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M16C v3.1

C Compiler, Assembler, Linker User's Manual

TASKING
Embedded software development from Altium

A publication of

Altium BV

Documentation Department

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MANUAL PURPOSE AND STRUCTURE

The documentation explains and describes how to use the M16C toolchain to program an M16C MCU.

Windows Users

You can use the tools either with the graphical Embedded Development Environment (EDE) or from the command line in a command prompt window.

Unix Users

For UNIX the toolchain works the same as it works for the Windows command line.

Directory paths are specified in the Windows way, with back slashes as in `\cm16c\bin`. Simply replace the back slashes by forward slashes for use with UNIX: `/cm16c/bin`.

Structure

The toolchain documentation consists of a User's Manual (this manual) which includes a Getting Started section and a separate Reference Manual.

First you need to install the software. This is described in Chapter 1, *Software Installation and Configuration*

After installation you are ready to follow the *Getting Started* in Chapter 2.

Next, move on with the other chapters which explain how to use the compiler, assembler, linker and the various utilities.

Once you are familiar with these tools, you can use the Reference Manual to lookup specific options and details to make full use of the M16C toolchain.

SHORT TABLE OF CONTENTS

Chapter 8: Using the Linker

Describes how you can use the linker. An extensive overview of all options is included in the Reference Manual.

Chapter 9: Using the Utilities

Describes several utilities and how you can use them to facilitate various tasks. The following utilities are included: control program, make utility and archiver.

CONVENTIONS USED IN THIS MANUAL

Notation for syntax

The following notation is used to describe the syntax of command line input:

bold	Type this part of the syntax literally.
italics	Substitute the italic word by an instance. For example: *filename* Type the name of a file in place of the word *filename*.
{ }	Encloses a list from which you must choose an item.
[ ]	Encloses items that are optional. For example **cm16c** [**-?**] Both **cm16c** and **cm16c -?** are valid commands.
|	Separates items in a list. Read it as OR.
...	You can repeat the preceding item zero or more times.
,...	You can repeat the preceding item zero or more times, separating each item with a comma.

Example

cm16c [*option*]... *filename*

You can read this line as follows: enter the command **cm16c** with or without an option, follow this by zero or more options and specify a *filename*. The following input lines are all valid:

```
cm16c test.c
cm16c -g test.c
cm16c -g -E test.c
```

Not valid is:

```
cm16c -g
```

According to the syntax description, you have to specify a filename.

Icons

The following illustrations are used in this manual:

Note: notes give you extra information.

Warning: read the information carefully. It prevents you from making serious mistakes or from loosing information.

This illustration indicates actions you can perform with the mouse. Such as EDE menu entries and dialogs.

Command line: type your input on the command line.

Reference: follow this reference to find related topics.

RELATED PUBLICATIONS

C Standards

- C A Reference Manual (fifth edition) by Samual P. Harbison and Guy L. Steele Jr. (2002, Prentice Hall)
- The C Programming Language (second edition) by B. Kernighan and D. Ritchie (1988, Prentice Hall)
- ISO/IEC 9899:1999(E), Programming languages – C [ISO/IEC]
  See also `http://www.ansi.org`
- DSP–C, An Extension to ISO/IEC 9899:1999(E), Programming languages – C [TASKING, TK0071–14]

MISRA C

- Guidelines for the Use of the C Language in Vehicle Based Software [MIRA limited, 1998]
  See also `http://www.misra.org.uk`
- MISRA–C:2004: Guidelines for the use of the C Language in critical systems [MIRA limited, 2004]
  See also `http://www.misra-c.com`

TASKING Tools

- M16C C Compiler, Assembler, Linker Reference Manual [TASKING, MB299–024–00–00]
- M16C C++ Compiler User’s Manual [TASKING, MA299–012–00–00]
- M16C CrossView Pro Debugger User’s Manual [TASKING, MA299–041–00–00]

M16C

- M16C Group Specification [Renesas]
- M16C/60/20 Series Software Manual [Renesas]

CHAPTER 1

SOFTWARE INSTALLATION AND CONFIGURATION

TASKING

CHAPTER 1

1.1 INTRODUCTION

This chapter guides you through the procedures to install the software on a Windows system or on a Linux or UNIX host.

The software for Windows has two faces: a graphical interface (Embedded Development Environment) and a command line interface. The Linux and UNIX software has only a command line interface.

After the installation, it is explained how to configure the software and how to install the license information that is needed to actually use the software.

1.2 SOFTWARE INSTALLATION

1.2.1 INSTALLATION FOR WINDOWS

1. Start Windows 95/98/XP/NT/2000, if you have not already done so.
2. Insert the CD–ROM into the CD–ROM drive.

   If the TASKING Showroom dialog box appears, proceed with Step 5.
3. Click the **Start** button and select **Run...**
4. In the dialog box type **`d:\setup`** (substitute the correct drive letter for your CD–ROM drive) and click on the **OK** button.

   The TASKING Showroom dialog box appears.
5. Select a product and click on the **Install** button.
6. Follow the instructions that appear on your screen.

   You can find your serial number on the invoice, delivery note, or picking slip delivered with the product.
7. License the software product as explained in section 1.4, *Licensing TASKING Products*.

1.2.2 INSTALLATION FOR LINUX

Each product on the CD–ROM is available as an RPM package, Debian package and as a gzipped tar file. For each product the following files are present:

```
SWproduct-version-RPMrelease.i386.rpm
swproduct_version-release_i386.deb
SWproduct-version.tar.gz
```

These three files contain exactly the same information, so you only have to install one of them. When your Linux distribution supports RPM packages, you can install the `.rpm` file. For a Debian based distribution, you can use the `.deb` file. Otherwise, you can install the product from the `.tar.gz` file.

RPM Installation

1. In most situations you have to be "root" to install RPM packages, so either login as "root", or use the **su** command.

2. Insert the CD–ROM into the CD–ROM drive. Mount the CD–ROM on a directory, for example `/cdrom`. See the Linux manual pages about **mount** for details.

3. Go to the directory on which the CD–ROM is mounted:

   ```
   cd /cdrom
   ```

4. To install or upgrade all products at once, issue the following command:

   ```
   rpm -U SW*.rpm
   ```

   This will install or upgrade all products in the default installation directory `/usr/local`. Every RPM package will create a single directory in the installation directory.

   The RPM packages are 'relocatable', so it is possible to select a different installation directory with the **--prefix** option. For instance when you want to install the products in `/opt`, use the following command:

   ```
   rpm -U --prefix /opt SW*.rpm
   ```

For Red Hat 6.0 users: The **--prefix** option does not work with RPM version 3.0, included in the Red Hat 6.0 distribution. Please upgrade to RPM verion 3.0.3 or higher, or use the `.tar.gz` file installation described in the next section if you want to install in a non–standard directory.

Debian Installation

1. Login as a user.

   Be sure you have read, write and execute permissions in the installation directory. Otherwise, login as ”root” or use the **su** command.

2. Insert the CD–ROM into the CD–ROM drive. Mount the CD–ROM on a directory, for example `/cdrom`. See the Linux manual pages about **mount** for details.

3. Go to the directory on which the CD–ROM is mounted:

   ```
   cd /cdrom
   ```

4. To install or upgrade all products at once, issue the following command:

   ```
   dpkg –i sw*.deb
   ```

   This will install or upgrade all products in a subdirectory of the default installation directory `/usr/local`.

Tar.gz Installation

1. Login as a user.

   Be sure you have read, write and execute permissions in the installation directory. Otherwise, login as ”root” or use the **su** command.

2. Insert the CD–ROM into the CD–ROM drive. Mount the CD–ROM on a directory, for example `/cdrom`. See the Linux manual pages about **mount** for details.

3. Go to the directory on which the CD–ROM is mounted:

   ```
   cd /cdrom
   ```

4. To install the products from the `.tar.gz` files in the directory `/usr/local`, issue the following command for each product:

   ```
   tar xzf SWproduct–version.tar.gz –C /usr/local
   ```

   Every `.tar.gz` file creates a single directory in the directory where it is extracted.

1.2.3 INSTALLATION FOR UNIX HOSTS

1. Login as a user.

   Be sure you have read, write and execute permissions in the installation directory. Otherwise, login as ”root” or use the **su** command.

   If you are a first time user, decide where you want to install the product. By default it will be installed in `/usr/local`.

2. Insert the CD–ROM into the CD–ROM drive and mount the CD–ROM on a directory, for example `/cdrom`.

   Be sure to use an ISO 9660 file system with Rock Ridge extensions enabled. See the UNIX manual pages about **mount** for details.

3. Go to the directory on which the CD–ROM is mounted:

   ```
   cd /cdrom
   ```

4. Run the installation script:

   ```
   sh install
   ```

   Follow the instructions appearing on your screen.

   First a question appears about where to install the software. The default answer is **`/usr/local`**.

   On some hosts the installation script asks if you want to install SW000098, the Flexible License Manager (FLEXlm). If you do not already have FLEXlm on your system, you must install it otherwise the product will not work on those hosts. See section 1.4, *Licensing TASKING Products*.

   If the script detects that the software has been installed before, the following messages appear on the screen:

   ```
          *** WARNING ***
   SWxxxxxx xxxx.xxxx already installed.
   Do you want to REINSTALL? [y,n]
   ```

   Answering **n** (no) to this question causes installation to abort and the following message being displayed:

   ```
   => Installation stopped on user request <=
   ```

Answer **y** (yes) to continue with the installation. The last message will be:

```
Installation of SWxxxxxx xxxx.xxxx completed.
```

5. If you purchased a protected TASKING product, license the software product as explained in section 1.4, *Licensing TASKING Products*.

1.3 SOFTWARE CONFIGURATION

Now you have installed the software, you can configure both the Embedded Development Environment and the command line environment for Windows, Linux and UNIX.

1.3.1 CONFIGURING THE EMBEDDED DEVELOPMENT ENVIRONMENT

After installation, the Embedded Development Environment is automatically configured with default search paths to find the executables, include files and libraries. In most cases you can use these settings. To change the default settings, follow the next steps:

1. Double–click on the EDE icon on your desktop to start the Embedded Development Environment (EDE).

2. From the **Project** menu, select **Directories...**

   The Directories dialog box appears.

3. Fill in the following fields:

   - In the **Executable Files Path** field, type the pathname of the directory where the executables are located. The default directory is `$(PRODDIR)\bin`.
   - In the **Include Files Path** field, add the pathnames of the directories where the compiler and assembler should look for include files. The default directory is `$(PRODDIR)\include`. Separate pathnames with a semicolon (;).

     The first path in the list is the first path where the compiler and assembler look for include files. To change the search order, simply change the order of pathnames.

- In the **Library Files Path** field, add the pathnames of the directories where the linker should look for library files. The default directory is `$(PRODDIR)\lib`. Separate pathnames with a semicolon (;).

  The first path in the list is the first path where the linker looks for library files. To change the search order, simply change the order of pathnames.

Instead of typing the pathnames, you can click on the **Configure...** button.

A dialog box appears in which you can select and add directories, remove them again and change their order.

1.3.2 CONFIGURING THE COMMAND LINE ENVIRONMENT

To facilitate the invocation of the tools from the command line (either using a Windows command prompt or using Linux or UNIX), you can set *environment variables*.

You can set the following variables:

Environment Variable	Description
PATH	With this variable you specify the directory in which the executables reside (default: `c:\cm16c\bin`). This allows you to call the executables when you are not in the `bin` directory. Usually your system already uses the PATH variable for other purposes. To keep these settings, you need to add (rather than replace) the path. Use a semicolon (;) to separate pathnames.
CM16CINC	With this variable you specify one or more additional directories in which the C compiler **cm16c** looks for include files. The compiler first looks in these directories, then always looks in the default `include` directory relative to the installation directory.
ASM16CINC	With this variable you specify one or more additional directories in which the assembler **asm16c** looks for include files. The assembler first looks in these directories, then always looks in the default `include` directory relative to the installation directory.
CCM16CBIN	With this variable you specify the directory in which the control program **ccm16c** looks for the executable tools. The path you specify here should match the path that you specified for the PATH variable.
CCM16COPT	With this variable you specify options and/or arguments to each invocation of the control program **ccm16c**. The control program processes these arguments before the command line arguments.
LIBM16C LIBR8C	With this variable you specify one or more alternative directories in which the linker **lkm16c** looks for library files for a specific core. The linker first looks in these directories, then always looks in the default `lib` directory.

Environment Variable	Description
LM_LICENSE_FILE	With this variable you specify the location of the license data file. You only need to specify this variable if the license file is not on its default location (`c:\flexlm` for Windows, `/usr/local/flexlm/licenses` for UNIX).
TASKING_LIC_WAIT	If you set this variable, the tool will wait for a license to become available, if all licenses are taken. If you have not set this variable, the tool aborts with an error message. (Only useful with floating licenses)
TMPDIR	With this variable you specify the location where programs can create temporary files. Usually your system already uses this variable. In this case you do not need to change it.

Table 1–1: Environment variables

The following examples show how to set an environment variable using the PATH variable as an example.

Example for Windows 95/98

Add the following line to your `autoexec.bat` file:

```
set PATH=%path%;c:\cm16c\bin
```

You can also type this line in a Command Prompt window but you will loose this setting after you close the window.

Example for Windows NT

1. Right–click on the `My Computer` icon on your desktop and select **Properties** from the menu.

   The System Properties dialog appears.

2. Select the **Environment** tab.

3. In the list of **System Variables** select **Path**.

4. In the **Value** field, add the path where the executables are located to the existing path information. Separate pathnames with a semicolon (;). For example: `c:\cm16c\bin`.

5. Click on the **Set** button, then click **OK**.

Example for Windows XP / 2000

1. Right–click on the `My Computer` icon on your desktop and select **Properties** from the menu.

   The System Properties dialog appears.

2. Select the **Advanced** tab.

3. Click on the **Environment Variables** button.

   The Environment Variables dialog appears.

4. In the list of **System variables** select **Path**.

5. Click on the **Edit** button.

   The Edit System Variable dialog appears.

6. In the **Variable value** field, add the path where the executables are located to the existing path information. Separate pathnames with a semicolon (;). For example: `c:\cm16c\bin`.

7. Click on the **OK** button to accept the changes and close the dialogs.

Example for UNIX

Enter the following line (C–shell):

```
setenv PATH $PATH:/usr/local/cm16c/bin
```

1.4 LICENSING TASKING PRODUCTS

TASKING products are protected with license management software (FLEXlm). To use a TASKING product, you must install the license key provided by TASKING for the type of license purchased.

You can run TASKING products with a node–locked license or with a floating license. When you order a TASKING product determine which type of license you need (UNIX products only have a floating license).

Node–locked license (PC only)

This license type locks the software to one specific PC so you can use the product on that particular PC only.

Floating license

This license type manages the use of TASKING product licenses among users at one site. This license type does not lock the software to one specific PC or workstation but it requires a network. The software can then be used on any computer in the network. The license specifies the number of users who can use the software simultaneously. A system allocating floating licenses is called a **license server**. A license manager running on the license server keeps track of the number of users.

1.4.1 OBTAINING LICENSE INFORMATION

Before you can install a software license you must have a "License Key" containing the license information for your software product. If you have not received such a license key follow the steps below to obtain one. Otherwise, you can install the license.

Windows

1. Run the License Administrator during installation and follow the steps to **Request a license key from Altium by E–mail**.

2. E–mail the license request to your local TASKING sales representative. The license key will be sent to you by E–mail.

UNIX

1. If you need a floating license on UNIX, you must determine the host ID and host name of the computer where you want to use the license manager. Also decide how many users will be using the product. See section 1.4.5, *How to Determine the Host ID* and section 1.4.6, *How to Determine the Host Name*.

2. When you order a TASKING product, provide the host ID, host name and number of users to your local TASKING sales representative. The license key will be sent to you by E–mail.

1.4.2 INSTALLING NODE-LOCKED LICENSES

If you do not have received your license key, read section 1.4.1, *Obtaining License Information*, before continuing.

1. Install the TASKING software product following the installation procedure described in section 1.2.1, *Installation for Windows*, if you have not done this already.

2. Create a license file by importing a license key or create one manually:

Import a license key

During installation you will be asked to run the License Administrator. Otherwise, start the License Administrator (**licadmin.exe**) manually.

In the License Administrator follow the steps to **Import a license key received from Altium by E–mail**. The License Administrator creates a license file for you.

Create a license file manually

If you prefer to create a license file manually, create a file called ”`license.dat`” in the `c:\flexlm` directory, using an ASCII editor and insert the license key information received by E–mail in this file. This file is called the ”license file”. If the directory `c:\flexlm` does not exist, create the directory.

If you wish to install the license file in a different directory, see section 1.4.4, *Modifying the License File Location*.

If you already have a license file, add the license key information to the existing license file. If the license file already contains any SERVER lines, you must use another license file. See section 1.4.4, *Modifying the License File Location*, for additional information.

The software product and license file are now properly installed.

1.4.3 INSTALLING FLOATING LICENSES

If you do not have received your license key, read section 1.4.1, *Obtaining License Information*, before continuing.

1. Install the TASKING software product following the installation procedure described earlier in this chapter on each computer or workstation where you will use the software product.
2. On each PC or workstation where you will use the TASKING software product the location of a license file must be known, containing the information of all licenses. Either create a local license file or point to a license file on a server:

Add a licence key to a local license file

A local license file can reduce network traffic.

On Windows, you can follow the same steps to import a license key or create a license file manually, as explained in the previous section with the installation of a node–locked license.

On UNIX, you have to insert the license key manually in the license file. The default location of the license file `license.dat` is in directory `/usr/local/flexlm/licenses` for UNIX.

If you wish to install the license file in a different directory, see section 1.4.4, *Modifying the License File Location*.

If you already have a license file, add the license key information to the existing license file. If the license file already contains any SERVER lines, make sure that the number of SERVER lines and their contents match, otherwise you must use another license file. See section 1.4.4, *Modifying the License File Location*, for additional information.

Point to a license file on the server

Set the environment variable **LM_LICENSE_FILE** to "*port@host*", where *host* and *port* come from the SERVER line in the license file. On Windows, you can use the License Administrator to do this for you. In the License Administrator follow the steps to **Point to a FLEXlm License Server to get your licenses**.

3. If you already have installed FLEXlm v8.4 or higher (for example as part of another product) you can skip this step and continue with step 4. Otherwise, install SW000098, the Flexible License Manager (FLEXlm), on the license server where you want to use the license manager.

It is not recommended to run a license manager on a Windows 95 or Windows 98 machine. Use Windows XP, NT or 2000 instead, or use UNIX or Linux.

4. If FLEXlm has already been installed as part of a non–TASKING product you have to make sure that the `bin` directory of the FLEXlm product contains a copy of the **Tasking** daemon. This file is present on every product CD that includes FLEXlm, in directory `licensing`.

5. On the license server also add the license key to the license file. Follow the same instructions as with "Add a license key to a local license file" in step 2.

See the FLEXlm PDF manual delivered with SW000098, which is present on each TASKING product CD, for more information.

1.4.4 MODIFYING THE LICENSE FILE LOCATION

The default location for the license file on Windows is:

```
c:\flexlm\license.dat
```

On UNIX this is:

```
/usr/local/flexlm/licenses/license.dat
```

If you want to use another name or directory for the license file, each user must define the environment variable **LM_LICENSE_FILE**.

If you have more than one product using the FLEXlm license manager you can specify multiple license files to the **LM_LICENSE_FILE** environment variable by separating each pathname (*lfpath*) with a '**;**' (on UNIX '**:**'):

Example Windows:

```
set LM_LICENSE_FILE=c:\flexlm\license.dat;c:\license.txt
```

Example UNIX:

```
setenv LM_LICENSE_FILE
/usr/local/flexlm/licenses/license.dat:/myprod/license.txt
```

If the license file is not available on these hosts, you must set **LM_LICENSE_FILE** to *port@host*; where *host* is the host name of the system which runs the FLEXlm license manager and *port* is the TCP/IP port number on which the license manager listens.

To obtain the port number, look in the license file at *host* for a line starting with "SERVER". The fourth field on this line specifies the TCP/IP port number on which the license server listens. For example:

```
setenv LM_LICENSE_FILE 7594@elliot
```

See the FLEXlm PDF manual delivered with SW000098, which is present on each TASKING product CD, for detailed information.

1.4.5 HOW TO DETERMINE THE HOST ID

The host ID depends on the platform of the machine. Please use one of the methods listed below to determine the host ID.

Platform	Tool to retrieve host ID	Example host ID
HP–UX	**lanscan** (use the station address without the leading '0x')	0000F0050185
Linux	**hostid**	11ac5702
SunOS/Solaris	**hostid**	170a3472
Windows	**licadmin** (License Administrator, or use **lmhostid**)	0060084dfbe9

Table 1–2: Determine the host ID

On Windows, the License Administrator (**licadmin**) helps you in the process of obtaining your license key.

If you do not have the program **licadmin** you can download it from our Web site at: http://www.tasking.com/support/flexlm/licadmin.zip . It is also on every product CD that includes FLEXlm, in directory `licensing`.

1.4.6 HOW TO DETERMINE THE HOST NAME

To retrieve the host name of a machine, use one of the following methods.

Platform	Method
UNIX	**hostname**
Windows NT	**licadmin** or: Go to the Control Panel, open "Network". In the "Identification" tab look for "Computer Name".
Windows XP/2000	**licadmin** or: Go to the Control Panel, open "System". In the "Computer Name" tab look for "Full computer name".

Table 1–3: Determine the host name

CHAPTER 2

GETTING STARTED

TASKING

CHAPTER 2

2.1 INTRODUCTION

With the TASKING M16C suite you can write, compile, assemble, link and locate applications for the several M16C cores.

Embedded Development Environment

The TASKING Embedded Development Environment (EDE) is a Windows application that facilitates working with the tools in the toolchain and also offers project management and an integrated editor.

EDE has three main functions: *Edit / Project management*, *Build* and *Debug*. The figure below shows how these main functionalities relate to each other.

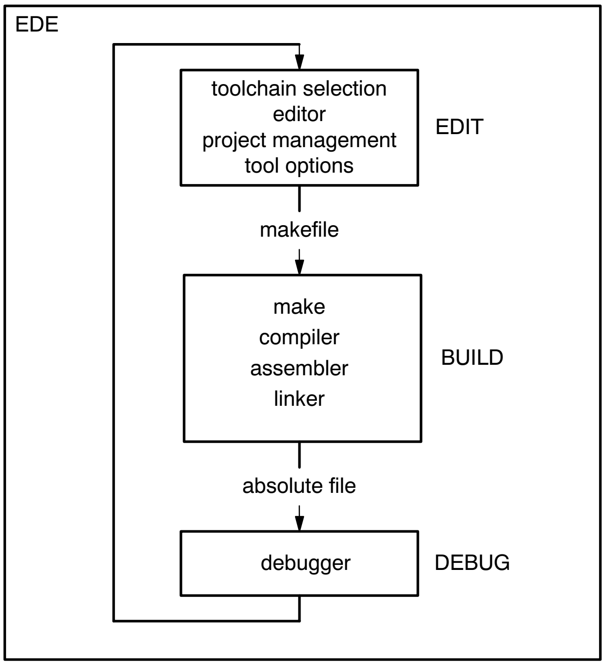


Figure 2–1: EDE development flow

In the **Edit** part you make all your changes:

- create a project space
- create and maintain one or more projects in a project space
- add, create and edit source files in a project
- set the options for each tool in the toolchain
- select another toolchain if you want to create an application for another target than the M16C.

