….

For the safe use of C there are many, often narrow industry specific, guides available. However, there is one which is generic embedded and has escaped into widespread use. The MISRA-C guide (or to give it it's full title:- The Motor Industry Software Reliability Association Guidelines For The Use Of The C Language In Vehicle Based Software). MISRA-C is available from MIRA (and also from Hitex UK). MISRA-C is a very readable set of rules that make sense for most C programming, embedded or not.

2.2 The Tile Hill Style Guide- History

The Tile Hill style guide has been produced not because it is "The Best" or "Only Way" but because every time I mentioned style guides we were asked if we had one people could use.

When we told people to search the net, look in libraries etc they usually said, "Can you send us the one you use?" Well, you asked for it! This is it, the Style Gulde I use at Hitex UK and Phaedrus Systems.

It has been developed over the last 12 years of software Engineering in several small, medium and large companies most working to or at ISO9000. It has been used on projects as diverse as an 8051 smart card through to a multiprocessor communications system that was based on Sparc, PowerPC and 68040 over time and also had some i486 content….

To get the folk law out of the way first: It is called the Tile Hill guide because at the time of it's first publication to a wider audience (I.E. Not to a project I was working on) I was working at Hitex UK. in Coventry.

Hitex (UK) is close to Tile Hill in Coventry UK which I have to drive through it twice a day. Also the title is a play on the legendary "**Indian Hill Recommended C Style and Coding Standards**" from AT&T Bell labs. My copy is Version 6 dated 1990.

Indian Hill was one of the famous Bell Labs. Tile Hill has no such distinction. The photo shows the **Tile Hill Newsagents** who do a fine range of newspapers, magazines, greetings cards, sweets and soft drinks. . They do not (as far as I know) have any involvement in software or embedded Engineering

Note:- I do not claim that the Tile Hill Guide is better or replaces the Indian Hill document. I just produced my own guide to the style I use because people asked for one. However whilst the Indian Hill guide is generic the Tile Hill Guide is aimed at embedded systems. I am not sure how much difference that makes if any.

2.3 Availability and templates

The Tile Hill Guide is freely available in electronic form, with all the source code templates from http://www.hitex.co.uk/ and http://quest.phaedsys.org/ At the time of writing the Indian Hill guide was available from at least ten sites. Do a search on "Indian Hill Labs". Though all the ones I found were dated 1990.

Jack Ganssel also has an embedded project guide available from http://www.ganssle.com/.

2.4 Errors and omissions

If you find any errors or omissions, have any constructive criticisms, or want to see something added contact the author at: - mailto:quest@phaedsys.org New versions will be posted to http://quest.phaedsys.org/

2.5 Additional contributors

At this point I should like to thank some of the people who have spotted my errors and omissions or made helpful suggestions and changes.

Paul Baker of **Thames Valley Controls Ltd** for proof reading and the many helpful suggestions. **www.tvcl.co.uk**

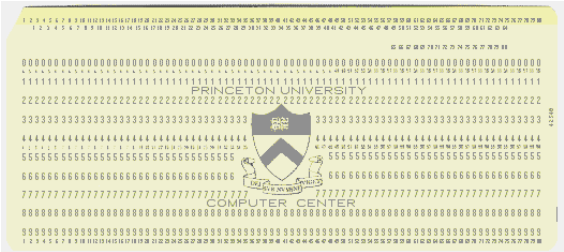
John Johnson of **DALSA Corporation**, Canada, for some ideas and sources that found their way into aspects of this series. http://www.dalsa.com/

Karsten Stegelmann Product Development Engineer of **VAISALA Impulsphysik GmbH** Germany for his helpful suggestions of the SCOPE define in header files (http://www.vaisala.com/)

2 The Style Guide- Rational

2.1 General notes

The idea behind the style guide and the reason they are misused is free will. Many years go (1950's to 1960's) computer programs were written on punched cards with 80 columns. The layout of each line was fixed as was whole sections of the program..



This card is from Douglas W. Jones A History of punched cards [Jones], which provides a fascinating history to early computer systems.

Computer languages developed from punched cards to initially typewriter like terminals and then onto VDU screens. Computer languages continued over from punch cards and required that commands start in certain columns and in a particular form COBOL or FORTRAN for example.

```
 MMAX = 1
  90   IF (MMAX-N) 100, 130, 130
 100   ISTEP = 2*MMAX
       DO 120 M=1,MMAX
         THETA = PI*FLOAT(ISI*(M-1))/FLOAT(MMAX)
         W = CMPLX(COS(THETA),SIN(THETA))
         DO 110 I=M,N,ISTEP
           J = I + MMAX
           TEMP = W*DATA(J)
           DATA(J) = DATA(I) - TEMP
           DATA(I) = DATA(I) + TEMP
 110     CONTINUE
 120   CONTINUE
       MMAX = ISTEP
       GO TO 90
 130   IF (ISI) 160, 140, 140
```

Example of Fortran.

As computers developed so the languages developed away from the punched card and there was more freedom of layout.

C was developed in the 1970's when VDU screens were common and new systems did not use punched cards. Therefore C was developed as a free format language. There is no fixed layout as regards columns. (There are a few exceptions to do with the pre-processor)

One white space has the same weight as 50 white spaces... This assumes that you are using black on white. For those of you using DOS screens it is

black spaces (in the case of Joe it is lilac spaces). Effectively, this means that the programmer is free to layout the source code as he or she sees fit. What is more there is no technical reason why the programmer has to keep their style constant. Even from line to line.

Many programmers will complain that they can use their own style and anything else imposed is an infringement of Civil Liberties and the end of Civilisation As We Know It! Most Project managers have too many other things to worry about. As long as the code compiles (reasonably[1]) clean they are happy.

The problem comes when you have several programmers working on one project or worse still several programmers on the project are changed…. The original "geniuses" move on and someone else has to do the maintenance. This is when you end up with many conflicting styles. Often within the same source file! This is where C learnt its reputation as being a ***read only*** language.

As the army discovered a long time ago it is easier to count and control a group of people if they are standing in lines and sets of lines than if they are just standing in a group. As an example (do this in private or you will thought of as very sad ☺, tip a box of paper clips on to your desk. Try and count them without moving them. Not easy is it. You could could them by moving them from one pile to another. However if you loose count you have to start again. Now try putting them it to rows of 5 with 5 rows to a block. Then all you have to do is count the blocks. It is also very easy to see if there is a paper clip missing in any row or block.

Likewise when the source code is laid out in a standard way is it far easier to spot anomalies and errors.