In the **Build** part you build your files:

- a makefile (created by the Edit part) is used to invoke the needed toolchain components, resulting in an absolute object file.

In the **Debug** part you can debug your project:

- call the TASKING debugger "CrossView Pro" with the generated absolute object file.

This *Getting Started* Chapter guides you step–by–step through the most important features of EDE

The TASKING EDE is an *embedded* environment and differs from a *native* program development.

A *native* program development environment is often used to develop applications for systems where the host system and the target are the same. Therefore, it is possible to run a compiled application directly from the development environment.

In an *embedded* environment, however, a simulator or target hardware is required to run an application. TASKING offers a number of simulators and target hardware debuggers.

Toolchain overview

You can use all tools in the toolchain from the embedded development environment (EDE) and from the command line in a Command Prompt window or a UNIX shell.

The next illustration shows all components of the M16C toolchain with their input and output files.

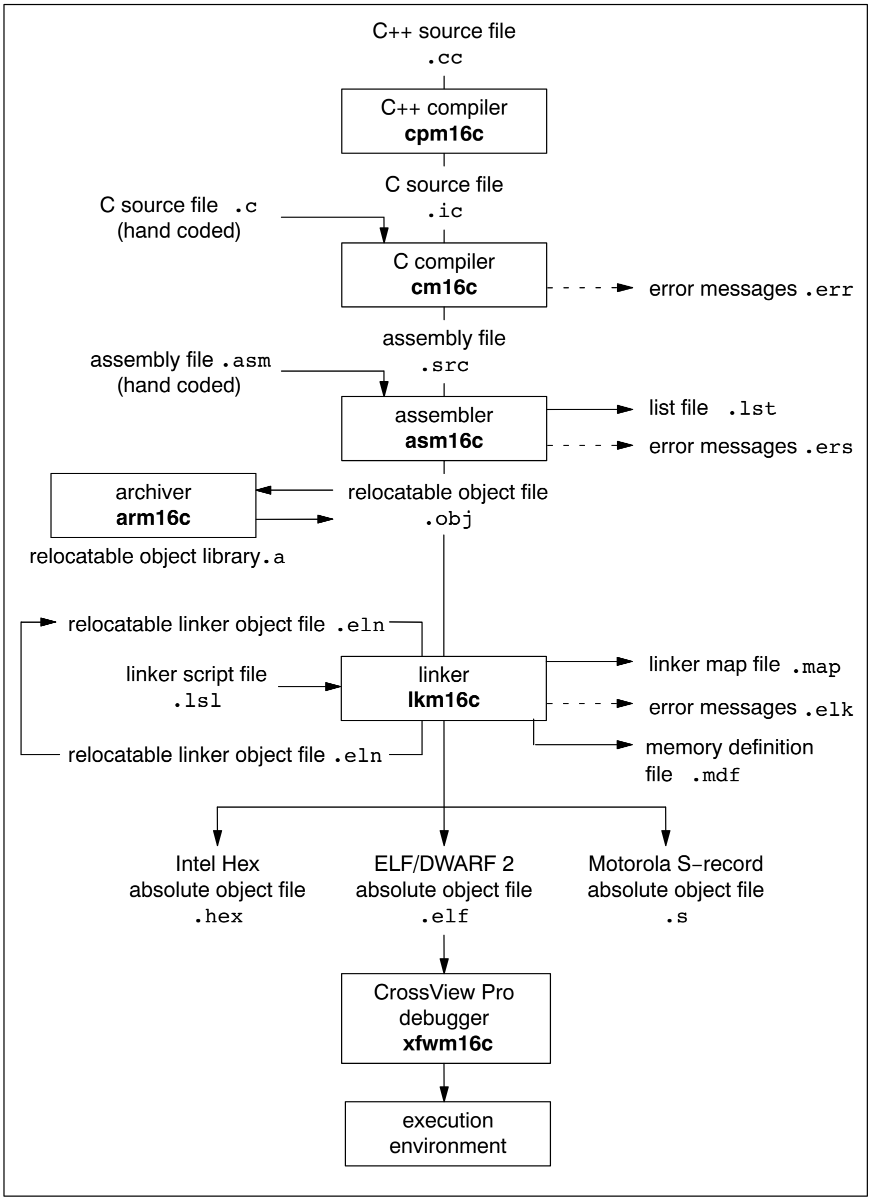


Figure 2–2: M16C toolchain

The following table lists the file types used by the M16C toolchain.

Extension	Description
Source files	
.cc	C++ source file, input for the C++ compiler
.c	C source file, input for the C compiler
.asm	Assembler source file, hand coded
.lsl	Linker script file using the Linker Script Language
Generated source files	
.ic	C source file, generated by the C++ compiler, input for the C compiler
.src	Assembler source file, generated by the C compiler, does not contain macros
Object files	
.obj	ELF/DWARF relocatable object file, generated by the assembler
.a	Archive with ELF/DWARF object files
.eln	Relocatable linker output file
.elf	ELF/DWARF absolute object file, generated by the locating part of the linker
.hex	Absolute Intel Hex object file
.s	Absolute Motorola S–record object file
List files	
.lst	Assembler list file
.map	Linker map file
.mdf	Memory definition file
.mcr	MISRA C report file
Error list files	
.err	Compiler error messages file
.ers	Assembler error messages file
.elk	Linker error messages file

Table 2–1: File extensions

2.2 WORKING WITH PROJECTS IN EDE

EDE is a complete project environment in which you can create and maintain project spaces and projects. EDE gives you direct access to the tools and features you need to create an application from your project.

A *project space* holds a set of projects and must always contain at least one project. Before you can create a project you have to setup a project space. All information of a project space is saved in a *project space file* (`.psp`):

- a list of projects in the project space
- history information

Within a project space you can create *projects*. Projects are bound to a target! You can create, add or edit files in the project which together form your application. All information of a project is saved in a *project file* (`.pjt`):

- the target for which the project is created
- a list of the source files in the project
- the options for the compiler, assembler, linker and debugger
- the default directories for the include files, libraries and executables
- the build options
- history information

When you build your project, EDE handles file dependencies and the exact sequence of operations required to build your application. When you push the **Build** button, EDE generates a makefile, including all dependencies, and builds your application.

Overview of steps to create and build an application

1. Create a project space
2. Add one or more projects to the project space
3. Add files to the project
4. Edit the files
5. Set development tool options
6. Build the application

2.3 START EDE

Start EDE

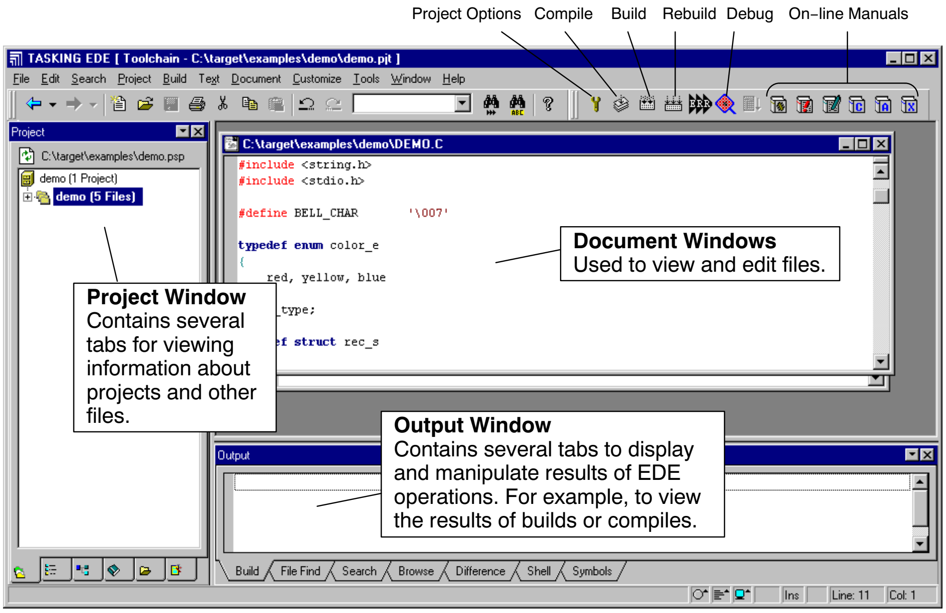
- Double–click on the EDE shortcut on your desktop.

  – or –

  Launch EDE via the program folder created by the installation program. Select **Start –> Programs –> TASKING *toolchain* –> EDE**.

Figure 2–3: EDE icon

The EDE screen contains a menu bar, a toolbar with command buttons, one or more windows (default, a window to edit source files, a project window and an output window) and a status bar.


Project Options
Compile
Build
Rebuild
Debug
On–line Manuals
TASKING EDE [Toolchain - C:\target\examples\demo\demo.pjt]
File Edit Search Project Build Text Document Customize Tools Window Help
Project
C:\target\examples\demo.psp
demo (1 Project)
demo (5 Files)
C:\target\examples\demo\DEMO.C
Output
Build File Find Search Browse Difference Shell Symbols
Ins Line: 11 Col: 1

```
#include <string.h>
#include <stdio.h>

#define BELL_CHAR       '\007'

typedef enum color_e
{
    red, yellow, blue

 _type;

ef struct rec_s
```

Document Windows
Used to view and edit files.

Project Window
Contains several tabs for viewing information about projects and other files.

Output Window
Contains several tabs to display and manipulate results of EDE operations. For example, to view the results of builds or compiles.

Figure 2–4: EDE desktop

2.4 USING THE SAMPLE PROJECTS

When you start EDE for the first time (see section 2.3, *Start EDE*), EDE opens with a ready defined project space that contains several sample projects. Each project has its own subdirectory in the `examples` directory. Each directory contains a file `readme.txt` with information about the example. The default project is called `demo.pjt` and contains a CrossView Pro debugger example.

Select a sample project

To select a project from the list of projects in a project space:

1. In the Project Window, right–click on the project you want to open.

   A menu appears.

2. Select **Set as Current Project**.

   The selected project opens.

3. Read the file `readme.txt` for more information about the selected sample project.

Building a sample project

To build the currently active sample project:

- Click on the **Execute 'Make' command** button.

*Once the files have been processed you can inspect the generated messages in the **Build** tab of the **Output** window.*

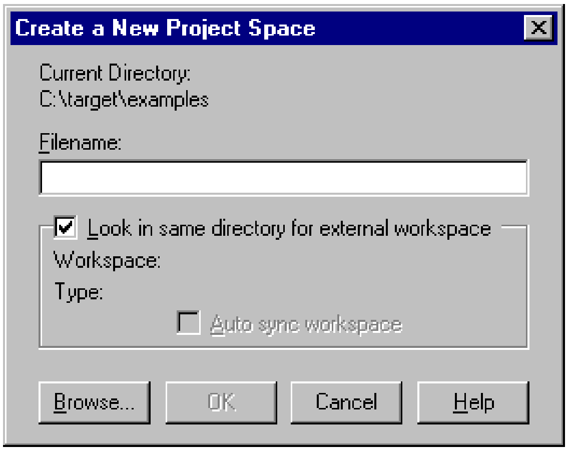
2.5 CREATE A NEW PROJECT SPACE WITH A PROJECT

Creating a project space is in fact nothing more than creating a project space file (`.psp`) in an existing or new directory.

Create a new project space

1. From the **File** menu, select **New Project Space...**

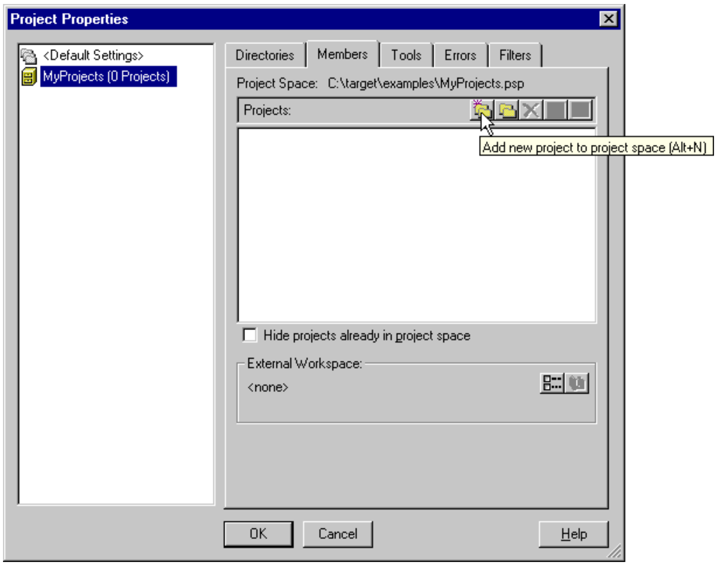
   The Create a New Project Space dialog appears.



2. In the the **Filename** field, enter a name for your project space (for example `MyProjects`). Click the **Browse** button to select a directory first and enter a filename.

3. Check the directory and filename and click **OK** to create the `.psp` file in the directory shown in the dialog.

   A project space information file with the name `MyProjects.psp` *is created and the Project Properties dialog box appears with the project space selected.*



Project Space: C:\target\examples\MyProjects.psp

Add new project to project space (Alt+N)

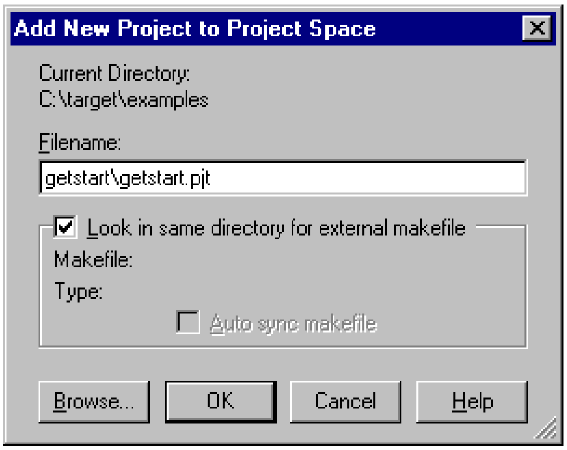
☐ Hide projects already in project space

External Workspace: <none>

Add a new project to the project space

4. In the Project Properties dialog, click on the **Add new project to project space** button (see previous figure).

   The Add New Project to Project Space dialog appears.



Current Directory:
C:\target\examples

Filename: getstart\getstart.pjt

☑ Look in same directory for external makefile

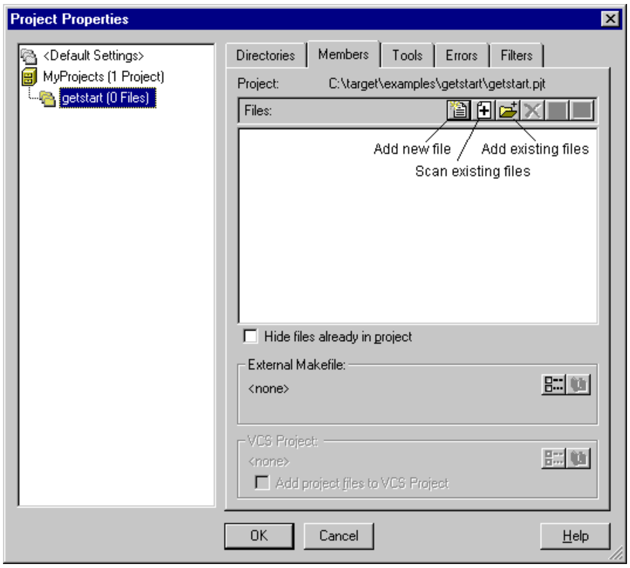
Makefile:

Type:

☐ Auto sync makefile

5. Give your project a name, for example `getstart\getstart.pjt` (a directory name to hold your project files is optional) and click **OK**.

   A project file with the name `getstart.pjt` *is created in the directory* `getstart`*, which is also created. The Project Properties dialog box appears with the project selected.*


Project Properties

<Default Settings>
MyProjects (1 Project)
getstart (0 Files)

Directories | Members | Tools | Errors | Filters

Project: C:\target\examples\getstart\getstart.pjt

Files:

☐ Hide files already in project

External Makefile:
<none>

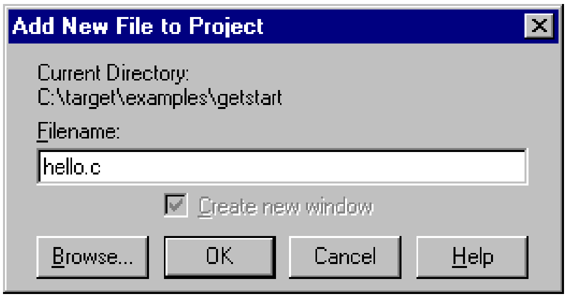
VCS Project:
<none>
☐ Add project files to VCS Project

Add new files to the project

Now you can add all the files you want to be part of your project.

6. Click on the **Add new file to project** button.

   The Add New File to Project dialog appears.


Add New File to Project

Current Directory:
C:\target\examples\getstart

Filename:
hello.c

☑ Create new window

7. Enter a new filename (for example `hello.c`) and click **OK**.

   A new empty file is created and added to the project. Repeat steps 6 and 7 if you want to add more files.

8. Click **OK**.

   The new project is now open. EDE loads the new file(s) in the editor in separate document windows.

   EDE automatically creates a *makefile* for the project (in this case `getstart.mak`). This file contains the rules to build your application. EDE updates the makefile every time you modify your project.

Edit your files

9. As an example, type the following C source in the `hello.c` document window:

```
#include <stdio.h>

void main(void)
{
    printf(”Hello World!\n”);
}
```

10. Click on the **Save the changed file <Ctrl–S>** button.

    EDE saves the file.

2.6 SET OPTIONS FOR THE TOOLS IN THE TOOLCHAIN

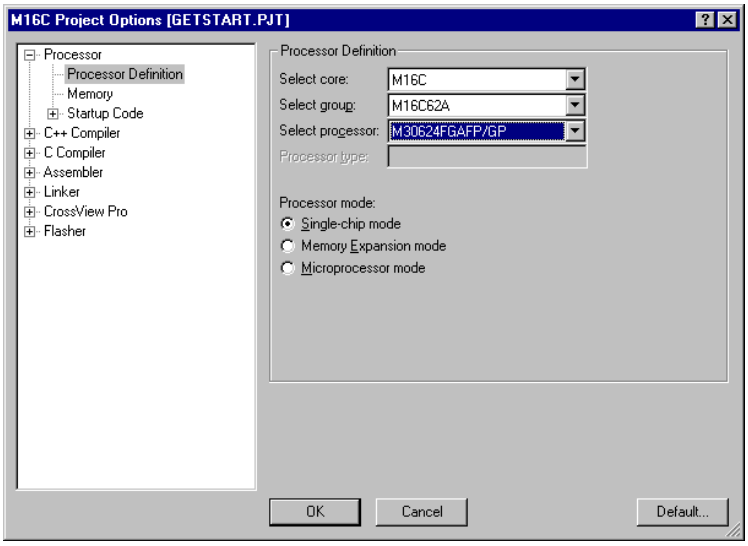
The next step in the process of building your application is to select a target processor and specify the options for the different parts of the toolchain, such as the C compiler, assembler, linker and debugger.

Select a target processor

1. From the **Project** menu, select **Project Options...**

   The Project Options dialog appears.

2. Expand the **Processor** entry and select **Processor Definition**.



M16C Project Options [GETSTART.PJT]

Processor Definition

Select core: M16C

Select group: M16C62A

Select processor: M30624FGAFP/GP

Processor type:

Processor mode:
- [✓ Single-chip mode]
- Memory Expansion mode
- Microprocessor mode

3. In the **Select core** list select (for example) **M16C**.

4. In the **Select group** list select (for example) **M16C62A**.

5. In the **Select processor** list select (for example) **M30624FGAFP/GP**.

6. Optional for some processors, select a **Processor mode**.

7. Click **OK** to accept the new project settings.

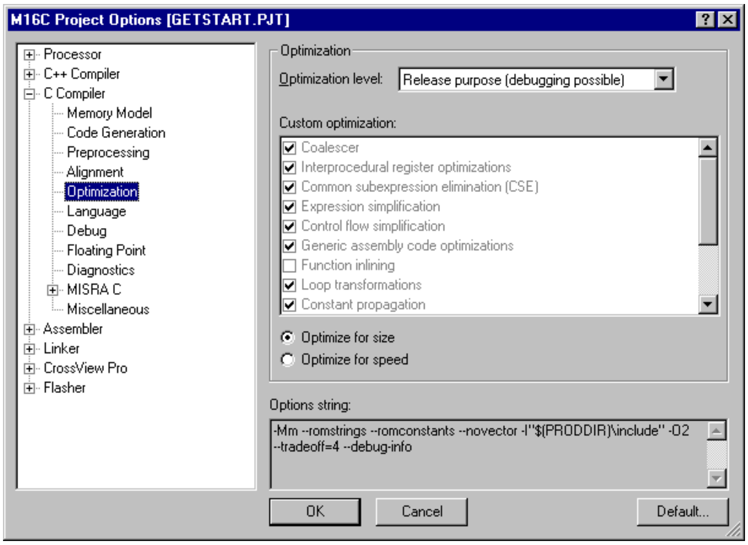
Set tool options

1. From the **Project** menu, select **Project Options...**

   The Project Options dialog appears. Here you can specify options that are valid for the entire project. To overrule the project options for the currently active file instead, from the ***Project*** *menu select* ***Current File Options...***

2. Expand the **C Compiler** entry.

   The C Compiler entry contains several pages where you can specify C compiler settings.



Optimization

Optimization level: Release purpose (debugging possible)

Custom optimization:

- [✓] Coalescer
- [✓] Interprocedural register optimizations
- [✓] Common subexpression elimination (CSE)
- [✓] Expression simplification
- [✓] Control flow simplification
- [✓] Generic assembly code optimizations
- [ ] Function inlining
- [✓] Loop transformations
- [✓] Constant propagation

[✓ Optimize for size] Optimize for speed

Options string:

```
-Mm --romstrings --romconstants --novector -I"$(PRODDIR)\include" -O2
--tradeoff=4 --debug-info
```

3. For each page make your changes. If you have made all changes click **OK**.

The **Cancel** button closes the dialog without saving your changes. With the **Default...** button you can restore the default project options (for the current page, or all pages in the dialog).

4. Make your changes for all other entries (Assembler, Linker, CrossView Pro, Flasher) of the Project Options dialog in a similar way as described above for the C compiler.

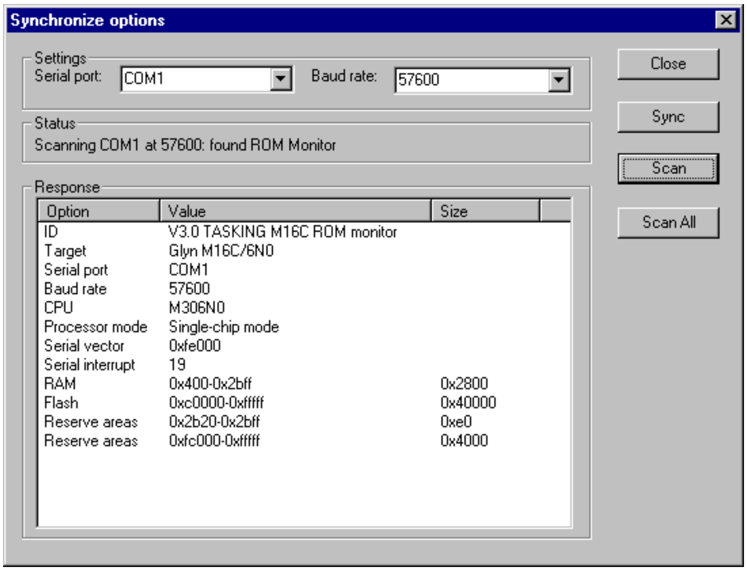
If available, the **Options string** field shows the command line options that correspond to your graphical selections.

Synchronize options with the ROM monitor

If you use a ROM monitor for debugging, you must be sure that all EDE settings are correct for communicating with the ROM monitor. If the ROM monitor target board is connected to your PC, EDE can automatically set the correct options based on the ROM monitor. To do this:

1. Click on the **Synchronize options with the ROM monitor** button.

The Synchronize Options dialog appears.



Settings
Serial port: COM1 Baud rate: 57600

Status
Scanning COM1 at 57600: found ROM Monitor

Response

Option	Value	Size
ID	V3.0 TASKING M16C ROM monitor	
Target	Glyn M16C/6N0	
Serial port	COM1	
Baud rate	57600	
CPU	M306N0	
Processor mode	Single-chip mode	
Serial vector	0xfe000	
Serial interrupt	19	
RAM	0x400-0x2bff	0x2800
Flash	0xc0000-0xfffff	0x40000
Reserve areas	0x2b20-0x2bff	0xe0
Reserve areas	0xfc000-0xfffff	0x4000

2. Specify the **Serial port** and **Baud rate** at which the ROM monitor is connected and click **Scan**. If you do not know the port or baud rate, you can click **Scan All** to scan all COM ports for the ROM monitor.

3. Click **Sync** to synchronize the shown options with the current project.

   A message appears that the current project has been synchronized with the ROM monitor.

4. Click **OK** to close the message box.

5. Click **Close** to close the dialog.

2.7 BUILD YOUR APPLICATION

If you have set all options, you can actually compile the file(s). This results in an absolute ELF/DWARF object file which is ready to be debugged.

Build your Application

To build the currently active project:

- Click on the **Execute ’Make’ command** button.

The file is compiled, assembled, linked and located. The resulting file is `getstart.elf`.

The build process only builds files that are out–of–date. So, if you click **Make** again in this example nothing is done, because all files are up–to–date.

Viewing the Results of a Build

Once the files have been processed, you can see which commands have been executed (and inspect generated messages) by the build process in the **Build** tab of the **Output** window.

This window is normally open, but if it is closed you can open it by selecting the **Output** menu item in the **Window** menu.

Compiling a Single File

1. Select the window (document) containing the file you want to compile or assemble.

2. Click on the **Execute ’Compile’ command** button. The following button is the execute Compile button which is located in the toolbar.

   If you selected the file `hello.c`*, this results in the compiled and assembled file* `hello.obj`.

Rebuild your Entire Application

If you want to compile, assemble and link/locate all files of your project from scratch (regardless of their date/time stamp), you can perform a rebuild.

- Click on the **Execute ’Rebuild’ command** button. The following button is the execute Rebuild button which is located in the toolbar.

2.8 HOW TO BUILD YOUR APPLICATION ON THE COMMAND LINE

If you are not using EDE, you can build your entire application on the command line. The easiest way is to use the *control program* **ccm16c**

1. In a text editor, write the file `hello.c` with the following contents:

```
#include <stdio.h>

void main(void)
{
    printf(”Hello World!\n”);
}
```

2. Build the file `getstart.elf`:

```
ccm16c –ogetstart.elf hello.c –v
```

The control program calls all tools in the toolchain. The ***–v*** *option shows all the individual steps. The resulting file is* `getstart.elf`.

2.9 DEBUG GETSTART.ELF

The application `getstart.elf` is the final result, ready for execution and/or debugging. The debugger uses `getstart.elf` for debugging but needs symbolic debug information for the debugging process. This information must be included in `getstart.elf` and therefore you need to compile and assemble `hello.c` once again.

```
ccm16c -g -ogetstart.elf hello.c
```

Now you can start the debugger with `getstart.elf` and see how it executes.

Start CrossView Pro

- Click on the **Debug application** button.

CrossView Pro is launched. CrossView Pro will automatically download the file `getstart.elf` *for debugging.*

See the *CrossView Pro Debugger User's Manual* for more information.

CHAPTER

C LANGUAGE

3

TASKING

CHAPTER 3

3.1 INTRODUCTION

The TASKING C cross–compiler (**cm16c**) fully supports the ISO C99 standard. In addition, it adds extra possibilities to write fast and compact code for the M16C and to use the special functions of the M16C.

In addition to the standard C language, the compiler supports the following:

- extra data type `__bit`
- intrinsic (built–in) functions that result in M16C specific assembly instructions
- pragmas to control the compiler from within the C source
- predefined macros
- the possibility to use assembly instructions in the C source
- keywords to specify memory types for data and functions
- attributes to specify alignment and absolute addresses
- keywords for programming interrupt routines
- libraries

All non–standard keywords have two leading underscores (__).

This chapter first describes programming strategies and tips for writing optimal code for the M16C. Next, the M16C specific characteristics of the C language are described into more detail.

3.2 PROGRAMMING STRATEGIES

3.2.1 MEMORY SPACES

Choosing Memory Spaces

The TASKING M16C toolchain introduces several qualifiers to control how and where you want to allocate C objects in memory. Among others, the following memory qualifiers exist:

• `__far`	anywhere in the 20 bit space, objects can be of any size.
• `__paged`	anywhere in the 20 bit space, objects must be smaller than 64 kB and will never cross 64k boundaries
• `__near`	first 64k
• `__bita`	first 8k (the bitaddressable space)

Most M16C instructions can address operands in memory only if they lie in the first 64k. For *far* addresses, expensive load/store instructions are needed. For this reason, using `__near` qualified variables generates much faster code than using `__far` or `__paged` variables.

A pointer to a `__near` qualified object fits in one 16 bit address register, for a pointer to a `__far` or `__paged` object the double register A1A0 is needed. Also, pointer arithmetic for `__near` pointers is much faster.

`__paged` qualified objects are guaranteed not to be allocated accross 64k boundaries. Therefor, pointer arithmetic on pointers to paged memory only requires updates of the A0 register. For pointers to far memory both A1 and A0 need to be altered. So, pointer arithmetic is often twice as fast for pointers to paged memory.

The stack lies always in the first 64k bytes, so a variable on the stack is implicitly `__near` qualified. This means that automatic variables are always fastest (regardless of the chosen memory model).

Objects qualified with `__bita` are bit–addressable. This means that setting and getting individual bits can be done with the fast bit instructions of the M16C.

String and Constant Allocation

Strings and constants can be allocated in both ROM and RAM memory. If allocated in RAM, they have to be initialized from a copy in ROM during program startup. So allocating in ROM saves both memory and time. You can achieve this by enabling the options **Keep strings in ROM** and **Keep constants in ROM** on the Code Generation page of the C Compiler options. Note that strings in ROM cannot be modified at run–time.

Usual M16C hardware configurations have no ROM in the *near* space (first 64k of memory). So by default, even with **Keep strings in ROM** and **Keep constants in ROM** enabled, `__near` qualified objects in those cases are allocated in RAM.

In case your hardware does have ROM in the near space, you should enable the option **ROM is available in first 64k of memory** on the Code Generation page of the C Compiler options.

Choosing a Memory Model

The memory model determines the default memory space qualifier for objects. It also determines which library must be linked (library functions have no memory qualifiers in their prototypes).

In the *small* memory model, all objects get the `__near` qualifier implicitly. In the *large* memory model, all objects get the `__far` qualifier implicitly. In the *medium* memory model, all constants, string literals and pointers get the `__paged` qualifier implicitly, while variables get the `__near` qualifier.

Note that the medium memory model is specifically tailored to allocate constants and strings in ROM. Constants get the `__paged` qualifier implicitly, so they can be put in ROM. Other variables get the `__near` qualifier for optimal performance. By default, pointers are implicitly `__paged` qualified, so they can point to both constants and variables. Variables that do not fit in *near* memory can easily be qualified as `__paged`, as this leads to no problems with default pointers and library calls. For before mentioned reasons, the *medium* memory model is the default.

Strategies

As explained above, allocating everything in the near memory space by using the small memory model yields the fastest and most compact code.

However, for larger projects this obviously is not an option. To reap some of the benefits though, you can use memory qualifiers to force frequently used and/or small variables in *near* memory and rarely used and/or large variables in *far* memory.

One strategy is to use the *small* memory model, but qualify large objects as `__paged` or `__far` when absolutely necessary. 'Far' pointers cannot be cast to 'near' pointers. The compiler will check this, but it can be inconvenient, especially for library calls.

Another strategy is the other way around: use the *large* memory model and qualify, where possible, variables as `__near`. Be careful with pointers though, default pointers are `__far` qualified and will produce inefficient code if used with `__near` objects.

3.2.2 BIT PROGRAMMING

The M16C has efficicient instructions to manipulate individual bits. However, these instructions are usually only available for variables in the first 8kB of memory (the *bita* space).

To generate these fast bit instructions, the compiler **cm16c** supports the `__bit` basic type. This type is implicitly allocated in the *bit* space.

Pointers to `__bit` variables are special, since they use bit addresses instead of bytes. Therefore, `__bit` variables do have some restrictions (see subsection *Bit Data Type* in section 3.3, *Data Types*).

By using the `__bit` type, the compiler **cm16c** can also generate fast bit instructions for bitfield operations. To make this possible, you have to allocate the structure in the *bita* space using the `__bita` memory qualifier:

```
__bita struct
{
     int bit0 : 1;
     int bit1 : 1;
     int bit2 : 1;
} threebits;
```

is equivalent to:

```
struct
      __bit bit0;
      __bit bit1;
      __bit bit2;
} threebits;
```

Note however that the upper example places bitfields in the *bita* space, making each bit within a byte addressable (mau 8), whereas the lower example places bits in the *bit* space making each bit directly addressable (mau 1).

Former TASKING M16C toolchains supported `__atbit()` for an equivalent construction. While this is still supported, its use is deprecated.

3.2.3 FLOATING-POINT

Floating–point operations are not supported by M16C hardware. Instead run–time functions are used to handle floating–points. Try to avoid using floating–point and use integers instead.

If you still need floating–point arithmetic, try to use single precision floating–point. Arithmetic with floats is much faster than with doubles.

To illustrate this using the *whetstone* example:

Whetstone	Float	Double	Achievement
whet.c	1869 bytes	2335 bytes	Size of module whet_CO is 20% smaller for float than for double.
whet.elf	9618 bytes	15079 bytes	Size of application is 36% smaller for float than for double.
time	36 sec	220 sec	Execution time is 84% faster for float than for double.

Floating–point constants like 1.0 are double precision according to the C standard. If you only need single precision, make sure to use the float postfix notation for constants, for example `1.0f`.

In ISO C99 all library function like `double cos(double)` have a single precision parallel function like `float cosf(float)`. Use these single precision functions whenever possible. The tgmath.h header file even contains type generic functions which automatically call the best variant (see section 2.2.13, *Math.h and Tgmath.h* in Chapter *Libraries* of the *Reference Manual*).

Variable argument lists can never be float, only double. But there is one exception: with the option **Use single precision float point only** on the floating–point page of the Compiler options, floats are used everywhere instead of doubles, also in varargs! This is the only way to have single precision floats in vararg functions like `printf`.

3.2.4 GENERAL OPTIMIZATION TIPS

Try to use *local* variables instead of *global* variables because:

- Locals can often be allocated in registers.
- Memory on the stack can be reused by sibling functions
- The compiler must assume external function calls read and write all global variables, which might make some optimizations impossible.

Avoid taking the address of variables (using the `&` operator) because:

- Variables whose address is taken cannot be allocated in a register
- The compiler must assume every external function can call the variable by reference, precluding some optimizations.

Optimization settings

Inline function calls

- Enable **Function inlining** (or choose the **Agressive (all)** optimization level) on the Optimization page of the Compiler options (command line option **–Oi** or **–O3**)
- Use function qualifiers `inline` and `__noinline` to give extra hints to the compiler.
- Inlining results in faster, but often in larger code if **Optimize for size** is not set.
- Debugging inlined code can be harder

Reverse inlining

- The compiler has an option to 'reverse inline' functions: by making a compiler–generated function for repeated code sequences. This always results in smaller, but slower code. To get the smallest code size possible, this optimization can really help.
- You can enable both **Function inlining** and **Reverse inlining** at the same time. Inlining may increase the possibilities for reverse inlining which leads to faster and smaller code.
- The **cm16c** compiler offers the option to compile several C–modules in one single pass, this is called *MIL linking*. This makes several compiler optimizations much more effective, notably inlining and reverse inlining.
- To enable MIL linking, enable the option **MIL linking (compile multiple C files simultaneously)** on the Optimization page of the C Compiler options, or choose **Agressive (all)** optimization).

Be cautious with inline assembly (__asm)

- `__asm()` statements are not analyzed by the compiler, they are copied verbatim to the output assembly. Because of this, the compiler cannot optimize the surrounding code. It is recommended to use plain C and intrinsic functions whenever possible.

3.3 DATA TYPES

The TASKING C compiler for the M16C architecture supports the following data types:

Type	Keyword	Size (bit)	Align (bit)	Ranges
Bit	`__bit`	1	1	0 or 1
Boolean	`_Bool`	1	8	0 or 1

Character	`char`
	`signed char`
		8	8	-2^{7} .. $2^{7}-1$

	`unsigned char`	8	8	0 .. $2^{8}-1$

Integral	`short`
	`signed short`
	`int`
	`signed int`
		16	8 / 16*	-2^{15} .. $2^{15}-1$

	`unsigned short`
	`unsigned int`
		16	8 / 16*	0 .. $2^{16}-1$

	`enum`	1 8 16	8 8 / 16* 8 / 16*	0 or 1 -2^{7} .. $2^{7}-1$ -2^{15} .. $2^{15}-1$

	`long`
	`signed long`
		32	8 / 16*	-2^{31} .. $2^{31}-1$

	`long long`
	`signed long long`
		64	8 / 16*	-2^{63} .. $-2^{63}-1$

	`unsigned long`	32	8 / 16*	0 .. $2^{32}-1$
	`unsigned long long`	64	8 / 16*	0 .. $2^{64}-1$
Pointer	`pointer to __sfr, __bita`	16	8 / 16*	0 .. $2^{13}-1$
	`pointer to __near`	16	8 / 16*	0 .. $2^{16}-1$
	`pointer to __far, __paged`	32	8 / 16*	0 .. $2^{20}-1$

Type	Keyword	Size (bit)	Align (bit)	Ranges
Floating Point	`float`	32	8 / 16*	$-3.402e^{38}$ .. $-1.175e^{-38}$ $1.175e^{-38}$ .. 3.402^{e38}
	`double` `long double`	64	8 / 16*	$-1.797e^{308}$ .. $-2.225e^{-308}$ $2.225e^{-308}$ .. $1.797e^{308}$
	`float _Imaginary`	32	8 / 16*	$-3.402e^{38}i$ .. $-1.175e^{-38}i$ $1.175e^{-38}i$ .. $3.402^{e38}i$
	`float _Complex`	32+32	8 / 16*	real part + imaginary part
	`double/ long double _Imaginary`	64	8 / 16*	$-1.797e^{308}i$ .. $-2.225e^{-308}i$ $2.225e^{-308}i$ .. $1.797e^{308}i$
	`double/ long double _Complex`	64+64	8 / 16*	real part + imaginary part

Table 3–1: Data Types

* For the marked data types, the alignment is 16 if you specify compiler option **--align**, otherwise the alignment is 8.

When you use the `enum` type, the compiler will use the smallest sufficient integer type (`_Bool`, `char`, `int`), unless you use compiler option **--integer-enumeration** (always use 16–bit integers for enumeration).

`float` is implemented in little endian IEEE 32–bit single precision format. `double` is implemented in little endian IEEE 64–bit double precision format.

When you compile for the R8C/tiny (compiler option **--r8c**) `__far` and `__paged` are the same as `__near`.

See also the *Applications Binary Interface (ABI)*.

Bit Data Type

You can use the `__bit` type to define scalars in the bit–addressable area and for the return type of functions. A struct containing bit fields cannot be used for this purpose, for example because the struct is aligned at a byte boundary. Unlike the `_Bool` type the `__bit` type is aligned on a bit boundary.

The following rules apply to `__bit` type variables:

- A `__bit` type variable is always unsigned.
- A `__bit` type variable can be exchanged with all other type–variables. The compiler generates the correct conversion.

  A `__bit` type variable is like a boolean. Therefore, if you convert an `int` type variable to a `__bit` type variable, it becomes 1 (true) if the integer is not equal to 0, and 0 (false) if the integer is 0. The next two C source lines have the same effect:

  ```
  bit_variable = int_variable;
  bit_variable = int_variable ? 1 : 0;
  ```
- Pointer to `__bit` is allowed, but you cannot take the address of a bit on the stack.
- The `__bit` type is allowed as a structure member. However, a bit structure can only contain members of type `__bit`, and you cannot push a bit structure on the stack or return a bit structure via a function.
- A union of a `__bit` structure and another type is not allowed.
- A `__bit` type variable is allowed as a parameter of a function.
- A `__bit` type variable is allowed as a return type of a function.
- A `__bit` typed expression is allowed as switch expression.
- The `sizeof` of a `__bit` type is 1.
- Global or static `__bit` type variable can be initialized.
- A `__bit` type variable can be declared volatile.

3.4 MEMORY QUALIFIERS

You can use memory qualifiers to allocate static objects in a particular part of the addressing space of the processor.

In addition, you can place variables at absolute addresses with the keyword `__at()`.

3.4.1 MEMORY TYPE QUALIFIERS

In the TASKING C language you can specify that a variable must lie in a specific part of memory. You can do this with a *memory type qualifier*.

You can use the following memory type qualifiers:

Qualifier	Description
__bita	Bit–addressable RAM (first 8 kB of memory)
__sfr	Defines a special function register. Special optimizations are performed on this type of variables. Data is located in the SFR space.
__near	Data is located in the first 64 kB of memory
__far	Data is located anywhere in memory
__paged	Data is located in a 64 kB page, anywhere in memory
__rom	Data defined with this qualifier is placed in ROM. This section is excluded from automatic initialization by the startup code. `__rom` is not the same as `const`.

Table 3–2: Memory type qualifiers

If you do not specify a memory type qualifier for the M16C, the variable implicitly gets the default memory type of the selected memory model (see section 3.5, *Memory Models*).

Functions are by default allocated in ROM. In this case you can omit the memory qualifier `__rom`. You cannot use memory qualifiers for function return values.

See also the assembler directive **DEFSECT** (Declare section), in section 3.3, *Assembler Directives*, in Chapter *Assembly Language* of the *Reference Manual*.

Examples using explicit memory types

```
__rom   char  text[] = "No smoking";
__bita  int   array[10][4];
```

The memory type qualifiers are treated like any other data type specifier (such as `unsigned`). This means the examples above can also be declared as:

```
char __rom   text[] = "No smoking";
int  __bita  array[10][4];
```

Pointers

Pointers declarations can have two memory type qualifiers. For example, the pointer itself can reside in the *bita* space, while pointing to a function that resides in the *rom* space: For example:

```
__rom char *__bita p;  /* pointer residing in BITA,
                          pointing to ROM */
```

In this declaration pointer `p` is qualified with `__bita` (allocated in bit–addressable RAM), but points to a `char` which is qualified with `__rom` (allocated in ROM). The memory type qualifier used to the left of the '*', specifies the target memory of the pointer, the memory type qualifier used to the right of the '*', specifies the storage memory of the pointer.

The TASKING M16C C compiler recognizes two types of pointers: pointers with a size of 2 bytes or 4 bytes in memory. Pointers to `__sfr`, `__bita` are 13–bit pointers (2 bytes in memory) and pointers to `__near` are 16–bit pointers and can point only to locations in the lowest 64K bytes of memory. Pointers to `__far` and `__paged` are 20–bit pointers (4 bytes in memory) and can point anywhere in memory. Pointer arithmetic with `__far` is 32 bits, whereas with `__paged` 16–bit pointer arithmetic is used, because an `__paged` object is always located in a 64 kB page.

Function pointers for the M16C core are always `__far` pointers and function pointers for the R8C core are always `__near` pointers.

Structures

A structure declaration is intended to specify the layout of a structure or union. A structure declaration itself, nor its members can be bound to any storage area. (Members of type pointer of course can point to variables in a particular memory space).

A tag then is used to define objects of the declared structure type. You can qualify this object with a memory type qualifier to allocate it in a particular memory space. The whole object, including its members is allocated in the specified memory.

```
struct S {
    __near int i;  /* referring to storage: not correct */
    __far char *p; /* used to specify target memory: correct */
    };
```

In the declaration above the compiler ignores the erroneous `__near` memory type qualifier.

```
__near struct S my_struct;
```

The compiler now reserves 6 bytes for the object my_struct: 2 bytes for `int i` and 4 bytes for pointer `p` which points to a variable in *far* memory. The following example is also correct:

```
__near struct S {
    int i;
    __near char *p;
    } my_struct
```

The example above combines the structure declaration `S` and the structure definition of `my_struct`. In this case the object `my_struct` is located in *near* memory where 4 bytes are reserved: 2 bytes for `int i` and 2 bytes for pointer `p` which points to a variable in *near* memory.