I worked on one fun project involving six nationalities on three continents. One of my team sent me an email after doing a review on another teams code:- (N.B. time how long it takes to read what this says)

th eo t
her tea mRe Gua
R d so ru c
E Co DeLay
O T A Sana
Rtf or M

It took me a while to work out what it actually said was:-
ThEoThErTeAmReGuArDsOrUcEc0DeLaYouTaSaNaRtFoRm

[1] Reasonably? For some this is only "some" warning, others turn off the compiler warnings and only look at errors….

Sorry, I meant "**theo tert eamr egua rdso ruce code layo tasa nart form**" or to restrict my civil liberties and stifle my creative spirit; "The other team regard source code layout as an art form". I am sure that you instantly spotted the '0' (zero) in place of the O and the misspellings. In fact now I come to look at it, the first 3 versions have different errors but I am sure that was obvious to you!

That illustration should have convinced you, even if it is only the time saving on reading it, that a uniform style to a set convention is a good idea. It makes the source easily readable to all with the likelihood of fewer errors.

Another far more dangerous example of code layout causing problems is one that actually came originally from a problem in a rapid transit system in a major city.

```
interlock = OFF;

if(TRUE == stop)
     flag = ON;
     interlock = ON;

if(ON == interlock)
     open_doors();
else
     apply_brakes();
     sound_alarm();
```

What it should do is only open the doors ***if*** stopped ***else*** apply brakes and sound alarm but not open doors. This code will in fact, obviously, always open the doors and sound the alarm but not apply the brakes.

I insisted that all code produced with teams I am involved with rigidly adhere to the principal of always using braces were possible, even on one line while or if statements as above. This may sound a bit draconian despite the example above but I have good reason.

I instigated this rule after three of my team spent two days trying to trace a bug caused by a two line ***if*** statement where only one line was actually inside the ***if***. It caused an error some distance from the '***if***' statement and was not immediately linked to the problem. When the ***if*** statement was considered all three engineers glancing at it saw a correct ***if*** statement and mentally put braces round the two statements. The mind saw what it thought should be there. The human mind is good at filling in the blanks with what it thinks is right. Ask any married person!

In this case the error was combined with another similar "non error" to produce a real problem much further away. The reason for c style guides is to make the code uniform so reducing the silly errors like this. There is no

right or wrong style, as long as it is consistent, but some have a tendency to reduce errors more than others.

The previous code example (according to my pedantic formatting) is actually the following:

```
interlock = OFF;

if(TRUE == stop)
{
     flag = ON;
}
interlock = ON;

if(ON == interlock)
{
     open_doors();
}
else
{
     apply_brakes();
}
sound_alarm();

Whereas what was meant was:

interlock = OFF;

if(TRUE == stop)
{
     flag = ON;
interlock = ON;
}

if(ON == interlock)
{
     open_doors();
}
else
{
     apply_brakes();
     sound_alarm();
}
```

By pedantically putting the braces in (taking a couple of seconds) we could have saved about 5 man-days of effort!

As mentioned previously this problem was actually based on a real problem on a rapid transit system in the Far East though programmers in the Midlands wrote the code! It actually made it as far as the test runs. The bug was only found by accident after another "freak" bug triggered the events for this one to become visible.

This should convince you that a uniform style is a good idea…. Well your troubles have just begun! Which style of layout to use? Everyone has their favourite and can see no reason why they should change. It is one of the most contentious parts of any style guide.

There are several recognised styles. All are equally good and bad. In personal order of preference from top to bottom with my favourite at the top.

```
If(style 1 Exdent)
{
     statement;
     statement;
}


If(style 2 Indent)
     {
     statement;
     statement;
     }


If(style 3 K&R){
     statement;
     statement;
}


If(style 4)
{statement;
     statement;
}
```

As a final thought: Your source code could land you in prison! Currently you have to show "due diligence" in anything you produce. Thus if there is a court case over something to do with a system containing your software you may be called upon to show that you exercised "Due Diligence" in constructing the software. The claimants are likely to have experts who will explain what an ideal software development process should be.

A uniform style in programming along with a coding standard has long been recognised as "Best Practice" in the software industry. You can be sure that the insurance company for the claimants will bring it up somewhere. They will ask "an you demonstrate that you took due diligence in constructing this software?"

Of course as a director or manager you may have more pressing problems if the Corporate Manslaughter Bill goes through. The stakes are getting higher. Given that software produced to a consistent style using a sensible coding standard using the correct support tools has consistently been

shown to get to market faster with fewer bugs there is no reason (legal or commercial) not to do it.

There is a fuller discussion of this topic in Embedded C: Traps and Pitfalls at www.phaedsys.org and the Home office documents are available at:

http://www.homeoffice.gov.uk/consult/invmans.htm

2.2 Additional Changes from the first version

Karsten Stegelmann Product Development Engineer of **VAISALA Impulsphysik GmbH** Germany http://www.vaisala.com made some helpful observations on the defines used in header files in section "4.3.4 Template for Header files" as below:-

I defined in the file filename_**M** and in the header file it was used for explicitly defining extern in all but the "home" file.

```
#ifdef CO0001_M
        void Application_Block(void);
#else
        extern void Application_Block(void);
#endif
```

However Karsten suggested the following method:

```
ifdef CO0001_M
    #define _SCOPE_ /**/
#else
    #define _SCOPE_ extern
#endif

_SCOPE_ void Application_Block1(void);
_SCOPE_ void Application_Block2(void);
_SCOPE_ void Application_Block3(void);
```

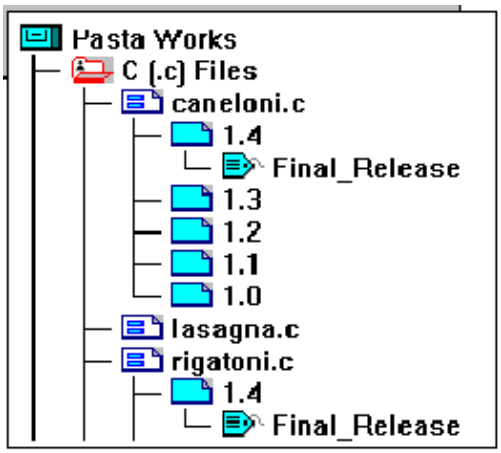
Whilst it is functionally the same thing it is more elegant and reduced the number of places the function prototype appears from three to two. This reduces the change of typographical or cut and past errors.

Karsten goes on to point out that this method can be used on Global variables as well. I have amended the Tile Hill Guide to reflect the suggestions.