Typedef

Typedef declarations follow the same scope rules as any declared object. Typedef names may be (re–)declared in inner blocks but not at the parameter level. However, in `typedef` declarations, memory type qualifiers are allowed. A `typedef` declaration should at least contain one type qualifier.

```
typedef __near int NEARINT;   /* storage type __near: OK */
typedef int __near *PTR;      /* PTR points to an int in __near
                                 PTR resides in default memory */
```

3.4.2 ACCESSING PERIPHERALS FROM C: __SFR

It is easy to access Special Function Registers (SFRs) that relate to peripherals from C. The SFRs are defined in a special function register file (`*.sfr`) as symbol names for use with the compiler. An SFR file contains the names of the SFRs and the bits in the SFRs.

Based on the target processor, the compiler includes the correct SFR file. (See compiler option **–C** in chapter *Tool Options* of the *Reference Manual*). Using the correct SFR file, you can access the special function registers and its individual bits using the symbols defined in the SFR file.

Example use in C for the M30100 target with SFR file `regm30100.sfr`

```
P0 = 0x88;  // fill port register p0
P1_3 = 1;   // set bit 3 of port register P1
if (P1_4 == 1)
{
     P1_3 = 0;
}
INT0EN = 1; // use of bit name: set the int0 interrupt
            // enable bit in the external interrupt
            // enable register.
```

The compiler generates:

```
_main:  type    func
        mov.b   #136, 224
        bset    3,225
        btst    4,225
        jltu    _2
        bclr    3,225
_2:
        bset    0,150
```

You can easily find a list of defined SFRs and defined bits by inspecting the SFR file for a specific core. The files are named `reg`*`core`*`.sfr`, for example `regm30100.sfr`.

Define Special Function Registers: __sfr

With the `__sfr` memory type qualifier you can define a symbol as a Special Function Register (SFR). The compiler may assume that special SFR operations can be performed on such symbols. The compiler can decide to use bit instructions for those special function registers that are bit accessible. For example, if bits are defined in the SFR definition, these bits can be accessed using bit instructions.

A typical definition of a special function register looks as follows:

```
typedef struct
     _Bool __b0:1;
     _Bool __b1:1;
     _Bool __b2:1;
     _Bool __b3:1;
     _Bool __b4:1;
     _Bool __b5:1;
     _Bool __b6:1;
     _Bool __b7:1;
   ...
     _Bool __b31:1;
} __bitstruct_t;

#define P0      (*(__sfr unsigned char *)0x00E0)
#define P0_0    ((__sfr __bitstruct_t *)&P0)->__b0
#define INTEN   (*(__sfr unsigned char *)0x0096)
#define INT0EN  ((__sfr __bitstruct_t *)&INTEN)->__b0
```

Example of access to the SFR:

```
P0 = 0x56;
P0_0 = INT0EN;
```

It is incorrect to optimize away access to registers. Therefore, the compiler deals with the special function registers as if they were declared with the **`volatile`** qualifier. In fact **`__sfr`** is treated as **`volatile __bita`**.

Non–initialized global SFR variables are not cleared at program startup. For example:

```
__sfr int i; // global SFR not cleared
```

It is not allowed to initialize global SFR variables. SFR variables are not initialized at startup. For example:

```
__sfr int j=10; // not allowed to initialize global SFR
```

See also compiler option **–C** (Use SFR definitions for CPU) in section *Compiler Options* in Chapter *Tool Options* of the *Reference Manual*.

3.4.3 DECLARE A DATA OBJECT AT AN ABSOLUTE ADDRESS: __at()

Just like you can declare a variable in a specific *part* of memory, you can also place an object at an *absolute address* in memory. This may be useful to interface with other programs using fixed memory schemes, or to access special function registers.

With the attribute `__at()` you can specify an absolute address.

Examples

```
unsigned char Display[80*24] __at( 0x2000 )
```

The array `Display` is placed at address 0x2000. In the generated assembly, an absolute section is created. On this position space is reserved for the variable `Display`.

```
int myvar __at(0x100)=1;
```

The variable `myvar` is placed at address 0x100 and is initialized at 1.

```
void f(void) __at( 0xf0ff + 1 ) { }
```

The function `f` is placed at address 0xf100.

Restrictions

Take note of the following restrictions if you place a variable at an absolute address:

- The argument of the `__at()` attribute must be a constant address expression.
- You can place only variables with static storage at absolute addresses. Parameters of functions, or automatic variables within functions cannot be placed at absolute addresses.
- When declared `extern`, the variable is not allocated by the compiler. When the same variable is defined within another module but on a different address, the compiler, assembler or linker will not notice.
- When the variable is declared `static`, no public symbol will be generated (normal C behavior).
- You cannot place structure members at absolute addresses.
- Absolute variables cannot overlap each other. If you define two absolute variables at the same address, the assembler and / or linker issues an error. The compiler does not check this.

- When you define the same absolute variable within two modules, this produces conflicts during link time. (An extern declaration in one module and a definition of the same variable in another module is of course possible.)

3.5 MEMORY MODELS

The M16C C compiler (**cm16c**) supports three reentrant memory models: small, medium and large. You can select one of these models with the compiler option **–M**.

If no memory model is specified on the command line, **cm16c** uses the *small* model because this model generates the most efficient code. The following table illustrates the meaning of each data model.

Model	Data	Constants	Pointers
Small	__near: in first 64 kB	__near	__near
Medium	__near: in first 64 kB	__paged	__paged
Large	__far: anywhere in 1 MB	__far	__far

*Table 3–3: **cm16c** memory models*

When you compile for the R8C/tiny (compiler option **––r8c**) only the small model is allowed.

Using predefined macro __MODEL__ to write conditional code

With the predefined macro __MODEL__ you can write conditional C code in one source for different memory models. Depending on the memory model for which you compile, the macro __MODEL__ expands to:

’s’	(small memory model)
’m’	(medium memory model)
’l’	(large memory model)

Example

```
#if __MODEL__ == 'l'
/* this part is only for the large memory model */
...

#endif
```

3.6 USING ASSEMBLY IN THE C SOURCE: __asm()

With the `__asm()` keyword you can use assembly instructions in the C source and pass C variables as operands to the assembly code. Be aware that C modules that contain assembly are not portable and harder to compile in other environments.

Furthermore, assembly blocks are not interpreted by the compiler: they are regarded as a black box. So, it is your responsibility to make sure that the assembly block is syntactically correct.

General syntax of the `__asm` *keyword*

```
__asm( "instruction_template"
       [ : output_param_list
       [ : input_param_list
       [ : register_save_list]]] );
```

instruction_template	Assembly instructions that may contain parameters from the input list or output list in the form: **%***parm_nr* [**.***regnum*]
%*parm_nr*[**.***regnum*]	Parameter number in the range 0 .. 31. With the optional **.***regnum* you can access an individual register from a register pair. For example, with the word register `R2R0`, `.0` selects register `R0`.
output_param_list	[[**"=**[**&**]*constraint_char***"(***C_expression***)**],...]
input_param_list	[[**"***constraint_char***"(***C_expression***)**],...]
&	Says that an output operand is written to before the inputs are read, so this output must not be the same register as any input.
constraint _char	Constraint character: the type of register to be used for the *C_expression*. (see table 3–4)
C_expression	Any C expression. For output parameters it must be an *lvalue*, that is, something that is legal to have on the left side of an assignment.
register_save_list	[[**"***register_name***"**],...]
register_name	Name of the register you want to reserve.

Typical example: adding two C variables using assembly

```
int a, b, result;

void main( void )
{
    __asm(”add.w %1, %2\n\t”
          ”mov.w %2, %0” : ”=m”(result) : ”r”(a), ”r”(b) );
}
```

generated code:

```
mov.w   _b, R0
mov.w   _a, R1
add.w R1, R0
mov.w R0, _result
```

`%0` corresponds to the first C variable, `%1` corresponds to the second and so on. The escape sequence `\t` generates a tab, `\n` generates a newline.

Specifying registers for C variables

With a *constraint character* you specify the register type for a parameter. In the example above, the `r` is used to force the use of registers (Rn) for the parameters `a` and `b`.

You can reserve the registers that are already used in the assembly instructions, either in the parameter lists or in the reserved register list (*register_save_list*, also called ”clobber list”). The compiler takes account of these lists, so no unnecessary register saves and restores are placed around the inline assembly instructions.

Constraint character	Type	Operand	Remark
a	address register	A0, A1	word register
A	address register	A1A0	double–word register
b	bit	R[0..3]H.[0..7] R[0..3]L.[0..7] A[0..1].[0..7] C *_bitvar*	bit registers/variables
h	data register	R[0..3]H R[0..3]L	byte registers
i	immediate value	*#value*	
m	memory	*address*, *label*, *_variable*	memory variable or function address

Constraint character	Type	Operand	Remark
r	data register	R[0..3]	word registers
R	registers	R2R0, R3R1	double–word registers
number	other operand	same as %*number*	used when input and output operands must be the same

Table 3–4: Available input/output operand constraints

Loops and conditional jumps

The compiler does not detect loops with multiple `__asm` statements or (conditional) jumps across `__asm` statements and will generate incorrect code for the registers involved.

If you want to create a loop with `__asm`, the whole loop must be contained in a single `__asm` statement. The same counts for (conditional) jumps. As a rule of thumb, all references to a label in an `__asm` statement must be in that same statement.

Example 1: no input or output

A simple example without input or output parameters. You can just output any assembly instruction:

```
__asm( "nop" );
```

Generated code:

```
nop
```

Example 2: using output parameters

Assign the result of inline assembly to a variable. With the constraint `h` a byte data register is chosen for the parameter; the compiler decides which data register it uses. The `%0` in the instruction template is replaced with the name of this data register. Finally, the compiler generates code to assign the result to the output variable.

```
char result;

void main( void )
{
    __asm( "mov.b #0xFF,%0" : "=h"(result));
}
```

Generated assembly code:

```
mov.b   #0xFF,R0H
mov.b   R0H,_result
```

Example 3: using input and output parameters

Add two C variables and assign the result to a third C variable. Data registers are used for the input and output parameters (constraint `r`, `%1` for `a` and `%2` for `b` in the instruction template) and memory is used for the output parameter (constraint `m`, `%0` for `result` in the instruction template). The compiler generates code to move the input expressions into the input registers and to assign the result to the output variable.

```
int a, b, result;

void add2( void )
{
    __asm(”add.w %1, %2\n\t”
          ”mov.w %2, %0” : ”=m”(result) : ”r”(a), ”r”(b) );
}
void main(void)
{
    a = 3;
    b = 4;
    add2();
}
```

Generated assembly code:

```
_add2:
    mov.w   _b, R0
    mov.w   _a, R1
    add.w R1, R0
    mov.w R0, _result

_main:
    mov.w   #3, _a
    mov.w   #4, _b
    jsr     _add2
```

Example 4: reserve registers

Sometimes an instruction knocks out certain specific registers. The most common example of this is a function call, where the called function is allowed to do whatever it likes with some registers. If this is the case, you can list specific registers that get clobbered by an operation after the inputs.

Same as *Example 3*, but now register `R0` is a reserved register. You can do this by adding a reserved register list (`: ”R0”`). As you can see in the generated assembly code, register `R0` is not used (the first register used is `R1`).

```
int a, b, result;

void add2( void )
{
   __asm(”add.w %1, %2\n\t”
         ”mov.w %2, %0” : ”=m”(result) : ”r”(a), ”r”(b) : ”R0”);
}
```

Generated assembly code:

```
mov.w   _b, R2
mov.w   _a, R1
add.w R1, R2
mov.w R2, _result
```

Example 5: input and output are the same

If the input and output must be the same you must use a number constraint. The following example inverts the value of the input variable `ivar` and returns this value to `ovar`. Since the assembly instruction `not.w` uses only one register, the return value has to go in the same place as the input value. To indicate that `ivar` uses the same register as `ovar`, the constraint ’0’ is used which indicates that `ivar` also corresponds with %0.

```
int ovar;

void invert(int ivar)
{
    __asm (”not.w %0”: ”=r”(ovar): ”0”(ivar) );
}

void main(void)
{
    invert(255);
}
```

Generated assembly code:

```
_invert:
    not.w   R0
    mov.w   R0,_ovar

_main:
    mov.w   #255,R0
    jsr    _invert
```

Example 6: inlining assembly functions

Because you can use any assembly instruction with the `__asm` keyword, you can use the `__asm` keyword to perform tasks that have no equivalence in C. By inlining such a function, rather than calling it, you can create fast 'functions' to perform tasks that have no equivalent in C. In fact, this way you create your own intrinsic functions.

First write a function with assembly in the body using the keyword `__asm`. We use the add routine from *Example 3*.

Next make sure that the function is inlined rather than being called. You can do this with the function qualifier `inline`. This qualifier is discussed in more detail in section 3.12.3, *Inlining Functions*.

```
int a, b, result;

inline void my_add( void )
{
    __asm("add.w %1, %2\n\t"
          "mov.w %2, %0" : "=m"(result) : "r"(a), "r"(b) );
}

void main(void)
{
    // call to function my_add
    my_add();
}
```

When you call this function from within your C source, the next assembly code will be inlined (not called!):

```
_main:
    ; __my_add code is inlined here
    mov.w   _b, R0
    mov.w   _a, R1
    add.w R1, R0
    mov.w R0, _result
```

Example 7: accessing individual registers in a register pair

You can access the individual registers in a register pair by adding a '.' after the operand specifier in the assembly part, followed by the index in the register pair.

```
int f1, f2;

void foo(long l)
{
    __asm ("mov.w %2.0, %0\n\t"
           "mov.w %2.1, %1"
           : "=m"(f1), "=m"(f2): "R"(l) );
}
```

The first `mov.w` instruction uses index #0 of argument 2 (which is a long placed in a RnRn register) and the second `mov.w` instruction uses index #1. The input operand is located in register pair R2R0. The assembly output becomes:

```
    mov.w R0, _f1
    mov.w R2, _f2
    rts
```

If the index is not a valid index (for example, the register is not a register pair, or the argument has not a register constraint), the '.' is passed into the assembly output. This way you can still use the '.' in assembly instructions.

3.7 CONTROLLING THE COMPILER: PRAGMAS

Pragmas are keywords in the C source that control the behavior of the compiler. Pragmas overrule compiler options.

The syntax is:

`#pragma` *`pragma-spec`* [**ON** | **OFF** | **DEFAULT**]

or:

`_Pragma(` *`"pragma-spec`* [**ON** | **OFF** | **DEFAULT**]*"* **`)`**

For example, you can set a compiler option to specify which optimizations the compiler should perform. With the `#pragma optimize` *`flags`* you can set an optimization level for a specific part of the C source. This overrules the general optimization level that is set in the C compiler Optimization page in the Project Options dialog of EDE (command line option **–O**).

The compiler recognizes the following pragmas, other pragmas are ignored.

Pragma name	Description
`alias` *`symbol=defined-symbol`*	Defines an alias for a symbol

`align`
`align-data`
`align-func`
	Specifies object alignment.
	See compiler option **––align** in section 4.1, *Compiler Options* in Chapter *Tool Options* of the *Reference Manual*.

`auto_switch`
`jump_switch`
`linear_switch`
`lookup_switch`
	Specifies switch statement.
	See section 3.11, *Switch Statement*

`clear` `noclear`	Specifies 'clearing' of non–initialized static/public variables
`extension isuffix`	Enables the language extension to specify imaginary floating–point constants by adding an 'i' to the constant
`extern` *`symbol`*	Forces an external reference

`inline`
`noinline`
`smartinline`
	Specifies function inlining.
	See section 3.12.3, *Inlining Functions*.

Pragma name	Description
`macro` `nomacro`	Specifies macro expansion
`message` *"string"* `...`	Emits a message to standard output
`optimize` *flags* `endoptimize`	Controls compiler optimizations. See section 5.3, *Compiler Optimizations* in Chapter *Using the Compiler*
`renamesect` *spec* `endrenamesect`	Changes section names See section 3.13, *Section Naming* and compiler option **–R** in section 4.1, *Compiler Options* in Chapter *Tool Options* of the *Reference Manual*
`source` `nosource`	Specifies which C source lines must be shown in assembly output. See compiler option **–s** in section 4.1, *Compiler Options* in Chapter *Tool Options* of the *Reference Manual*.
`tradeoff` *level*	Controls the speed/size tradeoff for optimizations. See compiler option **–t** in section 4.1, *Compiler Options* in Chapter *Tool Options* of the *Reference Manual*.
`warning [`*number*`,...]`	Disables warning messages. See compiler option **–w** in section 4.1, *Compiler Options* in Chapter *Tool Options* of the *Reference Manual*.
`weak` *symbol*	Marks a symbol as 'weak'

Table 3–5: Overview of pragmas

For a detailed description of each pragma, see section 1.6, *Pragmas*, in Chapter *C Language* of the *Reference Manual*.

3.8 PREDEFINED MACROS

In addition to the predefined macros required by the ISO C standard, the TASKING C compiler supports the predefined macros as defined in Table 3–6. The macros are useful to create conditional C code.

Macro	Description
__SINGLE_FP__	Defined when you use compiler option **–F** (Treat double as float)
__CM16C__	Identifies the compiler. You can use this symbol to flag parts of the source which must be recognized by the **cm16c** compiler only. It expands to the version number of the compiler.
__CPU__	Expands to the CPU type specified to the compiler option **–C**, or 0 otherwise.
__LITTLE_ENDIAN__	Expands to 1, indicating the processor accesses data in little–endian.
__MODEL__	Identifies the memory model for which the current module is compiled. For example, if you compile for the small memory model, the macro expands to s.
__M16C__	Defined when you select a M16C core.
__R8C__	Defined when you select a R8C core (**––r8c**).
__TASKING__	Identifies the compiler as a TASKING compiler. It expands to 1.
__DSPC__	Indicates conformation to the DSP–C standard. Expands to 0, DSP–C extensions are not supported.
__VERSION__	Identifies the version number of the compiler. For example, if you use version 3.0r1 of the compiler, __VERSION__ expands to 3000 (dot and revision number are omitted, minor version number in 3 digits).
__REVISION__	Identifies the revision number of the compiler. For example, if you use version 3.0r1 of the compiler, __REVISION__ expands to 1.
__BUILD__	Identifies the build number of the compiler, composed of decimal digits for the build number, three digits for the major branch number and three digits for the minor branch number. For example, if you use build 1.22.1 of the compiler, __BUILD__ expands to 1022001. If there is no branch number, the branch digits expand to zero. For example, build 127 results in 127000000.

Table 3–6: Predefined macros

Example

```
#ifdef __CM16C__
    /* this part is for the M16C compiler */
#endif
```

3.9 INITIALIZED VARIABLES

Non–static initialized variables use the same amount of space in both ROM and RAM (for all possible RAM memory spaces). This is because the initializers are stored in ROM and copied to RAM at start–up.

An exception is when an initialized variable resides in ROM by means of the `__rom` memory type qualifier or when you specify the option **––romconstants** to force constants in rom:

Examples

```
       int  i = 100;       /* 2 bytes in far rom and
                              2 bytes in ram         */
__rom  int  j = 3;         /* 2 bytes in rom, no ram */
__rom  char a[] = "HELP";  /* 5 bytes in rom, no ram */
```

Option **––romconstants** enabled:

```
const __far int i = 100;   /* 2 bytes in far rom only */
```

See also the next section 3.10, *Strings*.

3.10 STRINGS

A *string* is defined as a separate occurrence of a string in a C program. Array variables initialized with strings can have storage qualifiers, and are *not* the same as strings. See also section 3.9 *Initialized Variables*.

By default, strings are copied from ROM to RAM at start–up. However, string literals in a C source program, which are not used to initialize an array, have static storage duration and the ISO C standard does not require these strings to be modifiable. Therefore, allocating strings in ROM only is allowed.

With compiler option **––romstrings** the compiler will place strings in the ROM area.

Examples

```
char *world = "hello"; /* 5 bytes in far rom
                          5 bytes in ram     */
```

Option **––romstrings** enabled (in large memory model):

```
char *world = "hello"; /* 5 bytes in far rom only */
```

3.11 SWITCH STATEMENT

The TASKING C compiler supports three ways of code generation for a switch statement: a jump chain (linear switch), a jump table or a lookup table.

A *jump chain* is comparable with an if/else–if/else–if/else construction. A *jump table* is a table filled with target addresses for each possible switch value. The switch argument is used as an index within this table. A *lookup table* is a table filled with a value to compare the switch argument with and a target address to jump to. A binary search lookup is performed to select the correct target address.

By default, the compiler will automatically choose the most efficient switch implementation based on code and data size and execution speed. You can influence the selection of the switch method with compiler option **–t** (**––tradeoff**), which determines the speed/size tradeoff.

It is obvious that, especially for large switch statements, the jump table approach executes faster than the lookup table approach. Also the jump table has a predictable behavior in execution speed. No matter the switch argument, every case is reached in the same execution time. However, when the case labels are distributed far apart, the jump table becomes sparse, wasting code memory. The compiler will not use the jump table method when the waste becomes excessive.

With a small number of cases, the jump chain method can be faster in execution and shorter in size.

How to overrule the default switch method

You can overrule the compiler chosen switch method with a pragma:

```
#pragma linear switch    /* force jump chain code */
#pragma jump_switch      /* force jump table code */
#pragma lookup_switch    /* force lookup table code */
#pragma auto_switch      /* let the compiler decide
                            the switch method used */
```

Pragma `auto_switch` is also the default of the compiler.

3.12 FUNCTIONS

3.12.1 PARAMETER PASSING

A lot of execution time of an application is spent transferring parameters between functions. The fastest parameter transport is via registers. Therefore, function parameters are first passed via registers. If no more registers are available for a parameter, the parameter is passed via the stack. The table below shows the register usage when parameters of several types are passed.

Parameter Type	Parameter Number				
	1	**2**	**3**	**4**	**5 .. 16**
__bit / _Bool	0,R0	1,R0	2,R0	3,R0	4,R0 .. 15,R0
char	R0L	R0H			
8–bit struct	R0L	R0H			
short / int	R0	R2	R1	R3	
16–bit struct	R0	R2	R1	R3	
16–bit pointer	A0	A1			
32–bit pointer	A1A0				
long	R2R0	R3R1			
long long	R3R1R2R0				
float / float _Imaginary	R2R0	R3R1			
float _Complex	R3R1R2R0				
double / double _Imaginary	R3R1R2R0				

Table 3–7: Register usage for parameter passing

All '...' parameters of a variable argument list function are always passed over the stack. Parameters are pushed in reverse order, so all ISO C macros defined in `stdarg.h` can be applied.

Example with five arguments

```
func1( char a, long b, long c, int d, char e )
```

- `a` (first parameter) is passed in register R0L
- `b` (second parameter) is passed in registers R3R1
- `c` (third parameter) is passed via the stack
- `d` (fourth parameter) is passed in register R2
- `e` (fifth parameter) is passed in register R0H

Example with variable argument function

```
printf( char *format, ... )
```

- `format` (first parameter) is passed in register A0
- all other parameters are passed via the stack

3.12.2 FUNCTION RETURN TYPES

The C compiler uses registers to store C function return values, depending on the function return types.