3 Version control and other tools

Version Control is a much under used method for getting bug free code. For a full explanation see ***Embedded C Traps and Pitfalls [Hills].*** In simple terms ***version control*** means keeping track of *every version* of a source file. This seems a little daunting and more likely to introduce more errors. However if implemented properly it can drastically reduce errors and save a lot of time.

There are many ways of doing version control. The simplest is to archive directories of source code. The next step is one of the many version control programs. These are a form of database program. These programs make it possible to retrieve any version of the source code either by specific version or by using labels whole builds can be retrieved at the click of a mouse.



This can save much time hunting around for old versions and is also extremely useful when a new set of mods go wrong and you have to go back to a known good version.

One of the more useful features of most commercial VCS packages is "keywords" and "keyword expansion". Key words can automate much of the documentation in source files. Essentially when a VCS keyword is placed in a source file the VCS program will expand the keyword with specific information such as date, time, file-name user name and even file history.

For example the following file header block

```
/*****************************************************
** $Workfile:  $
** Name: Application Block
** Copyright :Keil (uk) 1999
** $Author: $
** $Revision:  $
**
** Analysis reference:123/ab/45678/001 5.6
** Input Parameters:  NONE
** Output Parameters: NONE
**
** $Log:  $
**
**  End of history
**/
```

will automatically have the keywords expanded when the file is put in (I.E. a version saved) and then taken back out to work on again.

```
/*****************************************************
** $Workfile:   U1CO0001.C  $
** Name: Application Block
** Copyright :Keil (uk) 1999
** $Author: Chris Hills$
** $Revision:   1.1  $
**
** Analysis reference:123/ab/45678/001 5.6
** Input Parameters:  NONE
** Output Parameters: NONE
**
** $Log:   C:/ENG/KOS2/A2C001.C_V  $
**
**   Rev 1.1   06 May 1998 16:48:28   HILLS_CA
**Issued for review
**
**   Rev 1.0   01 Apr 1998 13:09:02   HILLS_CA
**initial version
**
** End of history
*/
```

The good news is that the users cannot alter the comments above in the key word text. For example it I changed the history section the next time the file is pulled out the VCS will recreate the original text. The VCS administrator can change the history comments in the VCS but it is far easier to do it right the first time!

Incidentally one thing you should remember… it is not only the source code that needs version control. Test scripts, programs, make files and even the tools may need version control

There are several free version control programs about principally RCS, which is part of most Unix implementations. I have a PD DOS version. However a well documented (and used) manual version you do yourself, I.E. history logs, archive directories and back up to CD ROMs etc may be all you need.

It should be noted that a well-organised file system will save a lot of time and effort and makes a lot of sense in pure commercial terms never mind the engineering arguments. Especially if you build up a library of reusable components and use them in many versions of software.

Note:- Version Control Systems (VCS) are also known as Revision Control Systems (RCS). It is also sometimes referred to as Configuration Management System. In all cases System is often replaces with the word Software when talking about the control system software … Sometimes it is referred to as Software VCS (SVCS). The programs are often called VCS, RCS, SCCS depending where you first started to uses them.

3.1 Lint & static analysis

Lint is a static analysis tool. It is like a spelling and grammar checker for C. It will pick up basic indentation, globals that could be local, misuse of pointers, loss of precision and many other dubious uses of C. Static analysis will analyse source code without a compiler. This means that it can check in complete and un-compliable source.

Lint was the first and has been around since 1979 it is a command line tool that was intended to be run as part of the compiler chain in the make file. These days it will integrate into most IDE's.

It should be stressed that static analysis is recommended by virtually every C and C++ style and coding standards since the original Lint was created by the same team that put C and Unix together in 1974. Denise Ritchie in his paper: The Development of the C Language says:

Although the first edition of K&R described most of the rules that brought C's type structure to its present form, many programs written in the older, more relaxed style persisted, and so did compilers that tolerated it. To encourage people to pay more attention to the official language rules, to detect legal but suspicious constructions, and to help find interface mismatches undetectable with simple mechanisms for separate compilation, Steve Johnson adapted his pcc compiler to produce lint [Johnson 79b], which scanned a set of files and remarked on dubious constructions.

It is not a case of if you should use static analysis but which tool you will use!

Why use static analysis? The graph below should give some indication as to the cost of finding bugs. The closer to the point where they start the better.

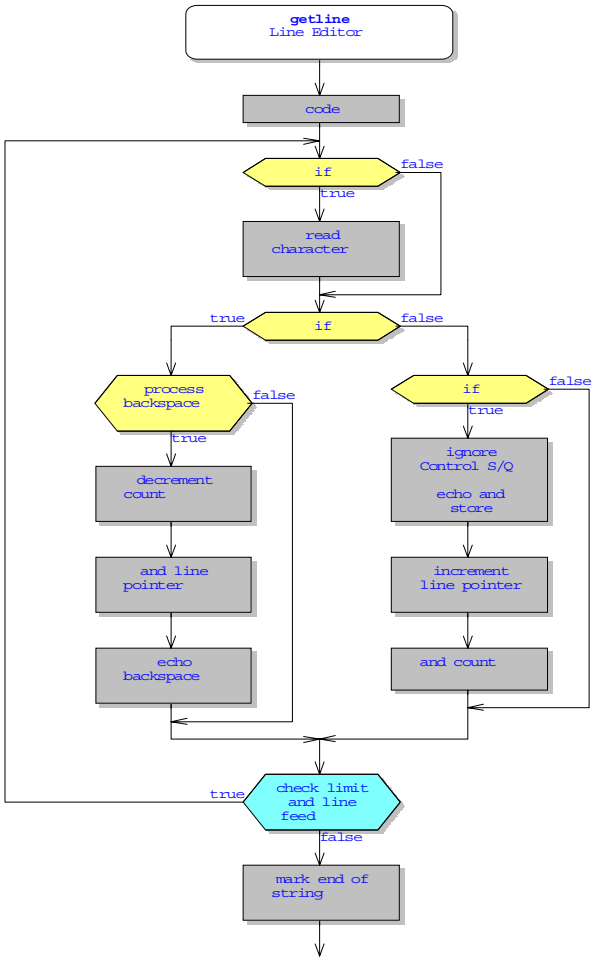
There are many tools (starting with Lint) going up to 10,000 £ or $ with extensive rules and templates many that can be made to test for house coding standards and styles. See Appendix B.

The simplest and easiest static analyser to use (and also the least expensive) is Lint. There are several free and public domain ones about. The first commercial one is PC-Lint at just over £100, which comes complete with configuration files for the majority of the worlds embedded C compilers. Which saves hours of setting up.

After that the sky is the limit which is often not the case for some embedded aerospace projects. Generally the more expensive the tool the more it will do, the deeper it will hunt and the better the graphical user interface.

3.3 DA-C

The program Development Assistant for C (DAC) is a wonderful tool where there is a lot of legacy code that needs to be brought up to standard. It will produce, from the source code, complete, commented, function flowcharts and program structure charts, as well as data structure charts all of which can be cut and pasted into your documentation.



Whilst not part of a style guide it can be very useful in re-documenting legacy projects where the original documents and design cannot be found. It too has a static analyser but it is not as powerful as lint. This makes it ideal for a first pass over legacy code before documenting.

One of my tests for commenting is to run DAC over the code and see if the flow charts make sense. The boxes are automatically completed using the comments in the code. Where there are no comments the word "CODE" is inserted. If the automatically generated flow chart does not make sense then the code had better be well constructed using defines and intuitive variable names.

As of summer 2002 DAC is automatically able to create documentation from the source code to IEEE 1016. It generate structure charts, tables of parameters and module/function information all with section numbering, contents and title page. The areas you have to complete contain instructions in a different colour.

4 The Tile Hill Embedded C Style Guide

This *style* guide should be read in conjunction with a suitable coding standard such as MISRA-C

This style guide should be used as part of a unified software development system. See Embedded C: Traps and Pitfalls [Hills] and the SCIL-Level Guide

A style guide is there to make the source readable. Coding standards make the code safer. Other tools make the project safer

This guide should be used for ALL software on the project. Exceptions are standard third party libraries. Where third party source is developed for the project it should comply with this guide and all of the project standards.

4.1 Files

4.1.1 File naming

File names shall not contain spaces. Whilst most host operating systems can now handle spaces in file names many of the tools whose roots are in DOS do not. The same holds true for directory paths and **spaces should not be used in directory names**.

4.1.2 File names should be kept short

The eight. three configuration for files is now a restriction of the tools rather than host operating systems. However as many tools still work to this format it is advisable to stay with it. In any event file names should be less that 16 alphanumeric ASCII characters.

4.1.3 Header file names

Header file names for header files containing function prototypes or defines for a particular source file should reflect the name of the source file they belong to. Header files should not use the name of any known standard library header file regardless of whether the library header files are being used or not.

4.1.4 Source files should be ASCII chars only

Source files should only contain printable ASCII characters.
This means that source files cannot be written in a word processor as a *.doc file. The only permitted exception is the EOF (End Of File) marker. Note this can cause problems if moving between operating systems such as VMS, Windows, MAC and Unix.

4.2 File name extensions

4.2.1 C/C++ File extensions

C/C++ File extensions shall follow the table below except where tools used require different extensions. Extensions should be up to three alpha characters.

C source files	*.c
C header files	*.h
C++ source files	*.cpp
C++ header files	*.hpp

4.2.2 Assembly files

Assembly files may have to use extensions required by the tool chain. Where this is not the case the following shall apply

8051	*.a51
251	*.a51
166	*.a66
Z80	*.a80
X86	*.a86

Any other family should follow a similar pattern

4.2.3 Miscellaneous files.

File extensions shall follow the table below except where tools used require different extensions. Extensions should be up to three alpha characters.

Object files	*.obj
Libraries	*.lib
OMF files	*.omf
Elf files	*.elf
List files	*.lst
Map files	*.map
Make files	*.mak
Batch files	*.bat
Intel Hex files	*.hex
S Rec files	*.mot

4.3 Templates for files

All source code is held in a number of files. These files should be laid out in a standard manner. The easiest way of doing this is to use templates for the file as a whole, the functions within it and the header files.

Much of the work involved can be automated using Revision Control Software (RCS). The version shown in the text is a manual version. The appendices contain versions of the templates for MS Source Safe, PVCS Version Manager, MKS Source Integrity and Clear Case. These templates will also be available from http://www.phaedsys.org

4.3.1 Source File Template

This should be a standard template used for all source code developed on the project. It is not required to re-engineer any third party source such as libraries. Any third part source developed for the project should use the templates.

1.1.1.1. File Information Block

These files should have an information block that conveys information to the reader. This information should be:

The name of the file.

1 The name of the application or project *
2 The initial author *
3 The copyright
4 The analysis or design reference
5 The current revision*
6 The change history.*

The items marked * can usually be supplied automatically by the VCS . The copyright block will usually be insisted upon and supplied by the company. It is usually the only part of the software process they take any note of!

1.1.1.2. Other information

The source file will contain logical sections. Functions are covered later. The file will start with the File Information block as detailed above. Following the FIB shall be the header files. The section shall start with a single line comment using * across the whole page. On the right hand end of the comment then the name of the section shall be placed with the section name at the right hand end of the comment. The case may be upper, lower or title case but must be consistent across the project.

/** Section Name */

The comment shall be full width of the standard listing paper when printed. This may be modified to the maximum width before any wrapping or loss

of text on screen or printer. In any even all the lines must be uniform. The sections shall be in the order described in the following sections.

1.1.1.2.1. Include

```
/****************************************** Include */
```

On the far right shall be the word "Include" to assist with locating the section in code reviews.

The header files shall be included in the following order

```
#define CO0001_M
#include <system.h>
#include <third-party-sw.h>
#include <project.h>
#include "local.h"
#include "ownheader.h"
```

The line #define CO0001_M is used with the files own header file. This permits the correct definition of local and external defines, prototypes etc. see section on header file templates.

Note it is not permitted to include a *.c file at any time.

Absolute paths may not be used. In some third party libraries that install to include/libX where include is the standard compiler library directory the following is permitted

```
#include <./libX/third-party-sw.h>
```

1.1.1.2.2. Define

The defines section shall be marked as follows with the word "defines" at the right hand end of the comment:-

```
/****************************************** Defines */

#define   name      value
#define   names     value
#define   named     value

Defines should be spaced with tabs into columns. This
enhances readability.
```

1.1.1.2.3. Global

The Globals section shall be marked as follows with the word "Globals" at the right hand end of the comment

```
/****************************************** Globals */

uint8_t   count     = 0;
int8_t    flag_one  = 0;

unit16_t  motor_one = 0;
int16_t   error_rate= 1;
```

As with defines the declarations should be tabbed into columns. This enhances readability.

There should only be one declaration per line.