Return type	Register
__bit / _Bool	C
char	R0L
8–bit struct	R0L
short / int	R0
16–bit struct	R0
16–bit pointer	A0
32–bit pointer	A1A0
long	R2R0
long long	R3R1R2R0
float / float _Imaginary	R2R0
float _Complex	R3R1R2R0
double / double _Imaginary	R3R1R2R0
double _Complex	on the stack

Table 3–8: Register usage for function return types

3.12.3 INLINING FUNCTIONS: INLINE

You can use the `inline` keyword to tell the compiler to inline the function body instead of calling the function. Use the `__noinline` keyword to tell the compiler *not* to inline the function body.

Normally, you must define inline functions in the same source module as in which you call the function, because the compiler only inlines a function in the module that contains the function definition. When you need to call the inline function from several source modules, you must:

- include the definition of the inline function in each module (for example using an include file containing the definition).
- enable **MIL linking** on the Optimizations page of the C compiler options and compile the involved files in the same run.

The compiler inserts the function body at the place the function is called. If the function is not called at all, the compiler does not generate code for it.

Example: inline

```
int  w,x,y,z;

inline int add( int a, int b )
{
     return( a + b );
}

void main( void )
{
     w = add( 1, 2 );
     z = add( x, y );
}
```

The function `add()` is defined before it is called. The compiler inserts (optimized) code for both calls to the `add()` function. The generated assembly is:

```
_main:
    mov.w   #3, _w
    mov.w   _y, A0
    add.w   _x, A0

    mov.w   A0, _z
```

Example: #pragma inline / #pragma noinline

Instead of the `inline` qualifier, you can also use `#pragma inline` and `#pragma noinline` to inline a function body:

```
int  w,x,y,z;

#pragma inline
int add( int a, int b )
{
     return( a + b );
}
#pragma noinline

void main( void )
{
     w = add( 1, 2 );
     z = add( x, y );
}
```

If a function has an `inline/__noinline` function qualifier, then this qualifier will overrule the current pragma setting.

#pragma smartinline

By default, small fuctions that are not too often called, are inlined. This reduces execution time at the cost of code size (compiler option **–Oi**).

With the `#pragma noinline / #pragma smartinline` you can temporarily disable this optimization.

With the compiler options **––inline–max–incr** and **––inline–max–size** you have more control over the function inlining process of the compiler.

See for more information of these options, section *Compiler Options* in Chapter *Tool Options* of the *Reference Manual*.

Combining inline with __asm to create intrinsic functions

With the keyword `__asm` it is possible to use assembly instructions in the body of an inline function. Because the compiler inserts the (assembly) body at the place the function is called, you can create your own intrinsic function.

See section 3.6, *Using Assembly in the C Source*, for more information about the `__asm` keyword.
Example 6 in that section shows how to inline assembly functions with the `inline` keyword.

3.12.4 INTRINSIC FUNCTIONS

Some specific M16C assembly instructions have no equivalence in C. *Intrinsic functions* give the possibility to use these instructions. Intrinsic functions are predefined functions that are recognized by the compiler. The compiler then generates the most efficient assembly code for these functions.

The compiler always inlines the corresponding assembly instructions in the assembly source rather than calling the function. This avoids unnecessary parameter passing and register saving instructions which are normally necessary when a function is called.

Intrinsic functions produce very efficient assembly code. Though it is possible to inline assembly code by hand, registers are used even more efficient by intrinsic functions. At the same time your C source remains very readable. Intrinsic functions do not limit the optimization possibilities of the compiler opposed to assembly that is hand coded with `__asm`.

You can use intrinsic functions in C as if they were ordinary C (library) functions. All intrinsics begin with a double underscore character. The following example illustrates the use of an intrinsic function and its resulting assembly code.

```
char q;
q = __divb_q( 10,3 );  // return quotient of divide
```

The resulting assembly code is inlined rather than being called:

```
mov.w   #10, R0
div.b   #3
mov.b   R0L, _q
```

For extended information about all available intrinsic functions, refer to section 1.5, *Intrinsic Functions*, in Chapter *C Language* of the *Reference Manual*.

3.12.5 CALLING ASSEMBLY FUNCTIONS: __asmfunc

For a fixed register–based interface between C and assembly functions the function qualifier `__asmfunc` is available. You can use this function qualifier for a prototype of an assembly function to be called from C or for a function definition of a C function to be called from assembly. Normally, the C compiler adds a leading underscore when it generates an assembly function, with `__asmfunc` the C compiler does not add the extra underscore.

Example:

```
           /* prototype of assembly function */
extern __asmfunc int
special_out( int port, long config, int value );

void main( void )
{
     long cfg;
     int y;
     ...
     if( special_out( 1, cfg, y ) ) /* call assembly
                                       function */
     {
          ...
     }
     ...
}
```

The number of arguments that can be passed is limited by the number of available registers. (See section 3.12.1, *Parameter Passing*. If too many arguments are used, the compiler will issue an error.

3.12.6 INTERRUPT FUNCTIONS

The TASKING M16C C compiler supports a number of function qualifiers and keywords to program interrupt service routines (ISR).

An *interrupt service routine* (or: interrupt function, or: interrupt handler) is called when an interrupt event (or: *service request*) occurs. This can be a software interrupt or a hardware interrupt.

A *software interrupt* occurs when certain instructions are executed. Software interrupt are *non–maskable*, which means that the interrupt cannot be enable or disabled by the interrupt enable flag (I flag) or that its interrupt priority cannot be changed by priority level.

A *hardware interrupt* can be a special (non–maskable) interrupt, for example an interrupt triggered by a watchdog timer, or a peripheral function interrupt generated by a microcomputer's internal function. Peripheral function interrupts are *maskable*, which means that the interrupt can be enable or disabled by the interrupt enable flag (I flag) or that its interrupt priority can be changed by priority level.

Each maskable interrupt has an *interrupt priority level*. This number (0 to 7) is set in the interrupt control register (*xxx*IC) by the interrupt control unit. If multiple interrupts occur at the same time, the interrupt request that has the highest priority is accepted. A request is handled if the priority number is higher than the processor interrupt priority level (IPL). An interrupt service routine can be interrupted again by another interrupt request with a higher priority. Interrupts with priority number 0 are never handled.

The M16C uses two interrupt vector tables for the hardware and software interrupts: a relocatable vector table and a fixed vector table. The interrupt vector contains the start address of the interrupt service routine.

With the following function qualifiers you can declare an interrupt handler using the relocatable or fixed vector table respectively:

```
__interrupt()
__interrupt_fixed()
```

For an extensive description of the M16C interrupt system, see chapter *Overview of Interrupt* in the *M16C Group Specification* [Renesas]

3.12.6.1 DEFINING AN INTERRUPT SERVICE ROUTINE: __interrupt()

A function can be declared as an interrupt service routine with one of the following function qualifiers:

```
__interrupt(vector,...)
__interrupt_fixed(vector,...)
```

Both function qualifiers takes *vector* as an argument which identifies the interrupt number entry in the interrupt vector table. This number must be in the range 0 to 63 for `__interrupt()` or 0 to 8 for `__interrupt_fixed()`. Interrupt functions cannot accept arguments and do not return anything.

For the relocatable vector table use:

```
__interrupt( vector,... )
void isr( void )
{ ... }
```

For the fixed vector table use:

```
__interrupt_fixed( vector,... )
void isr( void )
{ ... }
```

When you define an interupt service routine, the compiler generates the appropriate interrupt vector, consisting of an instruction jumping to the interrupt function. You can suppress this with the compiler option **––novector** or the **#pragma novector**. The difference between a normal function and an interrupt function is that an interrupt function ends with a RETI instruction instead of a RET instruction, and that all registers that might possibly be corrupted during the execution of the interrupt function are saved on function entry (this is called the *interrupt frame*) and restored on function exit.

Example

The next example illustrates the function definition for a function for a software interrupt with vector number 0x30 in the relocatable vector table:

```
int c;

void __interrupt( 0x30 ) transmit( void )
{
     c = 1;
}
```

Compiler option **--novector** (Do not generate interrupt vectors)

3.12.6.2 REGISTER BANK SWITCHING: __bankswitch

Normally when an interrupt function is called, all registers that might possibly be corrupted during the execution of the interrupt function are saved on the stack so the registers are available for the interrupt function. After return from thrrupt function the original values are restored from the stack.

With the function qualifier `__bankswitch` you can specify to use register bank 1 for the interrupt function. This minimizes the interrupt latency because registers do not need to be pushed on the stack. You can use this to reduce time for high–speed interrupt handling.

```
__interrupt( vector,... ) __bankswitch
void isr( void )
{
...
}

__interrupt_fixed( vector,... ) __bankswitch
void isr( void )
{
...
}
```

3.12.6.3 INTERRUPT FRAME: __frame()

With the function qualifier `__frame()` you can specify which registers must be saved for a particular interrupt function. Only the specified registers will be pushed and popped from the stack. The syntax is:

```
__interrupt( vector,... ) __frame( reg,... )
void isr( void )
{
...
}

__interrupt_fixed( vector,... ) __frame( reg,... )
void isr( void )
{
...
}
```

where, *reg* can be one of the following registers: R0..R3, A0, A1, FB or SB.

If you do not specify the function qualifier `__frame()`, the C compiler determines which registers must be pushed and popped.

Example

```
__interrupt(1) __frame(R0,R1)
void alarm( void )
{
     /* an interrupt function */
}
```

When you do not want the interrupt frame (saving/restoring registers) to be generated you can use the compiler option **--noframe**. In that case you will have to specify your own interrupt frame. For this you can use the inline capabilities of the compiler.

Compiler option **--noframe** (Do not generate frame for interrupt handler)

3.13 SECTION NAMING

The compiler generates code and data in several types of sections. The compiler uses the following section naming convention:

module–name[*_attr*]*_mem*[*_address*]

The *mem* suffix depends on the type of the section and the optional *attr* suffix depends on the section attributes and determines if the section is initialized, constant or uninitialized. The compiler adds the optional *_address* when you use the `__at()` keyword to specify an absolute address.

Type	*mem* **suffix**	**Description**	**Qualifier**
code	CO	program code	
data	DA	__near data (first 64 kB of memory)	__near
fdata	FD	__far data	__far
bit	BI	__bit type section	
bita	BA	__bita type section (bit–addressable data)	__bita

Table 3–9: Section types and mem section name suffixes

Attribute	*attr* **suffix**	**Description**	**Qualifier**
init	INI	defines that the section contains initialization data, which is copied from ROM to RAM at program startup	
clear	CLR	section is cleared (zeroed) at startup	
noclear	NCL	section is not cleared at startup	
romdata	RO	section contains data to be placed in ROM	__rom
fit 65536	PG	section fits in a 64 kB page	__paged

Table 3–10: Section attributes and attr section name suffixes

Rename sections

You can change the default section names with the following pragma:

#pragma renamesect *mem*=*name* [*attribute*] [**__at(** *address* **)**]

The new *name* replaces the *module–name* part of the section names that have type *mem*. With the optional *attribute* you can overrule the section attribute. With the optional `__at()` keyword you can place a section at an absolute address.

For example,

```
#pragma renamesect DA=flash clear __at(0x20)
```

All sections of type ’data’ have the name ”`flash_`*`attr`*`_DA`” and have attribute ’clear’ and ’at 0x20’.

The following pragma restores the default section naming for type *mem*.

#pragma endrenamesect *mem*

See also compiler option **–R** in section *Compiler Options* in Chapter *Tool Options* of the *Reference Manual*.

3.14 LIBRARIES

The TASKING C compiler comes with standard C libraries (ISO/IEC 9899:1999) and header files with the appropriate prototypes for the library functions. The standard C libraries are available in object format and in C or assembly source code.

A number of standard operations within C are too complex to generate inline code for. These operations are implemented as *run–time* library functions.

The `lib` directory of the toolchain contains subdirectories with separate libraries for the M16C and the R8C.

3.14.1 OVERVIEW OF LIBRARIES

The following tables lists the libraries included in the M16C toolchain, for the M16C and R8C processors.

Library to link	Description
libcs.a libcm.a libcl.a	C library for small, medium or large memory model (Some functions require the floating–point library. Also includes the startup code.)
libcss.a libcms.a libcls.a	Single precision C library for small, medium or large memory model (compiler option **–F**) (Some functions require the floating–point library. Also includes the startup code.)
libfps.a libfpm.a libfpl.a	Floating–point library (non–trapping) for each model
libfpst.a libfpmt.a libfplt.a	Floating–point library (trapping) for each model (Control program option **––fp–trap**)
librts.a librtm.a librtl.a	Run–time library for each model

Table 3–11: Overview of M16C libraries

Library to link	Description
libc.a	C library (Some functions require the floating–point library. Also includes the startup code.)
libcs.a	Single precision C library (compiler option **–F**) (Some functions require the floating–point library. Also includes the startup code.)
libfp.a	Floating–point library (non–trapping)
libfpt.a	Floating–point library (trapping) (Control program option **––fp–trap**)
librt.a	Run–time library

Table 3–12: Overview of R8C libraries

See section 2.2, *Library Functions*, in Chapter *Libraries* of the *Reference Manual* for an extensive description of all standard C library functions.

3.14.2 PRINTF AND SCANF FORMATTING ROUTINES

The C library functions `printf()`, `fprintf()`, `vfprintf()`, `vsprintf()`, ... call one single function, `_doprint()`, that deals with the format string and arguments. The same applies to all scanf type functions, which call the function `_doscan()`, and also for the `wprintf` and `wscanf` type functions which call `_dowprint()` and `_dowscan()` respectively. The C library contains three versions of these routines: `int`, `long` and `long long` versions. If you use floating–point, the formatter function for floating–point `_doflt()` or `_dowflt()` is called. Depending on the formatting arguments you use, the correct routine is used from the library. Of course the larger the version of the routine the larger your produced code will be.

Note that when you call any of the printf/scanf routines indirect, the arguments are not known and always the `long long` version with floating–point support is used from the library.

Example:

```
#include <stdio.h>

long L;

void main(void)
{
    printf( "This is a long: %ld\n", L );
}
```

The linker extracts the `long` version without floating–point support from the library.

3.14.3 REBUILDING LIBRARIES

If you have manually changed one of the standard C library functions, you need to recompile the standard C libraries.

'Weak' symbols are used to extract the most optimal implementation of a function from the library. For example if your application does not use floating–point variables the prinf alike functions do not support floating–point types either. The compiler emits strong symbols to guide this process. Do not change the order in which modules are placed in the library since this may break this process.

The sources of the libraries are present in the `lib\src` directory. This directory also contains subdirectories with a `makefile` for each type of library:

```
lib\src\
        m16c\
             libcl\makefile
             libcm\makefile
             libcs\makefile
             librtl\makefile
             librtm\makefile
             librts\makefile
        r8c\
             libc\makefile
             librt\makefile
```

To rebuild the libraries, follow the next steps.

First make sure that the `bin` directory for the toolchain is included in your PATH environment variable. (See section 1.3.2, *Configuring the Command Line Environment*.

1. Make the directory `lib\src\m16c\libcl` the current working directory.

   This directory contains a `makefile` *which also uses the default make rules from* `mkm16c.mk` *from the* `cm16c\etc` *directory.*

2. Edit the `makefile`.

See section 9.3, *Make Utility*, in Chapter *Utilities* for an extensive description of the make utility and makefiles.

3. Assuming the `lib\src\m16c\libcl` directory is still the current working directory, type:

   ```
   mkm16c
   ```

   to build the library.

   The new library is created in the `lib\src\m16c\libcl` *directory.*

4. Make a backup copy of the original library and copy the new library to the `lib\m16c` directory of the product.

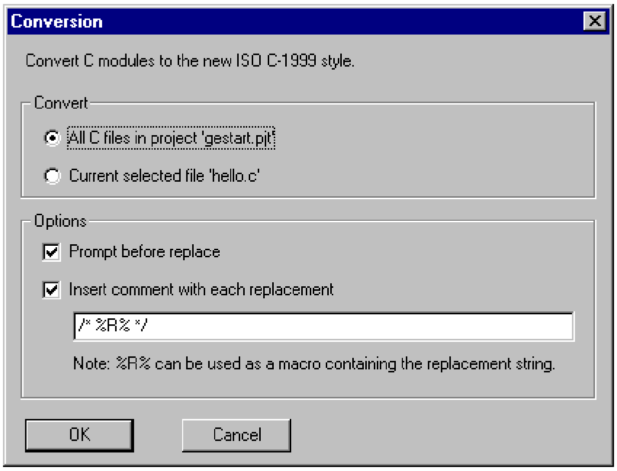
3.15 CONVERTING C MODULES TO ISO C99

The TASKING M16C C compiler fully supports the ISO/IEC 9899:1999(E) standard. V2.3 and older C source files may not meet the requirements of the ISO C99 standard. However, EDE provides an option to convert these files automatically.

To convert one or more C source files:

1. Click on the **Convert C modules to the ISO–C style** button**.**

The Conversion dialog box appears.



Conversion

Convert C modules to the new ISO C-1999 style.

Convert

(●) All C files in project 'gestart.pjt'

( ) Current selected file 'hello.c'

Options

☑ Prompt before replace

☑ Insert comment with each replacement

/* %R% */

Note: %R% can be used as a macro containing the replacement string.

2. Select whether you want to convert **All C files in project** or the **Current selected file**.

3. Enable or disable the options **Prompt before replace** and **Insert comment with each replacement**.

   If you select comments, you can format the comments to be inserted.

4. Type a format string in the comment field.

   For example, to insert C++ style comments with a date, type:
   `// 2004 1` (where `1` is replaced with the standard replacement message).

5. Click **OK** to start the conversion.

   During conversion the following will be changed:

   - M16C keywords with a single underscore are replaced with keywords with double underscore. For example, replace `_bit` with `__bit`.
   - Old predefined macro names are replaced with new macro names. For example, replace `_MODEL` with `__MODEL__`.
   - Pragmas are replaced, removed or commented because their meaning has changed. For example, replace `#pragma asm/endasm` part with `__asm` keyword.
   - M16C intrinsic functions with a single underscore are replaced with intrinsic functions with double underscore. For example, replace `_absb` with `__absb`.

CHAPTER

ASSEMBLY LANGUAGE

4

TASKING

CHAPTER 4

4.1 INTRODUCTION

This chapter describes the most important aspects of the M16C assembly language. For a complete overview of the M16C assembly language, refer to the *M16C Series Software Manual* [Renesas].

4.2 ASSEMBLY SYNTAX

An assembly program consists of zero or more statements. A statement may optionally be followed by a comment. Any source statement can be extended to more lines by including the line continuation character (\) as the last character on the line. The length of a source statement (first line and continuation lines) is only limited by the amount of available memory.

Mnemonics and directives are case insensitive. Labels, symbols, directive arguments, and literal strings are case sensitive.

The syntax of an assembly *statement* is:

[*label*[**:**]] [*instruction* | *directive* | *macro_call*] [**;***comment*]

label A label is a special symbol which is assigned the value and type of the current program location counter. A label can consist of letters, digits and underscore characters (**_**). The first character cannot be a digit. A label which is prefixed by whitespace (spaces or tabs) has to be followed by a colon (:). The size of an identifier is only limited by the amount of available memory.

Examples:

```
    LAB1:  ; This label is followed by a colon and
             can be prefixed by whitespace
LAB1       ; This label has to start at the beginning
             of a line
```

instruction An instruction consists of a mnemonic and zero, one or more operands. It must not start in the first column. Operands are described in section 4.4, *Operands of an Assembly Instruction*. The instructions are described in the *M16C Series Software Manual* [Renesas].

Examples:

```
REIT                    ; No operand
PUSH.W R0               ; One operand
ADD.W R0,R1             ; Two operands
STZX #12,#22,15[FB]     ; Three operands
```

directive With directives you can control the assembler from within the assembly source. These must not start in the first column. Directives are described in section 4.8, *Assembler Directives and Controls*.

macro_call A call to a previously defined macro. It must not start in the first column. Macros are described in section 4.10 *Macro Operations*.

You can use empty lines or lines with only comments.

Apart from the assembly statements as described above, you can put a so–called 'control line' in your assembly source file. These lines start with a **$** in the first column and alter the default behavior of the assembler.

$*control*

For more information on controls see section 4.8, *Assembler Directives and Controls*.

4.3 ASSEMBLER SIGNIFICANT CHARACTERS

You can use all ASCII characters in the assembly source both in strings and in comments. Also the extended characters from the ISO 8859–1 (Latin–1) set are allowed.

Some characters have a special meaning to the assembler. Special characters associated with expression evaluation are described in section 4.6.3, *Expression Operators*. Other special assembler characters are:

Character	Description
;	Start of a comment
\	Line continuation character or Macro operator: argument concatenation
?	Macro operator: return decimal value of a symbol
%	Macro operator: return hex value of a symbol
^	Macro operator: override local label
"	Macro string delimiter or Quoted string **DEFINE** expansion character
'	String constants delimiter
@	Start of a built–in assembly function
$	Location counter substitution
#	Constant number (immediate addressing mode)
++	String concatenation operator
[ ]	Substring delimiter or Indirect addressing mode operator

Note that macro operators have a higher precedence than expression operators.

4.4 OPERANDS OF AN ASSEMBLY INSTRUCTION

In an instruction, the mnemonic is followed by zero, one or more operands. An operand has one of the following types:

Operand	Description
symbol	A symbolic name as described in section 4.5, *Symbol Names*. Symbols can also occur in expressions.
register	Any valid data register (R0, R0H, R0L, R1, R1H, R1L, R2, R3), address register (A0, A1), frame base register (FB), static base register (SB), control register (PC, INTB, USP, ISP, FLG) or special function register. For some instruction you can use a register pair (R2R0, R3R1, A1A0).
expression	Any valid expression as described in the section 4.6, *Assembly Expressions*.
address	A combination of *expression*, *register* and *symbol*.

The M16C assembly language has several addressing modes. These described in detail in the *M16C Series Software Manual* [Renesas].

4.5 SYMBOL NAMES

User–defined symbols

A user–defined *symbol* can consist of letters, digits and underscore characters (_). The first character cannot be a digit. The size of an identifier is only limited by the amount of available memory. The case of these characters is significant. You can define a symbol by means of a label declaration or an equate or set directive.

Labels

Symbols used for memory locations are referred to as labels.

Reserved symbols

Register names and names of assembler directives and controls are reserved for the system, so you cannot use these for user–defined symbols. The case of these built–in symbols is insignificant.

Examples

```
CON1 EQU 3H     ; The symbol CON1 represents
                ; the value of 3 hex

MOV.W CON1 + 020H, R1     ; Move contents of address
                          ; 023H to register R1
```

Valid symbol names	**Invalid symbol names**	
`loop_1`	`1_loop`	(starts with a number)
`ENTRY`	`R0`	(reserved register name)
`a_B_c`	`DEFINE`	(reserved directive name)
`_aBC`		

4.6 ASSEMBLY EXPRESSIONS

An *expression* is a combination of symbols, constants, operators, and parentheses which represent a value that is used as an operand of an assembler instruction (or directive).