Types should be grouped logically, I.E. 8 bit, then 16 bit etc or by use. All the globals relating to a particular function.

1.1.1.2.4. Prototypes

The Prototypes section shall be marked as follows with the word "Prototypes" at the right hand end of the comment.

Only static or local function prototypes shall be permitted in this section. Externally visible prototypes shall be in a header. Therefore all prototypes in this section shall start with the C keyword "static"

```
/*************************************** Prototypes */

static void function(unit_8 variable)
```

Functions shall be fully specified.

1.1.1.3. File EOF Marker

Each file shall end with an End Of File marker or comment giving the name of the source file.

```
/*************************************************/
/*********** End of $Workfile:   CO0001.C  $ ******/
/*************************************************/
```

Example Template

```
/*****************************************************
** $Workfile:   CO0001.C  $
** Name: Application Block
** Copyright :Phaedrus Systems 1999
** $Author: Chris Hills$
** $Revision:   1.1  $
**
** Analysis reference:123/ab/45678/001 5.6
**
**
** $Log:   C:/ENG/caos/C00001.C_V  $
**
**  Rev 1.1   06 May 1998 16:48:28   HILLS_CA
**Issued for review
**
**  Rev 1.0   01 Apr 1998 13:09:02   HILLS_CA
**initial version
**
*/

/****************************************** Include */
#define CO0001_M

#include < system.h>
#include < thirdpartysw.h>
#include " project.h"

/****************************************** Defines */

#define name value
#define name value
#define name value

/****************************************** Globals */

/************************************** Prototypes */

static void function(void)


/*****************************************  Main */

void main(void)
{


}

/*****************************************************/
/***********  End of $Workfile:   CO0001.C  $******/
/*****************************************************/
```

4.3.2 Templates for functions

The file template should give the developer all the information on where the file started and how it got to its current state. The VCS in this case automatically puts in the history block. Where a VCs is not used it should be manually maintained. This should include any additional functions added (or removed) after the initial build.

Each function should also have a simple comment block giving the purpose of the function, the input and output parameters. Like the main file information block, where appropriate, the reference to the design or requirements should be included.

Only in exceptional cases should the function be fully documented (e.g. the description of algorithms) in the function template. This information should be in the documentation.

The function template shall start with a full width comment of the same length of the other comments in use. The function name shall be inserted

```
/************************************************ Convert_One */
/* Name: Convert_one
**
** Purpose: Converts Fahrenheit to Celsius
**
** Design reference: abd_123-abc
**
** Input Parameters: Temperature in Fahrenheit
** Permitted range:  -20 to 200
**
** Return Parameter: Temperature in Centigrade.
**
*/

uint_8 convert_one( Unit_8)
{
      …..
```

Where applicable ranges should be given, In this case the input Fahrenheit range permitted and the output range supplied.[2]

Main is, as always, a special case. In a self-hosted system main will not have any parameters or return values. It's function is clear therefore the second descriptive comment block is not required.

4.3.3 Order of functions

The functions shall be in top down order. In all source files the functions externally callable shall be at the top of the file. The most significant external function at the top of the file.

[2] Had this simple rule been applied to a project a multimillion-pound rocket might have flown a bit longer than 29 seconds!

The functions shall then follow in the order in which they are called in main. Static functions shall be last. Where possible all functions shall be lower in the file than the function that called it.

1.1.1.4. Main function

There shall be a function called ***main*** which shall be the first C function that is run after the start-up assembler. Main shall be the first function in it's source file but does not require a prototype.

In self-hosted environments ***main*** shall have the prototype:

void main(void)

Note: In strict ISO C in self-hosted environments "main" is not required to be called "main". It can technically be called anything you like. However 99% of the worlds debugging tools look for "main".

4.3.4 Templates for Header files

Header files shall contain function prototypes for functions that are not static and must be visible outside their home source file.

The template shall start with a full width single line comment of *'s

The File information block shall contain the following information:-

Name of the file*
Copyright
Author or team *
Revision or version number *
Reference to design or analysis document
History log*

The items marked * should be available automatically from the VCS.

One item that can also be added is the target CPU or compiler system that was used, also the intended crystal speed. This is more relevant where the header file is to be used when it's source file is only available as an object file, as in the case of a library function.

The end of the file shall have a single line EOF comment that includes the name of the file.

NOTES:-
This header files contains

#ifndef CO0001_H
#define CO0001_H

#endif /*end guard */

This permits only one inclusion of the header file and stops re-definitions. This should be part of your coding standard. The other set of defines

```
ifdef CO0001_M
    #define _SCOPE_ /**/
#else
    #define _SCOPE_ extern
#endif

_SCOPE_ void Application_Block1(void);
_SCOPE_ void Application_Block2(void);
_SCOPE_ void Application_Block3(void);
```

Are used with a #define in the files home source file #define CO0001_M that is above the include section to permit the correct declaration of externs

```
/*****************************************************/
/*
**  $Workfile:   CO0001.H  $
**
**  Copyright Phaedrus Systems Ltd
**  Author:    Chris Hills
**
** $Revision:   1.1  $
**
** Analysis reference: ab2-123-1.2.4
** Compiler : Keil C51
** Target     : 8051/Fa
**
** $Log:   G:/SHARED/ENG/caos/CO0001.H_v  $
**
**    Rev 1.0   01 Apr 1998 13:19:28   HILLS_CA
** Initial Version
*/

#ifndef CO0001_H
#define CO0001_H

ifdef CO0001_M
    #define _SCOPE_ /**/
#else
    #define _SCOPE_ extern
#endif

_SCOPE_ void Application_Block1(void);

/***** END of $Workfile:   CO0001.H  $ ************/
```

4.4 Braces and the One True Faith

There are several styles for the placement of braces, K&R, indent and extent. **The rule is consistency. The preferred method shown here is extent.**

```
If(clause)
{
     statement;
     statement;
}


while( clause)
{
     statement;
     statement;
}


for (init; until; step)
{
     statement;
     statement;
}
```

```
Nested if, whiles etc should be as follows

If(clause)
{
     while( clause)
     {
          statement;
          statement;
     }/*end while*/

     statement;
     statement;
}/*end if*/


NOTE some old libraries and some tools may require K&R
style
```

NOTE the use of /*end if */ and /*end while */ These are useful where there are nested sets of braces. In multiple nested ifs and while's this should be extended to more descriptive markers such as:

/* end while count ***/**

or

/* end if flag true */

4.5 Constants, Defines and Types

Magic numbers or literal numbers in C shall not be permitted. Defines or Const shall be used. There is a subtle difference between a const and a define. A define is a textual replacement, for example:

#define TRUE 1

Wherever TRUE is found in the source (but not in comments) it will be physically replaced by a 1. With a const a type is also required e.g.

const uint8_t TRUE 1;

The difference is that the const takes up physical space but when debugging it will show up as "TRUE " (with type information) where as the define will show up as 1 with no other information. In an idea world consts would be used but in embedded systems memory is usually at a premium.