Expressions can contain user–defined labels (and their associated integer or floating–point values), and any combination of integers, floating–point numbers, or ASCII literal strings.

Expressions follow the conventional rules of algebra and boolean arithmetic.

Expressions that can be evaluated at assembly time are called *absolute expressions*. Expressions where the result is unknown until all sections have been combined and located, are called *relocatable* or *relative expressions*.

When any operand of an expression is relocatable, the entire expression is relocatable. Relocatable expressions are emitted in the object file and are evaluated by the linker. Relocatable expressions can only contain integral functions; floating–point functions and numbers are not supported by the ELF/DWARF object format.

The assembler evaluates expressions with 64–bit precision in two's complement.

An *expression* can be any of the following:

- *numeric contant*
- *string*
- *symbol*
- *expression binary_operator expression*
- *unary_operator expression*
- **(** *expression* **)**
- *function call*

All types of expressions are explained in separate sections.

4.6.1 NUMERIC CONSTANTS

Numeric constants can be used in expressions. If there is no prefix, the assembler assumes the number is a decimal number.

Base	Description	Example

Binary	'**0B**' or '**0b**' followed by binary digits (0,1).	`0B1101`
		`0b11001010`

Hexadecimal	'**0X**' or '**0x**' followed by a hexadecimal digits (0–9, A–F, a–f).	`0X12FF`
		`0x45`
		`0x9abc`

Decimal, integer	Decimal digits (0–9).	`12`
		`1245`

Decimal, floating point	Includes a decimal point, or an '**E**' or '**e**' followed by the exponent.	`6E10`
		`.6`
		`3.14`
		`2.7e10`

4.6.2 STRINGS

ASCII characters, enclosed in single (') or double (″) quotes constitue an ASCII string. Strings between double quotes allow symbol substitution by a `DEFINE` directive, whereas strings between single quotes are always literal strings. Both types of strings can contain escape characters.

Strings constants in expressions are evaluated to a number (each character is replaced by its ASCII value). Strings in expressions can have a size of up to a long word (first 4 characters) or less depending on the operand of an instruction or directive; any subsequent characters in the string are ignored. In this case the assembler issues a warning. An exception to this rule is when a string longer than 4 characters is used in a DB assembler directive; in that case all characters result in a constant byte. Null strings have a value of 0.

Square brackets (**[ ]**) delimit a substring operation in the form:

[*string*,*offset*,*length***]**

offset is the start position within *string*. *length* is the length of the desired substring. Both values may not exceed the size of *string*.

Examples

```
'ABCD'              ; (0x41424344)

'''79'              ; to enclose a quote double it

"A\"BC"             ; or to enclose a quote escape it

'AB'+1              ; (0x4143) string used in expression

''                  ; null string

dl 'abcdef'         ; (0x61626364) 'ef' are ignored
                    ; warning: string value truncated

'ab'++'cd'          ; you can concatenate two strings
                    ; with the '++' operator.
                    ; This results in 'abcd'

['TASKING',0,4]     ; results in the substring 'TASK'
```

4.6.3 EXPRESSION OPERATORS

The next table shows the assembler operators. They are ordered according to their precedence. Operators of the same precedence are evaluated left to right. Expressions between parentheses have the highest priority (innermost first).

Valid operands include numeric constants, literal ASCII strings and symbols.

Most assembler operators can be used with both integer and floating–point values. If one operand has an integer value and the other operand has a floating–point value, the integer is converted to a floating–point value before the operator is applied. The result is a floating–point value.

Type	Oper ator	Name	Description
	( )	parentheses	Expressions enclosed by parenthesis are evaluated first.
Unary	+	plus	Returns the value of its operand.
	–	minus	Returns the negative of its operand.
	~	complement	Returns complement, integer only
	!	logical negate	Returns 1 if the operands’ value is 1; otherwise 0. For example, if `buf` is 0 then `!buf` is 1.
Arithmetic	*	multiplication	Yields the product of two operands.
	/	division	Yields the quotient of the division of the first operand by the second. With integers, the divide operation produces a truncated integer.
	%	modulo	Integer only: yields the remainder from a division of the first operand by the second.
	+	addition	Yields the sum of its operands.
	–	subtraction	Yields the difference of its operands.
Shift	<<	shift left	Integer only: shifts the left operand to the left (zero–filled) by the number of bits specified by the right operand.
	>>	shift right	Integer only: shifts the left operand to the right (sign bit extended) by the number of bits specified by the right operand.
Relational	<	less than	If the indicated condition is:
	<=	less or equal	– True: result is an integer 1
	>	greater than	– False: result is an integer 0
	>=	greater or equal	Be cautious when you use floating point values in an equality test; rounding errors can cause unexpected results.
	==	equal	
	!=	not equal	

Type	Oper ator	Name	Description
Bitwise	&	AND	Integer only: yields bitwise AND
	|	OR	Integer only: yields bitwise OR
	^	exclusive OR	Integer only: yields bitwise exlusive OR
Logical	&&	logical AND	Returns an integer 1 if both operands are nonzero; otherwise, it returns an integer 0.
	||	logical OR	Returns an integer 1 if either of the operands is nonzero; otherwise, it returns an integer 1

Table 4–1: Assembly expression operators

4.7 BUILT-IN ASSEMBLY FUNCTIONS

The assembler has several built–in functions to support data conversion, string comparison, and math computations. You can use functions as terms in any expression. Functions have the following syntax:

Syntax of an assembly function

*@function_name***(**[*argument*[**,***argument*]...]**)**

Functions start with the '@' character and have zero or more arguments, and are always followed by opening and closing parentheses. White space (a blank or tab) is not allowed between the function name and the opening parenthesis and between the (comma–separated) arguments.

The built–in assembler functions are grouped into the following types:

- **Mathematical functions** comprise, among others, transcendental, random value, and min/max functions.
- **String functions** compare strings, return the length of a string, and return the position of a substring within a string.
- **Macro functions** return information about macros.
- **Address calculation functions** return the high or low part of an address.
- **Assembler mode functions** relating assembler operation.

The following tables provide an overview of all built–in assembler functions. For a detailed description of these functions, see section 3.2, *Built–in Assembly Function*, in Chapter *Assembly Language* of the *Reference Manual*.

Overview of mathematical functions

Function	Description
@ABS(*expr*)	Absolute value
@MAX(*expr*,[,...,*exprN*])	Maximum value
@MIN(*expr*,[,...,*exprN*])	Minimum value
@SGN(*expr*)	Returns the sign of an expression as −1, 0 or 1

Overview of string functions

Function	Description
@CAT(*str1*,*str2*)	Concatenate strings
@LEN(*string*)	Length of string
@POS(*str1*,*str2*[,*start*])	Position of substring in string
@SCP(*str1*,*str2*)	Returns 1 if two strings are equal
@SUB(*string*,*expr*,*expr*)	Returns substring in string

Overview of macro functions

Function	Description
@ARG(’*symbol*’|*expr*)	Test if macro argument is present
@CNT()	Return number of macro arguments
@MAC(*symbol*)	Test if symbol is defined as a macro
@MXP()	Test if macro expansion is active

Overview of address calculation functions

Function	Description
@LSW(*expr*)	Returns lower 16 bits of expression value
@MSW(*expr*)	Returns bits 16..31 of expression value

Overview of assembler mode functions

Function	Description
@DEF('*symbol*'|*symbol*)	Returns 1 if symbol has been defined
@LST()	LIST control flag value

4.8 ASSEMBLER DIRECTIVES AND CONTROLS

An assembler directive is simply a message to the assembler. Assembler directives are not translated into machine instructions. There are three main groups of assembler directives.

- Assembler directives that tell the assembler how to go about translating instructions into machine code. This is the most typical form of assembly directives. Typically they tell the assembler where to put a program in memory, what space to allocate for variables, and allow you to initialize memory with data. When the assembly source is assembled, a location counter in the assembler keeps track of where the code and data is to go in memory.

  The following directives fall under this group:

  – Assembly control directives
  – Symbol definition directives
  – Data definition / Storage allocation directives
  – Debug directives
- Directives that are interpreted by the macro preprocessor. These directives tell the macro preprocessor how to manipulate your assembly code before it is actually being assembled. You can use these directives to write macros and to write conditional source code. Parts of the code that do not match the condition, will not be assembled at all.
- Some directives act as assembler options and most of them indeed do have an equivalent assembler (command line) option. The advantage of using a directive is that with such a directive you can overrule the assembler option for a particular part of the code. Directives of this kind are called *controls*. A typical example is to tell the assembler with an option to generate a list file while with the controls $LIST ON and $LIST OFF you overrule this option for a part of the code that you do *not* want to appear in the list file. Controls always appear on a separate line and start with a '$' sign in the first column.

The following controls are available:

– Assembly listing controls
– Miscellaneous controls

Each assembler directive or control has its own syntax. You can use assembler directives and controls in the assembly code as pseudo instructions.

4.8.1 OVERVIEW OF ASSEMBLER DIRECTIVES

The following tables provide an overview of all assembler directives. For a detailed description, see section 3.3.2, *Detailed Description of Assembler Directives*, in Chapter *Assembly Language* of the *Reference Manual*.

Overview of assembly control directives

Directive	Description
COMMENT	Start comment lines. You cannot use this directive in IF/ELSE/ENDIF constructs and MACRO/DUP definitions.
DEFINE	Define substitution string
DEFSECT	Define section name, type and attributes
END	End of source program
FAIL	Programmer generated error message
INCLUDE	Include file
MSG	Programmer generated message
RADIX	Change input radix for constants
SECT	Activate a declared section
UNDEF	Undefine DEFINE symbol
WARN	Programmer generated warning

Overview of symbol definition directives

Directive	Description
BTEQU	Bit equate
EQU	Assigns permanent value to a symbol
EXTERN	External symbol declaration
GLOBAL	Global symbol declaration
LOCAL	Local symbol declaration
SET	Set temporary value to a symbol
SIZE	Set size of symbol in the ELF symbol table
TYPE	Set symbol type in the ELF symbol table
WEAK	Mark symbol as 'weak'

Overview of data definition / storage allocation directives

Directive	Description
ALIGN	Define alignment
ASCII / ASCIZ	Define ASCII string without / with ending NULL byte
BS	Define block storage (initialized)
BSB	Define byte block storage (initialized)
BSBIT	Define bit block storage in bit–addressable data
BSW / BSL	Define word / long block storage (initialized)
DB	Define constant byte
DBIT	Define constant bit
DS	Define storage
DW / DL	Define a word / long constant
FLOAT / DOUBLE	Define a float / double constant

Overview of macro and conditional assembly directives

Directive	Description
DUP	Duplicate sequence of source lines
DUPA	Duplicate sequence with arguments
DUPC	Duplicate sequence with characters
DUPF	Duplicate sequence in loop
ENDM	End of macro or duplicate sequence
EXITM	Exit macro
IF/ELIF/ELSE/ENDIF	Conditional assembly
MACRO	Define macro
PMACRO	Undefine (purge) macro

Overview of debug directives

Directive	Description
CALLS	Passes call information to object file. Used by the linker to build a call graph and calculate stack size

4.8.2 OVERVIEW OF ASSEMBLER CONTROLS

The following tables provide an overview of all assembler controls. For a detailed description, see section 3.3.4, *Detailed Description of Assembler Controls*, in Chapter *Assembly Language* of the *Reference Manual*.

Overview of assembly listing controls

Control	Description
$LIST ON/OFF	Generation of assembly list file temporary ON/OFF
$LIST "*flags*"	Exclude / include lines in assembly list file
$PAGE	Generate formfeed in assembly list file
$PAGE *settings*	Define page layout for assemly list file
$PRCTL	Send control string to printer
$STITLE *string*	Set program subtitle in header of assembly list file
$TITLE *string*	Set program title in headerof assembly list file

Overview of miscellaneous assembler controls

Control	Description
$CASE ON/OFF	Case sensitive user names ON/OFF
$DEBUG ON/OFF	Generation of symbolic debug ON/OFF
$DEBUG "*flags*"	Generation of symbolic debug ON/OFF
$IDENT LOCAL/GLOBAL	Assembler treats labels by default as local or global
$OBJECT	Alternative name for the generated object file
$OPTJ ON/OFF	Turn on/off conditional optimization
$WARNING OFF [*num*]	Suppress one or all warnings

4.9 WORKING WITH SECTIONS

Sections are absolute or relocatable blocks of contiguous memory that can contain code or data. Some sections contain code or data that your program declared and uses directly, while other sections are created by the compiler or linker and contain debug information or code or data to initialize your application. These sections can be named in such a way that different modules can implement different parts of these sections. These sections are located in memory by the linker (using the linker script language, LSL) so that concerns about memory placement are postponed until after the assembly process.

All instructions and directives which generate data or code must be within an active section. The assembler emits a warning if code or data starts without a section definition and activation. The compiler automatically generates sections. If you program in assembly you have to define sections yourself.

For more information about locating sections see section 8.6.7 *The Section Layout Definition: Locating Sections* in chapter *Using the Linker*.

Section definition

Sections are defined with the DEFSECT directive and have a name. A section may have attributes to instruct the linker to place it on a predefined starting address, or that it may be overlaid with another section.

DEFSECT "*name*", *type* [, *attribute*]... [**AT** *address*]

See the DEFSECT directive in section 3.3.2, *Detailed Description of Assembler Directives*, in chapter *Assembly Language* of the *Reference Manual*, for a complete description of all possible attributes.

Section activation

Sections are defined once and are activated with the SECT directive.

SECT ”*name*”

The linker will check between different modules and emits an error message if the section attributes do not match. The linker will also concatenate all matching section definitions into one section. So, all ”code” sections generated by the compiler will be linked into one big ”code” chunk which will be located in one piece. By using this naming scheme it is possible to collect all pieces of code or data belonging together into one bigger section during the linking phase. A SECT directive referring to an earlier defined section is called a continuation. Only the name can be specified.

Example 1

```
DEFSECT   ”test_CO”, CODE
SECT      ”test_CO”
```

Defines and activates a relocatable section in CODE memory. Other parts of this section, with the same name, may be defined in the same module or any other module. Other modules should use the same DEFSECT statement. When necessary, it is possible to give the section an absolute starting address with the locator description file.

Example 2

```
DEFSECT   ”test_ABS_CO”, CODE AT 0x1000
SECT      ”test_ABS_CO”
```

Defines and activates an absolute section named `test_ABS_CO` starting on address 0x1000.

Example 3

```
DEFSECT   ”test_CLR_DA”, DATA, CLEAR
SECT      ”test_CLR_DA”
```

Defines a relocatable named section in DATA memory. The CLEAR attribute instructs the linker to clear the memory located to this section. When this section is used in another module it must be defined identically. Continuations of this section in the same module are as follows:

```
SECT ”test_CLR_DA”
```

4.10 MACRO OPERATIONS

Macros provide a shorthand method for inserting a repeated pattern of code or group of instructions. Yuo can define the pattern as a macro, and then call the macro at the points in the program where the pattern would repeat.

Some patterns contain variable entries which change for each repetition of the pattern. Others are subject to conditional assembly.

When a macro is called, the assembler executes the macro and replaces the call by the resulting in–line source statements. ’In–line’ means that all replacements act as if they are one the same line as the macro call. The generated statements may contain substitutable arguments. The statements produced by a macro can be any processor instruction, almost any assembler directive, or any previously–defined macro. Source statements resulting from a macro call are subject to the same conditions and restrictions as any other statements.

Macros can be *nested*. The assembler processes nested macros when the outer macro is expanded.

4.10.1 DEFINING A MACRO

The first step in using a macro is to define it in the source file. The definition of a macro consists of three parts:

- *Header*, which assigns a name to the macro and defines the arguments.
- *Body*, which contains the code or instructions to be inserted when te macro is called.

- *Terminator*, which indicates the end of the macro definition (ENDM directive).

A macro definition takes the following form:

```
Header:       macro_name MACRO [arg[,arg]...] [; comment]
                         .
Body:                    source statements
                         .
Terminator:              ENDM
```

If the macro name is the same as an existing assembler directive or mnemonic opcode, the assembler replaces the directive or mnemonic opcode with the macro and issues a warning.

The arguments are symbolic names that the macro preprocessor replaces with the literal arguments when the macro is expanded (called). Each argument must follow the same rules as global symbol names. Argument names cannot start with a percent sign (**%**).

Example

The macro definition:

```
CONSTD  MACRO  reg,value                        ;header
    mov.w   #value,reg                          ;body
    ENDM                                        ;terminator
```

The macro call:

```
    DEFSECT  "data",DATA
    SECT    "data"

    CONSTD  R0,0x1234

    END
```

The macro expands as follows:

```
    mov.w   #0x1234,R0
```

4.10.2 CALLING A MACRO

To invoke a macro, construct a source statement with the following format:

```
[label] macro_name [arg[,arg]...]          [; comment]
```

where:

label	An optional label that corresponds to the value of the location counter at the start of the macro expansion.
macro_name	The name of the macro. This may not start in the first column.
arg	One or more optional, substitutable arguments. Multiple arguments must be separated by commas.
comment	An optional comment.

The following applies to macro arguments:

- Each argument must correspond one–to–one with the formal arguments of the macro definition. If the macro call does not contain the same number of arguments as the macro definition, the assembler issues a warning.
- If an argument has an embedded comma or space, you must surround the argument by single quotes (').
- You can declare a macro call argument as NULL in three ways:
  - enter delimiting commas in succession with no intervening spaces

    ```
    macroname ARG1,,ARG3 ; the second argument
                           is a NULL argument
    ```

  - terminate the argument list with a comma, the arguments that normally would follow, are now considered NULL

    ```
    macroname ARG1,      ; the second and all following
                           arguments are NULL
    ```

  - declare the argument as a NULL string
- No character is substituted in the generated statements that reference a NULL argument.

4.10.3 USING OPERATORS FOR MACRO ARGUMENTS

The assembler recognizes certain text operators within macro definitions which allow text substitution of arguments during macro expansion. You can use these operators for text concatenation, numeric conversion, and string handling.

Operator	Name	Description
\	Macro argument concatenation	Concatenates a macro argument with adjacent alphanumeric characters.
?	Return decimal value of symbol	Substitutes the **?***symbol* sequence with a character string that represents the decimal value of the symbol.
%	Return hex value of symbol	Substitutes the **%***symbol* sequence with a character string that represents the hexadecimal value of the symbol.
"	Macro string delimiter	Allows the use of macro arguments as literal strings.
^	Macro local label override	Causes local labels in its term to be evaluated at normal scope rather than at macro scope.

*Argument Concatenation Operator – *

Consider the following macro definition:

```
SWAP_REG MACRO REG1,REG2          ;swap register contents
     XCHG.B    R\REG1\H, R\REG2\H
     ENDM
```

The macro is called as follows:

```
     SWAP_REG  0,1
```

The macro expands as follows:

```
     XCHG.B    R0H, R1H
```

The macro preprocessor substitutes the character '0' for the argument REG1, and the character '1' for the argument REG2. The concatenation operator (\) indicates to the macro preprocessor that the substitution characters for the arguments are to be concatenated with the character 'R'.

Without the '\' operator the macro would expand as:

```
     XCHG.B    RREG1H, RREG2H
```

which results in an assembler error (invalid operand).

Decimal value Operator – ?

Instead of substituting the formal arguments with the actual macro call arguments, you can also use the *value* of the macro call arguments.

Consider the following source code that calls the macro SWAP_SYM after the argument AREG has been set to 0 and BREG has been set to 1.

```
AREG SET      0
BREG SET      1
     SWAP_SYM  AREG,BREG
```

If you want to replace the arguments with the *value* of AREG and BREG rather than with the literal strings 'AREG' and 'BREG', you can use the **?** operator and modify the macro as follows:

```
SWAP_SYM   MACRO  REG1,REG2       ;swap memory contents
     XCHG.W    R\?REG1, R\?REG2
     ENDM
```

The macro first expands as follows:

```
     XCHG.W    R\?AREG, R\?BREG
```

Then **?**AREG is replaced by '0' and **?**BREG is replaced by '1':

```
     XCHG.W    R\0, R\1
```

Because of the concatenation operator '\' the strings are concatenated:

```
     XCHG.W    R0, R1
```

Hex Value Operator – %

The percent sign (**%**) is similar to the standard decimal value operator (**?**) except that it returns the hexadecimal value of a symbol.

Consider the following macro definition:

```
GEN_LAB   MACRO  LAB,VAL,STMT
LAB\%VAL  STMT
     ENDM
```

A symbol with the name NUM is set to 10 and the macro is called with NUM as argument:

```
NUM SET       10
    GEN_LAB    HEX,NUM,NOP
```

The macro expands as follows:

```
HEXA NOP
```

The `%VAL` argument is replaced by the character 'A' which represents the hexadecimal value 10 of the argument `VAL`.

Argument String Operator – "

To generate a literal string, enclosed by single quotes ('), you must use the argument string operator (") in the macro definition.

Consider the following macro definition:

```
STR_MAC    MACRO  STRING
    DB  "STRING"
    ENDM
```

The macro is called as follows:

```
  STR_MAC  ABCD
```

The macro expands as follows:

```
   DB  'ABCD'
```

Within double quotes `DEFINE` directive definitions can be expanded. Take care when using constructions with quotes and double quotes to avoid inappropriate expansions. Since a `DEFINE` expansion occurs before a macro substitution, all `DEFINE` symbols are replaced first within a macro argument string:

```
    DEFINE LONG  'short'
STR_MAC    MACRO  STRING
    MSG 'This is a LONG STRING'
    MSG "This is a LONG STRING"
    ENDM
```

If the macro is called as follows:

```
   STR_MAC  sentence
```

The macro expands as:

```
   MSG 'This is a LONG STRING'
   MSG 'This is a short sentence'
```

Single quotes prevent expansion.

Macro Local Label Override Operator – ^

If you use labels in macros, the assembler normally generates another unique name for the labels (such as `LAB__M_L0000001`).

The macro ^–operator prevents name mangling on macro local labels.

Consider the following macro definition:

```
INIT   MACRO ARG, CNT
       MOV.W #CNT,A0
^LAB:
       DB ARG
       DEC.W A0
       JNZ ^LAB
       ENDM
```

The macro is called as follows:

```
      INIT 2,4
```

The macro expands as:

```
       MOV.W #4,A0
LAB:
       DB 2
       DEC.W A0
       JNZ LAB
```

Without the ^ operator, the macro preprocessor would choose another name for LAB because the label already exists. The macro then would expand like:

```
       MOV.W #4,A0
LAB__M_L000001:
       DB 2
       DEC.W A0
       JNZ LAB__M_L000001
```

4.10.4 USING THE DUP, DUPA, DUPC, DUPF DIRECTIVES AS MACROS

The DUP, DUPA, DUPC, and DUPF directives are specialized macro forms to repeat a block of source statements. You can think of them as a simultaneous definition and call of an unnamed macro. The source statements between the DUP, DUPA, DUPC, and DUPF directives and the ENDM directive follow the same rules as macro definitions.