Note this should not be taken to extremes.

Where MAX_STRING = 250 the following shall be permitted:-

Uint8_t output_buffer[MAX_STRING+1]

Where an additional byte is required for the null terminator. However the following and all similar are prohibited:

```
#define       ONE   = 1
const uint8_t ONE   = 1;
```

Exceptions would be for S-Boxes in DES routines.

4.5.1 Long constants

Long constants shall be written using a capital L suffix NOT a lower case l as a lower case l can be confused with a 1. Thus 121212 would be written:

```
#define  name 121212L
```

4.5.2 Hex constants

Hexadecimal constants shall be used for all bit masks and where bit patterns are important. They shall be written using a lower case x and the hexadecimal letters (A, B, C ,D, E, F) in upper case. Thus 0f would be written :

```
#define name 0x0F
```

4.5.3 Octal Constants

Octal constants should not be used.

4.5.4 Const

A const shall be used on any values that shall not change during the lifetime of the program.

This will include parameters passed to functions where the parameter will not be changed in the function e.g.

Uint8_t function(const unit8_t temperature);

4.5.5 Defines

Define shall be used on any values that shall not change during the lifetime of the program.

Defines shall be in UPPER-CASE

4.5.6 Types

Types should be completely specified. This includes signed and unsigned types. Types should also have their size fully specified.

Type	Minimum # Bits	No Smaller Than
char	8	
short	16	char
int	16	short
long	32	int
float	24	
double	38	float
any *	14	
char *	15	any *
void *	15	any *

Some machines have more than one possible size for a given type. The size you get can depend both on the compiler and on various compile-time flags. The following table shows ``safe'' type sizes on the majority of systems. Unsigned numbers are the same bit size as signed numbers.

Unless a short is both larger than a char and smaller than an int. short should not be used. I.E. short may be used where

```
char   == 8 bits
short  == 16 bits
int    == 32 bits
long   == 64 bits
```

In order to ensure portability and that the correct types are used ISO C defines the following types definitions to be used

```
int8_t     uint8_t
```

```
int16_t    uint16_t
int32_t    uint32_t
int64_t    uint64_t
```

These should be used in a header file as follow (example for an 8 bit architecture).

```
typedef signed     char   int8_t;
typedef unsigned   char   uint8_t;
typedef signed     int    int16_t;
typedef unsigned   int    uint16_t;
typedef signed     long   int32_t;
typedef unsigned   long   uint32_t;
```

Note the use of tabs to keep the typedefs in columns.

4.6 Structures and Unions

Structures shall not be declared in a nested form.

```
Struct name
{
        uint8_t         size;
        uint8_t         number;
        int16_t         speed;
        int16_t         direction;
        struct part
        {
                uint8_t         rate1;
                uint8_t         rate2;
                int16_t         climb1;
                int16_t         climb2;
        )parts;

};
```

Each structure should be declared separately as follows:

```
struct part
        {
                uint8_t         rate1;
                uint8_t         rate2;
                int16_t         climb1;
                int16_t         climb2;
        );

Struct name
{
        uint8_t         size;
        uint8_t         number;
```

```
        int16_t         speed;
        int16_t         direction;
        struct part     parts;

};
```

Only one declaration per line.

4.7 Flow Control

4.7.1 Function calls in control clauses

Function calls should not be used in flow control statements. For example:-

```
If( printf("hello world\n"))
{
        statements;
}

While( Get_result() )
{
        statements;
}
```

This is partly because of side effects, partly for debugging and also readability.

4.7.2 Null Statements

Null control statements shall be clearly written as shown below using braces to hold the null line with a comment.

```
While( TRUE == Ri)
{
      ; /*NULL  Loop */
}
```

4.8 Comments

Comments shall follow the style

/* single line comment */

```
/*
** multiple
** Line
** Comment
*/
```

The comment system // should not be used unless it is documented that ALL tools in the system will accept this method. Many do not.

In which case the system

```
// single line comment

//
// multiple
// Line
// Comment
//
```

Shall be used.

It shall not be permitted to mix both types of comment markers in a project. This excludes third party libraries. However where possible 3rd party libraries should conform to the guide.

4.8.1 Nested comments

Comments shall not be nested.

4.8.2 Commenting out code

Code shall not be commented out. Dead code that is commented out is dangerous as it is very easy to make it live again.

4.8.3 Comment density

This is extremely difficult to mandate. The phrase often seen in coding standards is "Comments shall be meaningful" Which is pointless and no help at all.

The current rule of thumb is 30% of the file by volume. However some code written well using Consts and defines may need few comments.

Other code may need many comments. What is obvious to the programmer may not be obvious to another programmer (or even the original programmer 6 months later).

The requirements for comments can only be found through code review. There is no magic formula or automatic answer. A metrics tool [see DAC] can tell you if you have more or less than your arbitrary level eg 30% but

no tool can tell you if the comments make sense or if more (or less) are needed.

A manual code review is the only answer

5 Source Code Templates

There follows a set of file templates for several popular version control systems. These can be used as they are or modified to suit your own requirements. Their inclusion here implies no recommendation for or against. They are just the ones I have come across.

Microsoft Source Safe. PVCS from Merant/Intersolve, source Intrgrity from MKS and RCS from Component Software all use keywords in a similar way.

Rational's Clear Case does not have key words. This is due to the way the system works. Clear Case is designed to be used over distributed databases and networks. This permits safe developments over several separate sites (that do not even need to be on the same continent). I have used this system with a development team running into three figures on 10 sites on three continents. It was an embedded Unix project.

I have used all of the VCS listed here are one time or another. Each has it's own strong points and much will come down to how you get on with the interface. I would urge you to look at the levels of support and the costs. Also check for compatibility with the other tools you wish to use.

Source Integrity is available from www.MKS.com

Source Safe is available from Microsoft

PVCS is available from www.merant.com

ClearCase is available from www.rational.com

CS-RCS is available from :-http://www.componentsoftware.com/ and, at the time of writing, is free for single users.

5.1 Source Safe Templates

```
/*********************************************************
** $Workfile:  $
** Name:
** Copyright :Phaedrus Systems 1999
** $Author: $
** $Revision: $
**
** Analysis reference:
**
** Compiler :
** Target   :
**
** $Log: $
**
*/

/****************************************** Include */
#define CO0001_M

#include < system.h>
#include < thirdpartysw.h>
#include " project.h"

/****************************************** Defines */

#define name value
#define name value
#define name value


/****************************************** Globals */

/*************************************** Prototypes */

static void function(void)


/*****************************************  Main */

void main(void)
{


}

/*********************************************************/
/***********  End of $Workfile: $******/
/*********************************************************/
```

```
/*****************************************************/
/*
**  $Workfile: $
**
**  Copyright:  Ltd
**  $Author: $
**
** $Revision: $
**
** Analysis reference:
** Compiler :
** Target   :
**
** $Log: $
**
*/

#ifndef CO0001_H
#define CO0001_H

ifdef CO0001_M
    #define _SCOPE_ /**/
#else
    #define _SCOPE_ extern
#endif

_SCOPE_   function_name()


#endif /*end guard */
```

/*** END of $Workfile: $ ***********/**

```
/*****************************************     */
/* Name:
**
** Purpose:
**
** Design reference:
**
** Input Parameters:
** Permitted range:
**
** Return Parameter:.
**
*/
```

5.2 MKS Source Integrity Templates

```
/*****************************************************
** $RCSfile$
** Name:
** Copyright :Phaedrus Systems 1999
** $Author$
** $Revision$
** $ProjectName$
** Analysis reference:
**
** Compiler :
** Target   :
**
** $Log$
**
*/

/****************************************** Include */
#define CO0001_M

#include < system.h>
#include < thirdpartysw.h>
#include " project.h"

/****************************************** Defines */


#define name value
#define name value
#define name value

/****************************************** Globals */

/****************************************** Prototypes */

static void function(void)


/******************************************  Main */

void main(void)
{


}

/*****************************************************/
/***********  End of $RCSfile$******/
/*****************************************************/
```

```
/*****************************************************/
/*
**  $RCSfile$
**  $ProjectName$
**  Copyright:  Ltd
**  $Author$
**
** $Revision: $
**
** Analysis reference:
** Compiler :
** Target   :
**
** $Log$
**
*/

#ifndef CO0001_H
#define CO0001_H

ifdef CO0001_M
    #define _SCOPE_ /**/
#else
    #define _SCOPE_ extern
#endif

_SCOPE_   function_name()


#endif /*end guard */

/***** END of $RCSfile$ ************/
```

5.3 PVCS Templates

```
/*********************************************************
** $Workfile:  $
** Name:
** Copyright :Phaedrus Systems 1999
** $Author: $
** $Revision: $
**
** Analysis reference:
**
** Compiler :
** Target   :
**
** $Log: $
**
*/

/****************************************** Include */
#define CO0001_M

#include < system.h>
#include < thirdpartysw.h>
#include " project.h"

/****************************************** Defines */

#define name value
#define name value
#define name value

/****************************************** Globals */

/*************************************** Prototypes */

static void function(void)


/******************************************  Main */

void main(void)
{


}

/*********************************************************/
/***********  End of $Workfile: $******/
/*********************************************************/
```

```
/*****************************************************/
/*
**  $Workfile: $
**
**  Copyright:  Ltd
**  $Author: $
**
** $Revision: $
**
** Analysis reference:
** Compiler :
** Target   :
**
** $Log: $
**
*/

#ifndef CO0001_H
#define CO0001_H

ifdef CO0001_M
    #define _SCOPE_ /**/
#else
    #define _SCOPE_ extern
#endif

_SCOPE_   function_name()


#endif /*end guard */

/***** END of $Workfile: $ ************/


/*****************************************     */
/* Name:
**
** Purpose:
**
** Design reference:
**
** Input Parameters:
** Permitted range:
**
** Return Parameter:.
**
*/
```

5.4 Clear CASE Templates

```
/*****************************************************
** Workfile:
** Name:
** Copyright :
** Author:
** Revision:
**
** Analysis reference:
**
** Compiler :
** Target   :
**
**
**
*/

/****************************************** Include */
#define CO0001_M

#include <system.h>
#include <3rd party.h>
#include "project type defs"
#include "own module.h"

/****************************************** Defines */

#define name value
#define name value
#define name value


/****************************************** Globals */

/************************************** Prototypes */

static void function(void)


/*****************************************  Main */

void main(void)
{


}

/*****************************************************/
/***********  End of Workfile: ******/
/*****************************************************/
```

```
/*************************************************/
/*
** Workfile:
**
** Copyright:  Ltd
** Author:
**
** Revision:
**
** Analysis reference:
** Compiler :
** Target   :
**
** $Log: $
**
*/

#ifndef CO0001_H
#define CO0001_H

ifdef CO0001_M
    #define _SCOPE_ /**/
#else
    #define _SCOPE_ extern
#endif

_SCOPE_   function_name()


#endif /*end guard */

/***** END of Workfile:  ************/



/*****************************************     */
/* Name:
**
** Purpose:
**
** Design reference:
**
** Input Parameters:
** Permitted range:
**
** Return Parameter:.
**
*/
```

5.5 Component Software's RCS

```
//*****************************************************************
//
//      $RCSfile:$
//      Copyright
//      $Author:$
//      $Revision:$
//      $Date:$
//
//      Specification Document :
//      Compiler:
//      Target
//
//      $Log:$
//
//
//********************************************************** Include
#define UNIQUE_FILE_ID_HERE

#include <system.h>
#include <3rd party.h>
#include "project type defs"
#include "own module.h"

//********************************************************** Defines


//********************************************************** Globals


//********************************************************** Prototypes

// statics only!

//************************************************************ Main

void main(void)
{
        //Null statement
}

//*****************************************************************
/                               End of $RCSfile:$
//*****************************************************************
```

```
//*************************************************************
//
//      $RCSfile:$
//      Copyright
//      $Author:$
//      $Revision:$
//      $Date:$
//
//      Specification Document :
//      Compiler:
//      Target
//
//      $Log:$
//
//
#ifndef UNIQUE_FILE_ID_H
#define UNIQUE_FILE_ID_HERE_H

#ifdef UNIQUE_FILE_ID_M
     #define _SCOPE_ /**/
#else
    #define _SCOPE_ extern
#endif


_SCOPE_    function_name()

#endif // end guard

//*************************************************************
//                  End of $RCSfile:$
//*************************************************************
```

6 Appendix B Lint and Example Program

The following program, BADCODE.C, is one of the example programs provided with our evaluation kits. This program has a lot of errors and is intended to demonstrate the error detecting and correcting capabilities of our tools.