For a detailed description of these directives, see section 3.3, *Assembler Directives*, in Chapter *Assembly Language* of the *Reference Manual*.

4.10.5 CONDITIONAL ASSEMBLY: IF, ELIF AND ELSE DIRECTIVES

With the conditional assembly directives you can instruct the macro preprocessor to use a part of the code that matches a certain condition.

You can specify assembly conditions with arguments in the case of macros, or through definition of symbols via the `DEFINE`, `SET`, and `EQU` directives.

The built–in functions of the assembler provide a versatile means of testing many conditions of the assembly environment.

You can use conditional directives also within a macro definition to check at expansion time if arguments fall within a certain range of values. In this way macros become self–checking and can generate error messages to any desired level of detail.

The conditional assembly directive `IF` has the following form:

```
IF   expression
 .
 .
[ELIF  expression] ;(the ELIF directive is optional)
 .
 .
[ELSE]             ;(the ELSE directive is optional)
 .
 .
ENDIF
```

The *expression* must evaluate to an absolute integer and cannot contain forward references. If *expression* evaluates to zero, the `IF`–condition is considered FALSE. Any non–zero result of *expression* is considered as TRUE.

For a detailed description of these directives, see section 3.3, *Assembler Directives*, in Chapter *Assembly Language* of the *Reference Manual*.

CHAPTER 5

USING THE COMPILER

TASKING

CHAPTER 5

5.1 INTRODUCTION

EDE uses a *makefile* to build your entire project, from C source till the final ELF/DWARF object file which serves as input for the debugger.

Although in EDE you cannot run the compiler separately from the other tools, this chapter discusses the options that you can specify for the compiler.

On the command line it is possible to call the compiler separately from the other tools. However, it is recommended to use the control program **ccm16c** for command line invocations of the toolchain (see section 9.2, *Control Program*, in Chapter *Using the Utilities*). With the control program it is possible to call the entire toolchain with only one command line.

The compiler takes the following files for input and output:

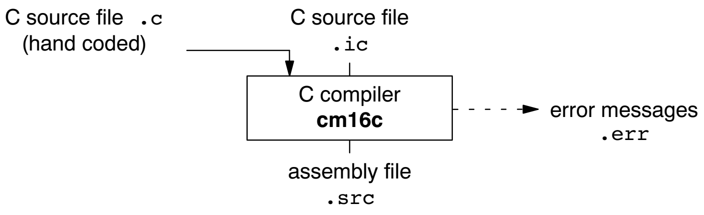


Figure 5–1: C compiler

This chapter first describes the compilation process which consists of a *frontend* and a *backend* part. During compilation the code is optimized in several ways. The various optimizations are described in the second section. Third it is described how to call the compiler and how to use its options. An extensive list of all options and their descriptions is included in the section 4.1, *Compiler Options*, in Chapter 4, *Tool Options*, of the *Reference Manual*. Finally, a few important basic tasks are described.

5.2 COMPILATION PROCESS

During the compilation of a C program, the compiler **cm16c** runs through a number of phases that are divided into two groups: *frontend* and *backend*.

The backend part is not called for each C statement, but starts after a complete C module or set of modules has been processed by the frontend (in memory). This allows better optimization.

Frontend phases

1. The preprocessor phase:

   The preprocessor includes files and substitutes macros by C source. It uses only string manipulations on the C source. The syntax for the preprocessor is independent of the C syntax but is also described in the ISO/IEC 9899:1999(E) standard.

2. The scanner phase:

   The scanner converts the preprocessor output to a stream of tokens.

3. The parser phase:

   The tokens are fed to a parser for the C grammar. The parser performs a syntactic and semantic analysis of the program, and generates an intermediate representation of the program. This code is called MIL (Medium level Intermediate Language).

4. The frontend optimization phase:

   Target processor *independent* optimizations are performed by transforming the intermediate code.

Backend phases

1. Instruction selector phase:

   This phase reads the MIL input and translates it into Low level Intermediate Language (LIL). The LIL objects correspond to an M16C processor instruction, with an opcode, operands and information used within the compiler.

2. Peephole optimizer phase:

   This phase replaces instruction sequences by equivalent but faster and/or shorter sequences, rearranges instructions and deletes unnecessary instructions.

3. Register allocator phase:

   This phase chooses a physical register to use for each virtual register.

4. The backend optimization phase:

   Performs target processor *independent* and *dependent* optimizations which operate on the Low level Intermediate Language.

5. The code generation/formatter phase:

   This phase reads through the LIL operations to generate assembly language output.

5.3 COMPILER OPTIMIZATIONS

The compiler has a number of optimizations which you can enable or disable. To enable or disable optimizations:

1. From the **Project** menu, select **Project Options...**

   The Project Options dialog box appears.

2. Expand the **C Compiler** entry and select **Optimization**.

3. Select an optimization level in the **Optimization level** box.

   or:

   In the **Optimization level** box, select **Custom optimization** and enable the optimizations you want in the **Custom optimization** box.

Optimization levels

The TASKING C compilers offer four optimization levels and a custom level, at each level a specific set of optimizations is enabled.

- **Level 0**: No optimizations are performed. The compiler tries to achieve a 1–to–1 resemblance between source code and produced code. Expressions are evaluated in the order written in the source code, associative and commutative properties are not used.
- **Level 1**: Enables optimizations that do not affect the debug–ability of the source code. Use this level when you are developing/debugging new source code.
- **Level 2**: Enables more aggressive optimizations to reduce the memory footprint and/or execution time. The debugger can handle this code but the relation between source code and generated instructions may be hard to understand. Use this level for those modules that are already debugged. This is the default optimization level.
- **Level 3**: Enables aggressive global optimization techniques. The relation between source code and generated instructions can be very hard to understand. The debugger does not crash, will not provide misleading information, but does not fully understand what is going on. Use this level when your program does not fit in the memory provided by your system anymore, or when your program/hardware has become too slow to meet your real–time requirements.
- **Custom level**: you can enable/disable specific optimizations.

Optimization pragmas

If you specify a certain optimization, all code in the module is subject to that optimization. Within the C source file you can overrule the compiler options for optimizations with `#pragma optimize` *`flag`* and `#pragma endoptimize`. Nesting is allowed:

```
#pragma optimize e    /* Enable expression
...                      simplification              */
... C source ...
...
#pragma optimize c    /* Enable common expression
...                      elimination. Expression
... C source ...         simplification still enabled */
...
#pragma endoptimize   /* Disable common expression
...                      elimination                 */
#pragma endoptimize   /* Disable expression
...                      simplification              */
```

The compiler optimizes the code between the pragma pair as specified.

You can enable or disable the optimizations described below. The command line option for each optimization is given in brackets.

See also option **–O** (**––optimize**) in section 4.1, *Compiler Options*, of Chapter *Tool Options* of the *Reference Manual*.

Generic optimizations (frontend)

Common subexpression elimination (CSE) *(option* ***–Oc/–OC****)*

The compiler detects repeated use of the same (sub–)expression. Such a "common" expression is replaced by a variable that is initialized with the value of the expression to avoid recomputation. This method is called *common subexpression elimination* (CSE).

Expression simplification *(option* ***–Oe/–OE****)*

Multiplication by 0 or 1 and additions or subtractions of 0 are removed. Such useless expressions may be introduced by macros or by the compiler itself (for example, array subscription).

Constant propagation *(option* ***–Op/–OP****)*

A variable with a known constant value is replaced by that value.

Function Inlining *(option* ***–Oi/–OI****)*

Small functions that are not too often called, are inlined. This reduces execution time at the cost of code size.

Compaction (reverse inlining) *(option* ***–Or/–OR****)*

Compaction is the opposite of *inlining functions*: large chunks of code that occur more than once, are transformed into a function. This reduces code size at the cost of execution speed.

Control flow simplification *(option* ***–Of/–OF****)*

A number of techniques to simplify the flow of the program by removing unnecessary code and reducing the number of jumps. For example:

Switch optimization:
A number of optimizations of a switch statement are performed, such as removing redundant case labels or even removing an entire switch.

Jump chaining:

A (conditional) jump to a label which is immediately followed by an unconditional jump may be replaced by a jump to the destination label of the second jump. This optimization speeds up execution.

Conditional jump reversal:

A conditional jump over an unconditional jump is transformed into one conditional jump with the jump condition reversed. This reduces both the code size and the execution time.

Dead code elimination:

Code that is never reached, is removed. The compiler generates a warning messages because this may indicate a coding error.

Subscript strength reduction (option **–Os**/**–OS**)

An array of pointer subscripted with a loop iterator variable (or a simple linear function of the iterator variable), is replaced by the dereference of a pointer that is updated whenever the iterator is updated.

Loop transformations (option **–Ol**/**–OL**)

Temporarily transform a loop with the entry point at the bottom, to a loop with the entry point at the top. This enables *constant propagation* in the initial loop test and code motion of loop invariant code by the *CSE* optimization.

Forward store (option **–Oo**/**–OO**)

A temporary variable is used to cache multiple assignments (stores) to the same non–automatic variable.

Core specific optimizations (backend)

Coalescer (option **–Oa**/**–OA**)

The coalescer seeks for possibilities to reduce the number of moves (MOV instruction) by smart use of registers. This optimizes both speed as code size.

Interprocedural register optimization (option **–Ob**/**–OB**)

Register allocation is improved by taking note of register usage in functions called by a given function.

Peephole optimizations *(option* **–Oy**/**–OY***)*

The generated assembly code is improved by replacing instruction sequences by equivalent but faster and/or shorter sequences, or by deleting unnecessary instructions.

Generic assembly optimizations *(option* **–Og**/**–OG***)*

A set of target independent optimizations that increase speed and decrease code size.

Optimize 'call+return' to jump *(option* **–Oz**/**–OZ***)*

A function call which is immediately followed by a function return is replaced by a jump. With this optimization a call trace is no longer possible.

5.3.1 OPTIMIZE FOR SIZE OR SPEED

You can tell the compiler to focus on execution speed or code size during optimizations. You can do this by specifying a size/speed trade–off level from 0 (speed) to 4 (size). This trade–off does not turn optimization phases on or off. Instead, its level is a weight factor that is used in the different optimization phases to influence the heuristics. The higher the level, the more the compiler focuses on code size optimization.

To specify the size/speed trade–off optimization level:

1. From the **Project** menu, select **Project Options...**

   The Project Options dialog box appears.

2. Expand the **C Compiler** entry and select **Optimization**.

3. Select one of the options **Optimize for size** or **Optimize for speed**.

See also option **–t** (**––tradeoff**) in section 4.1, *Compiler Options*, in Chapter *Tool Options* of the *Reference Manual*.

5.4 CALLING THE COMPILER

EDE uses a *makefile* to build your entire project. This means that you cannot run the compiler only. If you compile a single C source file from within EDE, the file is also automatically assembled. However, you can set options specific for the compiler. After you have build your project, the output files of the compilation step are available in your project directory.

To compile your program, click either one of the following buttons:

Compiles and assembles the currently selected file. This results in a relocatable object file (`.obj`).

Builds your entire project but looks whether there are already files available that are needed in the building process. If so, these files will not be generated again, which saves time.

Builds your entire project unconditionally. All steps necessary to obtain the final `.elf` file are performed.

To only check for syntax errors, click the following button:

Checks the currently selected file for syntax errors, but does not generate code.

Select a target processor (core)

Because the toolchain supports several processor cores, you need to choose a processor type first.

To access the M16C processor options:

1. From the **Project** menu, select **Project Options...**

   The Project Options dialog box appears.

2. Expand the **Processor** entry and select **Processor Definition**.

3. In the **Select processor** list select the target processor.

4. (Optional) Fill in the **Startup Code** page.

5. Click **OK** to accept the processor options.

   Processor options affect the invocation of all tools in the toolchain. In EDE you only need to set them once. The corresponding options for the compiler are listed in table 5–1.

Based on the target processor, the compiler includes a *special function register file* `regcpu.sfr`. This is an include file written in C syntax which is shared by the compiler, assembler and debugger. Once the compiler reads an SFR file you can reference the special function registers (SFR) and bits within an SFR using symbols defined in the SFR file.

To specify the search path and include directories

1. From the **Project** menu, select **Directories...**

   The Directories dialog box appears.

2. Fill in the directory path settings and click **OK**.

To access the compiler options

1. From the **Project** menu, select **Project Options...**

   The Project Options dialog box appears.

2. Expand the **C Compiler** entry, fill in the various pages and click **OK** to accept the compiler options.

   The compiler command line equivalences of your EDE selections are shown simultaneously in the ***Options string*** *box.*

The following processor options are available:

EDE options	Command line
Processor Definition	
Select processor Compile for R8C/tiny instead of M16C/60	**–C***cpu* **––r8c**
Memory	
Internal memory	*EDE only*
Startup Code	
Add <project>_cstart.src to your project	*EDE only*

Table 5–1: Processor options

The following project directories are available:

EDE options	**Command line**
Directories	
Executable files path	*$PATH environment*
Include files path	**–I***dir*
Library files path	*linker option* **–L***dir*

Table 5–2: Project directories

The following compiler options are available:

EDE options	**Command line**
Memory Models	
Compile using small/medium/large memory model	**–M**{**s**|**m**|**l**}
Code Generation	
Keep strings in ROM	**––romstrings**
Keep constants in ROM	**––romconstants**
ROM is available in first 64k of memory	**––near–rom**
Generate code for fixed interrupt vector	**––novector**
Generate frame for interrupt routines	**––noframe**
Preprocessing	
Define user *macro*	**–D***macro*[=*def*]
Include an extra file at the beginning of the C source	**–H***file*
Store the C compiler preprocess output (*file*`.pre`)	**–E***flag*
Alignment	
Align functions to an even address	**––align–func**
Align data to an even address	**––align–data**
Optimization	
Optimization level Custom optimization	**–O**{**0**|**1**|**2**|**3**} **–O***flag*
Optimize for size/speed	**–t**{**0**|**4**}
Language	
ISO C standard 90 or 99 (default: 99)	**–c**{**90**|**99**}
Treat 'char' variables as unsigned instead of signed	**–u**

EDE options	Command line
Treat 'int' bitfield as signed	**––signed–bitfields**
Treat enumerated types always as integer	**––integer–enumeration**
Language extensions Allow C++ style comments in C source Check assignment constant string to non constant string pointer	**–A***flag* **–Ap** **–Ax**
Debug	
Generate debug information	**–g**
Floating Point	
Use single precision floating point only	**–F**
Floating point trap/exception handling	*control program option* **––fp–trap**
Diagnostics	
Report all warnings Suppress all warnings Suppress specific warnings Treat warnings as errors	*no option –w* **–w** **–w***num*[,*num*]... **––warnings–as–errors**
MISRA–C	
MISRA–C rules	**––misrac=**{**all**|*nr*[–*nr*],...}
Produce MISRA–C report file	*linker option* **––misra–c–report**
Generate warnings instead of errors for advisory MISRA–C rules	**––misrac–advisory–warnings**
Generate warnings instead of errors for required MISRA–C rules	**––misrac–required–warnings**
MISRA–C version	**––misrac–version=***year*
Miscellaneous	
Merge C source code with assembly in output file (`.src`)	**–s**
Additional C Compiler options	*options*

Table 5–3: Compiler options

The following options are available on the command line, and you can set them in EDE through the **Additional C Compiler options** field in the **Miscellaneous** page:

Description	Command line
Display invocation syntax	**–?**
Align all objects on an even address	**––align**
Maximum size of a match with code compaction (default: 200)	**––compact–max–size** = *value*
Redirect diagnostic messages to a file	**––error–file**[=*file*]
Read options from file	**–f *file***
Always inline function calls	**––inline**
Maximum size increment inlining (in %) (default: 25)	**––inline–max–incr=** *value*
Maximum size for function to always inline (default: 10)	**––inline–max–size=** *value*
Keep output file after errors	**–k**
Maximum call depth, default infinite (default: –1)	**––max–call–depth=** *value*
Send output to standard output	**–n**
Do not clear non–initialized global variables	**––noclear**
Do not generate frame for interrupt handler	**––noframe**
Specify name of output file	**–o** *file*
Rename sections	**–R***mem=name*
Treat external definitions as "static"	**––static**
Display version header only	**–V**

Table 5–4: Compiler options only available on the command line

The invocation syntax on the command line is:

```
cm16c [option]... [file]
```

The input file must be a C source file (`.c` or `.ic`).

```
cm16c test.c
```

This compiles the file `test.c` and generates the file `test.src` which serves as input for the assembler.

For a complete overview of all options with extensive description, see section 4.1, *Compiler Options*, of Chapter *Tool Options* of the *Reference Manual*.

5.5 HOW THE COMPILER SEARCHES INCLUDE FILES

When you use include files, you can specify their location in several ways. The compiler searches the specified locations in the following order:

1. The absolute pathname, if specified in the `#include` statement. Or, if no path or a relative path is specified, the same directory as the source file. This is only possible for include files that are enclosed in "".

This first step is not done for include files enclosed in <>.

2. The directories that are specified in the **Project | Directories** dialog (**–I** option).

3. The paths which were set during installation. You can still change these paths.

See section 1.3.1, *Configuring the Embedded Development Environment* and environment variable CM16CINC in section 1.3.2, *Configuring the Command Line Environment*, in Chapter *Software Installation*.

4. The default `include` directory relative to the installation directory.

5.6 COMPILING FOR DEBUGGING

Compiling your files is the first step to get your application ready to run on a target. However, during development of your application you first may want to debug your application.

To create an object file that can be used for debugging, you must instruct the compiler to include *symbolic debug information* in the source file.

To include symbolic debug information

1. From the **Project** menu, select **Project Options...**

The Project Options dialog box appears.

2. Expand the **C Compiler** entry and select **Debug Information**.

3. Enable the option **Generate debug information**.

4. Click **OK** to accept the new project settings.

```
cm16c -g
```

Debug and optimizations

Due to different compiler optimizations, it might be possible that certain debug information is optimized away. Therefore, it is best to specify **Debug purpose** (**–O1**) when you want to debug your application. This is a special optimization level where the source code is still suitable for debugging.

1. From the **Project** menu, select **Project Options...**

   The Project Options dialog box appears.

2. Expand the **C Compiler** entry and select **Optimization**.

3. In the **Optimization level** box, select **Debug purpose**.

5.7 C CODE CHECKING: MISRA-C

The C programming language is a standard for high level language programming in embedded systems, yet it is considered somewhat unsuitable for programming safety–related applications. Through enhanced code checking and strict enforcement of best practice programming rules, TASKING MISRA–C code checking helps you to produce more robust code.

MISRA–C specifies a subset of the C programming language which is intended to be suitable for embedded automotive systems. It consists of a set of rules, defined by MISRA–C:2004 in *Guidelines for the use of the C Language in critical systems* (MIRA Limited, 2004).

The compiler also supports the MISRA–C:1998 version of the MISRA–C rules. You can select this version with the following C compiler option:

```
--misrac-version=1998
```

For a complete overview of all MISRA–C rules, see Chapter 8, *MISRA–C Rules*, in the *Reference Manual*.

Implementation issues

The MISRA–C implementation in the compiler supports nearly all rules. Only few rules are not supported because they address documentation, run–time behavior, or other issues that cannot be checked by static source code inspection, or because they require an application–wide overview.

During compilation of the code, violations of the enabled MISRA–C rules are indicated with error messages and the build process is halted.

MISRA–C rules are divided in *required rules* and *advisory rules*. If rules are violated, errors are generated causing the compiler to stop. With the following options warnings, instead of errors, are generated for either or both the required rules and the advisory rules:

```
--misrac-required-warnings

--misrac-advisory-warnings
```

Note that not all MISRA–C violations will be reported when other errors are detected in the input source. For instance, when there is a syntax error, all semantic checks will be skipped, including some of the MISRA–C checks. Also note that some checks cannot be performed when the optimizations are switched off.

Quality Assurance report

To ensure compliance to the MISRA–C rules throughout the entire project, the TASKING M16C linker can generate a MISRA–C Quality Assurance report. This report lists the various modules in the project with the respective MISRA–C settings at the time of compilation. You can use this in your company's quality assurance system to provide proof that company rules for best practice programming have been applied in the particular project.

Apply MISRA–C code checking to your application

1. From the **Project** menu, select **Project Options...**

   The Project Options dialog box appears.

2. Expand the **C Compiler** entry and select **MISRA–C**.

3. Select a MISRA–C configuration. Select a predefined configuration for conformance with the required rules in the MISRA–C guidelines.

   It is also possible to read a MISRA–C configuration from an external file.

4. (Optional) In the **MISRA–C Rules** entry, specify the individual rules.

```
cm16c --misrac={all | number [-number],...}
```

See compiler option **––misrac** in section 4.1, *Compiler Options* in Chapter *Tool Options* of the *Reference Manual*.

See linker option **––misra–c–report** in section 4.3, *Linker Options* in Chapter *Tool Options* of the *Reference Manual*.

5.8 C COMPILER DIAGNOSTICS

At compile time, the **cm16c** compiler reports the following types of error messages:

F Fatal errors

After a fatal error the compiler immediately aborts compilation.

E Errors

Errors are reported, but the compiler continues compilation. No output files are produced unless you have set the compiler option **––keep–output–files** (the resulting output file may be incomplete).

W Warnings

Warning messages do not result into an erroneous assembly output file. They are meant to draw your attention to assumptions of the compiler for a situation which may not be correct. You can control warnings in the **C Compiler | Diagnostics** page of the **Project | Project Options...** menu (compiler option **–w**).

I Information

Information messages are always preceded by an error message. Information messages give extra information about the error.

S System errors

System errors occur when internal consistency checks fail and should never occur. When you still receive the system error message

```
S9##: internal consistency check failed – please report
```

please report the error number and as many details as possible about the context in which the error occurred. The following helps you to prepare an e–mail using EDE:

1. From the **Help** menu, select **Technical Support –> Prepare Email...**

   The Prepare Email form appears.

2. Fill out the the form. State the error number and attach relevant files.

3. Click the **Copy to Email client** button to open your email application.

   A prepared e–mail opens in your e–mail application.

4. Finish the e–mail and send it.

Display detailed information on diagnostics

1. In the **Help** menu, enable the option **Show Help on Tool Errors**.

2. In the **Build** tab of the **Output** window, double–click on an error or warning message.

   A description of the selected message appears.

```
cm16c --diag=[format:]{all | number,...}
```

See compiler option **--diag** in section 4.1, *Compiler Options* in Chapter *Tool Options* of the *Reference Manual*.