Following are listings of the example program, output from the C51 compiler, and output from PC-Lint. The C51 Compiler detects and reports 12 errors and warnings while PC-Lint detects and reports 26 errors and warnings.

As you can see, the quantity and quality of the error messages reported by PC-Lint is greater than that reported by the C compiler.

```
/*---------------------------------------------------------
BADCODE.C

Copyright 1995 KEIL Software, Inc.

This source file is full of errors.  You can use uVision
to compile and
correct errors in this file.
---------------------------------------------------------*/

#incldue <stdio.h>

void main (void, void)
{
unsigned i;
long fellow;

fellow = 0;

fer (i = 0; i < 1OOO; i++)
  {
  printf ("I is %u\n", i);

  fellow += i;
  printf ("Fellow = %ld\n, fellow);
  printf ("End of loop\n")
  }
}
```

C51 Output

When compiled with the C51 compiler, the BADCODE program generates the following errors and warnings:

```
MS-DOS C51 COMPILER V5.02
Copyright (c) 1995 KEIL SOFTWARE, INC.  All rights reserved.
*** ERROR 315 IN LINE 10 OF BADCODE.C: unknown #directive 'incldue'
*** ERROR 159 IN LINE 12 OF BADCODE.C: 'typelist': type follows void
*** WARNING 206 IN LINE 19 OF BADCODE.C: 'fer': missing function-
prototype
*** ERROR 267 IN LINE 19 OF BADCODE.C: 'fer': requires ANSI-style
prototype
*** ERROR 141 IN LINE 19 OF BADCODE.C: syntax error near ';'
*** ERROR 141 IN LINE 19 OF BADCODE.C: syntax error near 'OOO'
*** ERROR 202 IN LINE 19 OF BADCODE.C: 'OOO': undefined identifier
*** ERROR 141 IN LINE 19 OF BADCODE.C: syntax error near ')'
*** WARNING 206 IN LINE 21 OF BADCODE.C: 'printf': missing function-
prototype
*** ERROR 103 IN LINE 24 OF BADCODE.C: '<string>': unclosed string
*** ERROR 305 IN LINE 24 OF BADCODE.C: unterminated string/char const
*** ERROR 141 IN LINE 25 OF BADCODE.C: syntax error near 'printf'

C51 COMPILATION COMPLETE.  2 WARNING(S),  10 ERROR(S)
```

PC-Lint Output

When the same code is parsed by PC-Lint, the BADCODE program generates the following errors and warnings:

```
--- Module:   badcode.c
badcode.c  10  Error 16: Unrecognized name
badcode.c  10  Error 10: Expecting end of line
badcode.c  12  Error 66: Bad type
badcode.c  12  Error 66: Bad type
badcode.c  19  Info 718: fer undeclared, assumed to return int
badcode.c  19  Info 746: call to fer not made in the presence of a
prototype
badcode.c  19  Error 10: Expecting ','
badcode.c  19  Error 26: Expected an expression, found ';'
badcode.c  19  Warning 522: Expected void type, assignment, increment
or decrement
badcode.c  19  Error 10: Expecting ';'
badcode.c  19  Error 10: Expecting ';'
badcode.c  21  Info 718: printf undeclared, assumed to return int
badcode.c  21  Info 746: call to printf not made in the presence of a
prototype
badcode.c  23  Info 737: Loss of sign in promotion from long to
unsigned long
badcode.c  23  Info 713: Loss of precision (assignment) (unsigned
long to long)
badcode.c  24  Error 2: Unclosed Quote
badcode.c  25  Error 10: Expecting ','
badcode.c  26  Error 10: Expecting ','
badcode.c  26  Error 26: Expected an expression, found '}'
badcode.c  26  Warning 559: Size of argument no. 2 inconsistent with
format
badcode.c  26  Warning 516: printf has arg. type conflict (arg. no. 2
-- pointer vs. unsigned int) with line 21
badcode.c  27  Warning 550: fellow (line 15) not accessed

--- Global Wrap-up
Warning 526: printf (line 21, file badcode.c) not defined
Warning 628: no argument information provided for function printf
(line 21, file badcode.c)
Warning 526: fer (line 19, file badcode.c) not defined
Warning 628: no argument information provided for function fer (line
19, file badcode.c)
```

7 References

Beach & Hills Hitex *C51 Primer 4th* Ed, Hitex UK, 2002, http://www.hitex.co.uk

COX B, Software ICs and Objective C, Interactive Programming Environments, McGraw Hill, 1984

Hatton L, Safer C, Mcgraw-Hill(1994)

Hills C A, Embedded C: Traps and Pitfalls Chris Hills, Phaedrus Systems, September 1999, http://www.phaedsys.org

Hills C A, Embedded Debuggers Chris Hills & Mike Beach, Hitex (UK) Ltd. April 1999 http://www.hitex.co.uk & http://www.phaedsys.org

Hills CA & Beach M, Hitex, SCIL-Level A paper project managers, team leaders and Engineers on the classification of embedded projects and tools. Useful for getting accountants to spend money Download from www.scil-level.org

[Johnson] S. C. Johnson, 'Lint, a Program Checker,' in Unix Programmer's Manual, Seventh Edition, Vol. 2B, M. D. McIlroy and B. W. Kernighan, eds. AT&T Bell Laboratories: Murray Hill, NJ, 1979.

[Jones] A History of punched cards. Douglas W. Jones Associate Professor of Computer Science at the University of Iowa. http://www.cs.uiowa.edu/~jones/cards/index.html

Kernighan Brian W, The Practice of Programming. Addison Wesley 1999

Koenig A C Traps and Pitfalls, Addison Wesley, 1989

K&R The C programming Language 2nd Ed., Prentice-Hall, 1988

MISRA Guidelines For The Use of The C Language in Vehicle Based Software. 1998 From www.misra.org.uk and www.hitex.co.uk

Ritchie D. M. The Development of the C Language Bell Labs/Lucent Technologies Murray Hill, NJ 07974 USA 1993 available from his web site http://cm.bell-labs.com/cm/cs/who/dmr/index.htm. This is well worth reading.

Hitex (UK) Ltd.
Warwick Uni Science Park
Coventry, CV4 7EZ
http://www.hitex.co.uk/
chills@hitex.co.uk

Chris@phaedsys.org
http://quest.phaedsys.org/