5.9 RUN–TIME ERROR CHECKING

To be able to perform *run–time error checking*, the compiler adds extra code to your C source. Because of the inserted code, applications will run slower and require more memory. Therefore it is recommended to use run–time checking only during the development of the software.

A message is printed on stdout (which is connected to the CrossView Terminal Window) if an run–time error is detected. Every message is preceded by the code address where the error was detected. The source file name and line number are not printed, because that would increase the code and data size. To obtain the source position, you can either lookup the address in the map file, or set a breakpoint on `__runtime_error` in the debugger to back–trace the error.

Run–time error checking can be done at application wide scope or at module scope. Only `malloc()` checks are always executed at application wide scope.

The following run–time checks are available:

Bounds checking

Bounds checking verifies all pointer operations to detect buffer overflows and other illegal operations. The bounds checking code keeps track of the bounds of all objects that may have their address taken somewhere in the application.

Pointer arithmetic

When a pointer is incremented or decremented, the old and new values should point to the same object: it would be an error if the new pointer value is outside the current object. Likewise, comparing or subtracting pointers to different objects results in undefined behavior according to the ISO C standard, and will be flagged as well.

Dereferencing invalid pointer

The ISO C standard allows a pointer to point to the first byte after an object, but dereferencing such a pointer is an error. Therefore, a pointer to the first address after an object is considered to point ”inside” the object, but dereferencing the pointer will be flagged by the bounds checking code.

Uninitialized pointers / null pointer

Uninitialized automatic pointers are initialized to a special value that triggers a run–time error when used. Dereferencing or updating a null pointer will also trigger a run–time error.

Considerations

- Sub–objects such as structure members, or objects from a memory pool in the application are not checked for overflow.
- An offset calculation in a static pointer initializer is performed by the assembler, and cannot be checked.
- Pointers to function parameters cannot be checked.

Unhandled case in a switch

This option reports an unhandled case value in a switch without a default part. It simply completes any switch without a default part with an extra function call. This has little impact on the execution speed. To avoid this type of run–time error, add an empty `default` part to the case switch when the switch is not supposed to have a case for every possible value.

Malloc checks

This option uses wrappers around the functions `malloc()`, `realloc()` and `free()` that will check for common dynamic memory allocation errors like:

- buffer overflow
- write to freed memory
- multiple calls to free
- passing an invalid pointer to free

For this check some additional code from the library is extracted, but it has minimal impact on on your application code size. The dynamic memory usage increases only by a couple of bytes per allocation.

Memory allocated by `malloc()` is deliberately initialized with a non–zero value to force a failure when the application fails to initialize the memory.

To detect a buffer overflow, a sentinel byte is placed directly after every allocation. The sentinel is checked when the memory is freed. Likewise, a "magic" number before the allocation makes it possible to detect a buffer underflow. This duplicates some functionality of the bounds checking, but with lower overhead.

A call to `free()` overwrites the memory to force a failure when the memory is used after it has been freed. To detect modification of memory that has been freed, a call to malloc() will check the items freed since the previous call (with a maximum of 4) for changes.

Stack overflow

This option adds a test for stack overflow at the start of every function and for every variable length array declaration. Enabling this check will extend the function prolog code with a stack overflow test.

Because the functions that report the stack overflow need some stack space themselves, the overflow is reported *before* the limit is reached. This margin is set at 24 bytes.

Division by zero

Reports division by zero when during program execution an attempt was made to divide by zero. This check will test the divisor just before a division takes place.

5.9.1 STEP 1: BUILD YOUR APPLICATION FOR RUN-TIME ERROR CHECKING

To instruct the compiler to add run–time checking code:

For checks at application wide scope:

1. From the **Project** menu, select **Project Options...**

   The Project Options dialog box appears.

Or, for checks at module scope:

   From the Project menu, select **Current File Options...**

   The File Options dialog box appears.

2. Expand the **C Compiler** entry and select **Run–time Error Checking**.
3. Enable one or more of the following options:
   - **Bounds checking**
   - **Report unhandled case in a switch**
   - **Malloc consistency checks**
   - **Stack overflow check**
   - **Division by zero check**

cm16c --runtime=[*flags*]

Instead of using the compiler option to enable run–time error checking for your whole application, you can also use **#pragma runtime** to enable run–time error checking for parts of the application. The pragma works exactly the same as the compiler option.

```
#pragma runtime flags
```

Compiler option **––runtime** in section 4.1, *Compiler Options*, in Chapter 4, *Tool Options*, of the *Reference Manual*.

When a run–time error is detected, by default a message is printed on stdout (which is connected to the CrossView Terminal Window) while the program continues. If this is not desirable, you can replace the default error function `__runtime_error()` by a custom function.

5.9.2 STEP 2: EXECUTE THE APPLICATION

Once you have compiled and linked the application for run–time error checking, it must be executed. Start CrossView Pro and run your application in simulation mode.

Run the program as usual: the program should run normally taking the same input as usual and producing the same output as usual. The application will run somewhat slower that normal because of the extra time spent on performing the error checks.

Small heap problem

When the program does not run as usual, this is typically caused by a shortage of heap space. In this case an out of memory message is issued (when running with file system simulation, it is displayed in the FSS0 Terminal window).

To solve this problem, increase the size of the heap:

1. From the **Project** menu, select **Project Options...**

   The Project Options dialog box appears.

2. Expand the **Linker** entry and select **Stack/Heap**

3. Enter a new value for **Heap size** (in bytes), for example 1000.

Below are a number of code examples which generate the possible errors for the several run–time error checking options.

5.9.3 EXAMPLES PRODUCING RUN-TIME ERRORS

Example 1: Bounds checking

C source

```
int sum (int* arr, int n)
{
    int total = 0;
    for (int i = 0; i < n; i++)
    {
        total += arr[i];
    }
    return total;
}
```

```
int distance (int* arr1, int* arr2)
{
    if (arr2 > arr1)
    {
        return arr2 - arr1;
    }
    else
    {
        return arr1 - arr2;
    }
}

char* inc (char* ptr)
{
    return ptr + 10;
}

int deref (char* ptr)
{
    return *ptr;
}

int list1 [] = {1, 2, 3, 4, 5};
int list2 [] = {6, 7, 8, 9, 10};

int main (void)
{
    char* uninit1;
    static char* uninit2;
    sum(list1, 5);                  // OK
    sum(list1, 6);                  // overflow
    distance(list1+1, list1+5);     // OK
    distance(list1+1, list2+5);     // different objects
    inc(uninit1);                   // uninitialized pointer
    inc(uninit2);                   // null pointer
    deref(uninit1);                 // uninitialized pointer
    deref(uninit2);                 // null pointer
    return 0;
}
```

Ouput

```
error at 000c2283: access beyond end of object
                   [00000600,0000060a]
error at 000c2294: pointer a008001a outside object
                   [00000600,0000060a]
error at 000c22d3: comparing pointers to different objects
                   (00000616/00000602)
error at 000c22f1: subtracting pointers to different objects
                   (00000616/00000602)
error at 000c23d9: arithmetic on uninitialized pointer
error at 000c23e0: arithmetic on null pointer
error at 000c2356: dereferencing uninitialized pointer
error at 000c2356: dereferencing null pointer
```

Example 2: Unhandled case

C source

```
int sum (int* arr, int n)
{
    int total = 0;
    for (int i = 0; i < n; i++)
    {
        total += arr[i];
    }
    return total;
}
```

Ouput

```
error at 000c16b6: unhandled case
```

Example 3: Malloc checks

C source

```
#include <stdlib.h>
#include <string.h>

typedef    struct
{
    char* item1;
    char* item2;
} node_t;

int main (void)
{
    char* buf = malloc(5);
    strcpy(buf, "hello");      // error: buffer too small
    free(buf);                 // OK
    free(buf);                 // error: duplicate free
    free(&buf);                // error: invalid pointer
    *buf = '\0';               // error: writing to freed memory
    node_t* node = malloc(sizeof(node_t));
    free(node->item1);         // error: uninitialized memory
    free(node);                // OK
    free(node->item2);         // error: deallocated memory
}
```

Ouput

```
error at 000c240b: malloc buffer overflow
                   (address 00000e0e, size 5)
error at 000c2415: memory already freed
                   (address 00000e0e, size 5)
error at 000c241e: calling free with an invalid pointer
                   (00000859)
error at 000c243b: freed memory was modified
                   (address 00000e0e, size 5)
error at 000c245b: calling free with an invalid pointer
                   (aaaaaaaa)
error at 000c2491: calling free with an invalid pointer
                   (bbbbbbbb)
```

Example 4: Stack overflow

C source

```
void main (void)
{
    int     bigsize = 10000;
    int array[bigsize];         // stack overflow. Calls abort.
}
```

Ouput

```
error at 000c2ab2: stack overflow
```

Example 5: Division by zero

C source

```
#include <stdio.h>

int b=0;
float f;

int main (void)
{
    f=10/b;
    printf(”f=%f”,f);
    return f;
}
```

Ouput

```
error at 000c3ab5: division by zero
```

CHAPTER 6

PROFILING

TASKING

CHAPTER 6

6.1 WHAT IS PROFILING?

Profiling is a collection of methods to gather data about your application which helps you to identify code fragments where execution consumes the greatest amount of time.

TASKING supplies a number of profiler tools each dedicated to solve a particular type of performance tuning problem. Performance problems can be solved by:

- Identifying time–consuming algorithms and rewrite the code using a more time–efficient algorithm.
- Identifying time–consuming functions and select the appropriate compiler optimizations for these functions (for example, enable loop unrolling or function inlining).
- Identifying time consuming loops and add the appropriate pragmas to enable the compiler to further optimize these loops.

A profiler helps you to find and identify the time consuming constructs and provides you this way with valuable information to optimize your application.

TASKING employs various schemes for collecting profiling data, depending on the capabilities of the target system and different information needs.

6.1.1 THREE METHODS OF PROFILING

There are several methods of profiling: recording by an instruction set simulator, profiling using the debugger and profiling with code instrumentation techniques. Each method has its advantages and disadvantages.

Profiling by an instruction set simulator

On way way to gather profiling information is built into the instruction set simulator (ISS). The ISS records the time consumed by each instruction that is executed. The debugger then retrieves this information and correlates the time spent for individual instructions to C source statements.

Advantages

– it gives (cycle) accurate information with extreme fine granularity

– the executed code is identical to the non–profiled code

Disadvantages

– the method requires an ISS as execution environment

Profiling with the debugger

The second method of profiling is built into the debugger. You specify which functions you want to profile. The debugger places breakpoints on the function entry and all its exit addresses and measures the time spent in the function and its callees.

Advantages

– the executed code is identical to the non–profiled code

Disadvantage

– each time a profiling breakpoint is hit the target is stopped and control is passed to the debugger. Although the debugger restarts the application immediately, the application's performance is significantly reduced.

See Section *Profiling* in Chapter *Special Features* of the *CrossView Pro Debugger User's Manual*.

Profiling using code instrumentation techniques

The TASKING compiler contains an option to add code to your application which takes care of the profiling process. This is called *code instrumentation*. The gathered profiling data is first stored in the target's memory and will be written to a file when the application finishes execution or when the function `__prof_cleanup()` is called.

Advantages

– it can give a complete call graph of the application annotated with the time spend in each function and basic block

– this profiling method is execution environment independent

– the application is profiled while it executes on its aimed target taking real–life input

Disadvantage

– instrumentation code creates a significant run–time overhead, and instrumentation code and gathered data take up target memory

This method provides a valuable complement to the other two methods and will be described into more detail below.

6.2 PROFILING USING CODE INSTRUMENTATION

Profiling can be used to determine which parts of a program take most of the execution time.

Once the collected data are presented, it may reveal which parts of your code execute slower than expected and which functions contribute most to the overall execution time of a program. It gives you also information about which functions are called more or less often than expected. This information not only may reveal design flaws or bugs that had otherwise been unnoticed, it also reveals parts of the program which can be effectively optimized.

Important considerations

The code instrumentation method adds code to your original application which is needed to gather the profiling data. Therefore, the code size of your application increases. Furthermore, during the profiling process, the gathered data is initially stored into dynamically allocated memory of the target. The heap of your application should be large enough to store this data. Since code instrumentation is done by the compiler, assembly functions used in your program do not show up in the profile.

The profiling information is collected during the *actual execution* of the program. Therefore, the input of the program influences the results. If a part/function of the program is not activated while the program is profiled, no profile data is generated for that part/function.

It is possible to execute the application multiple times (while varying the input data) and combine the profiling results of those runs.
(See section 6.2.3, *Step 3: displaying profiling results*).

Overview of steps to perform

To obtain a profile using code instrumentation, perform the following steps:

1. Compile and link your program with profiling enabled

2. Execute the program to generate the profiling data

3. Display the profiling results

6.2.1 STEP 1: BUILD YOUR APPLICATION FOR PROFILING

The first step is to add the code that takes care of the profiling, to your application. This is done with compiler options:

For profiling at application wide scope:

1. From the **Project** menu, select **Project Options...**

   The Project Options dialog box appears.

Or, for profiling at module scope:

   From the Project menu, select **Current File Options...**

   The File Options dialog box appears.

2. Expand the **C Compiler** entry and select **Profiler**.

3. Enable one or more of the following profiler options to select which profiles should be obtained.

   - **Block counters** (not with ***Call graph*** or ***Function timers***)
   - **Call graph**
   - **Function counters**
   - **Function timers**

   Block counters (not in combination with Call graph or Time)

   This will instrument the code to perform basic block counting. As the program runs, it will count how many time it executed each branch of each `if` statement, each iteration of a `for` loop, and so on. Note that though you can combine Block counters with Function counters, this has no effect because Function counters is a subset of Block counters.

   Call graph (not in combination with Block counters)

   This will instrument the code to reconstruct the run–time call graph. As the program runs it stores the relation between the caller and the gathered profiling data.

   Function counters

   This will instrument the code to perform function call counting. This is a subset of the basic Block counters.

Time (not in combination with Block counters)

This will instrument the code to measure the time spent in a function. This includes the time spent in all called functions (callees).

Clock(): ticks per second

The profiler uses the C library function `clock()` to measure time. This is a target dependent function. Default, the `clock()` function is implemented for the Tasking simulator which runs at 10 MHz. If you do not use the simulator for execution, you must provide your own `clock()` function. To obtain correct time measurements, fill in the resolution of your `clock()` function (in MHz). The default is 10 MHz.

4. From the **Build** menu select **Rebuild**.

For the command line, see the command line compiler option **−p** (**−−profile**) in Section 4.1, *Compiler Options* in Chapter *Tool Options* of the reference manual.

6.2.1.1 PROFILING MODULES AND LIBRARIES

Profiling individual modules

It is possible to profile individual C modules. In this case only limited profiling data is gathered for the functions in the modules compiled without the profiling option. When you use the suboption **Call graph**, the profiling data reveals which profiled functions are called by non–profiled functions. The profiling data does *not* show how often and from where the non–profiled functions themselves are called. Though this does not affect the flat profile, it might reduce the usefulness of the call graph.

Profiling library functions

EDE and/or the control program **tcc** will link your program with the standard version of the C library `libc*.a`. Functions from this library which are used in your application, will not be profiled. If you do want to incorporate the library functions in the profile, you must set the appropriate compiler options in the C library makefiles and rebuild the library.

6.2.1.2 LINKING PROFILING LIBRARIES

When building your application, the application must be linked against a profile library. EDE (or the control program **tcc**) automatically select the correct library based on the profiling options you specified. However, if you compile, assemble and link your application manually, make sure you specify the correct library.

See Section 8.4, *Linking with Libraries* in Chapter *Using the Linker* for an overview of the (profiling) libraries.

6.2.2 STEP 2: EXECUTE THE APPLICATION

Once you have compiled and linked the application for profiling, it must be executed to generate the profiling data. Run the program as usual: the program should run normally taking the same input as usual and producing the same output as usual. The application may run somewhat slower than normal because of the extra time spent on collecting the profiling data.

Startup code

The startup code initializes the profiling functions by calling the function `__prof_init()`. EDE will automatically make the required modifications to the startup code. Or, when you use the control program, this extracts the correct startup code from the C library.

If you use your own startup code, you must manually insert a call to the function `__prof_init` just before the call to `_main` and its stack setup.

An application can have multiple entry points, such as `main()` and other functions that are called by interrupt. This does not affect the profiling process.

Small heap problem

When the program does not run as usual, this is typically caused by a shortage of heap space. In this case an out of memory message is issued. (When running with file system simulation, it is displayed on the Debug console.)

To solve this problem, increase the size of the heap:

1. From the **Project** menu, select **Project Options...**

   The Project Options dialog box appears.

2. Expand the **Linker** entry and select **Stack/Heap**

3. Enter a new value for **Heap size** (in bytes).

After execution

When the program has finished (returning from `main()`), the exit code calls the function `__prof_cleanup()`. This function writes the gathered profiling data to a file on the host system using the debugger's file system simulation features. If your program does *not* return from `main()`, you can force this by inserting a call to the function `__prof_cleanup()` in your application source code. Please note the double underscores when calling from C code!

The resulting profiling data file is named `amon.prf`. This file is written to the current working directory.

If your program does not run under control of the debugger and therefore cannot use the file simulation system (FSS) functionality to write a file to the host system, you must implement a way to pass the profiling data gathered on the target to the host. Adapt the function `_prof_cleanup()` in the profiling libraries or the underlying I/O functions for this purpose.

6.2.3 STEP 3: DISPLAYING PROFILING RESULTS

The result of the profiler can be displayed in EDE.

1. Return to the EDE window.
2. In EDE, from the **Build** menu select **Profile**.

   The Select Profile Files dialog appears.

   Normally, profiling information is stored in the file `amon.prf`. However, you can rename this file to keep previous results.
3. Browse to the profile file you want to display (`amon.prf` or one of the renamed profiling files).

   It is possible to select multiple .prf files. The results are combined.
4. Click **OK** to confirm.

   The profile information of the selected file is displayed in the Profiling tab of the Output window.

The Output–Profiling window

Results table	Shows the timing and call information for all functions and/or blocks in the profile.
Callers table	Shows the functions that called the focus function.
Callees table	Shows the functions that are called by the focus function.

- Double clicking on a function in a table, makes the function the focus function.
- To sort the rows in the table, click on one of the column headers.
- Right–clicking in a table opens a quick–access menu.
- With the copy functions it is possible to copy a table (or selected rows) to other applications. To select one or more rows, hold down the Shift–key or Ctrl–key and click the rows you want to add to the selection.

The profiling information

Based on the profiling options you have set before compiling your application, some columns in the profiling window may remain empty. The columns in the tables represent the following information:

In the *results* table:

Module	The C source module in which the function resides.
#Line	Line number of first statement in the Function.
Function	The function for which profiling data is gathered and (if present) the code block number.
Total time	Total amount of time (seconds) that was spend in the function. This includes the time spent in callees of the function.
Self time	Total amount of time (seconds) that was spend executing the command of the function itself. This *excludes* the spent in callees of the function.
% in function	The relative amount of time spent in this function. These should add up to 100%.
Calls/Block Counts	Number of calls (function counters) and basic block counts.
#Callers	Number of functions by which this function is called. Each function should have at least one caller (except `_START`).
#Callees	Number of different functions that can be called from this function.

In the *caller* table:

Module	The C source module in which the function resides.
#Line	Line number of first statement in the Function.
Caller	The name(s) of the function(s) which called the focus function.
Total time	Total amount of time (seconds) that was spend in the focus function. This includes the time spent in callees of the function.
Self time	Total amount of time (seconds) that was spend executing the command of the focus function itself. This *excludes* the spent in callees of the function.
Contribution%	Relative amount of time contributed to the total time of the focus function. These should add up to 100%.
Calls	Number of calls *to* the focus function.
Calls %	Number of calls *to* the focus function as a percentage of all calls to the focus function. These should add up to 100%.

In the *callee* table:

This table basically contains the same columns as the caller table. Only the **caller** column is replaced by the **callee** column which also changes the meaning of the **calls** and **calls %** column:

Callee	The name(s) of the function(s) that are called by the focus function.
Calls	Number of calls *from* the focus function.
Calls %	Number of calls *from* the focus function as a percentage of all calls from the focus function. These should add up to 100%.

Note that the **self time** of the focus function plus the **total time** of its callees result in the **total time** of the focus function.

Presumable incorrect call graph

The call graph is based on the *compiled* source code. Due to compiler optimizations the call graph may therefore seem incorrect at first sight. For example, the compiler can replace a function call immediately followed by a return instruction by a jump to the callee, thereby merging the callee function with the caller function. In this case the time spent in the callee function is not recorded separately anymore, but added to the time spent in the caller function (which, as said before, now holds the callee function). This represents exactly the structure of your source in assembly but may differ from the structure in the initial C source.

CHAPTER 7

USING THE ASSEMBLER

TASKING

CHAPTER 7

7.1 INTRODUCTION

The assembler converts hand–written or compiler–generated assembly language programs into machine language, resulting in object files in the Executable and Linking Format (ELF).

The assembler takes the following files for input and output:

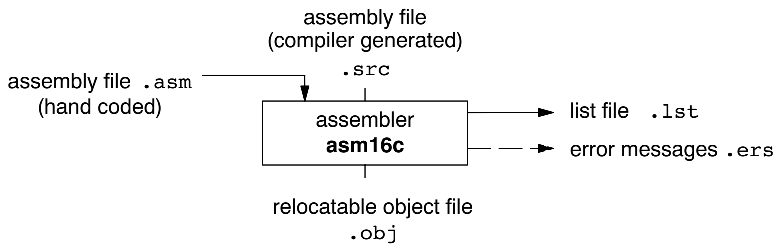


Figure 7–1: Assembler

This chapter first describes the assembly process. The various assembler optimizations are described in the second section. Third it is described how to call the assembler and how to use its options. An extensive list of all options and their descriptions is included in the *Reference Manual*. Finally, a few important basic tasks are described.

7.2 ASSEMBLY PROCESS

The assembler generates relocatable output files with the extension `.obj`. These files serve as input for the linker.

Phases of the assembly process

1. Parsing of the source file: preprocessing of assembler directives and checking of the syntax of instructions

2. Optimization (instruction alignment, size and generic instructions)

3. Generation of the relocatable object file and optionally a list file

The assembler integrates file inclusion and macro facilities. See section 4.10, *Macro Operations*, in Chapter *Assembly Language* for more information.

7.3 ASSEMBLER OPTIMIZATIONS

The **asm16c** assembler performs various optimizations to reduce the size of the assembled applications. To enable or disable optimizations:

1. From the **Project** menu, select **Project Options...**

   The Project Options dialog box appears.

2. Expand the **Assembler** entry and select **Optimization**.

You can enable or disable the optimizations described below. The command line option for each optimization is given in brackets.

See also option **–O** (**––optimize**) in section 4.2, *Assembler Options*, in Chapter *Tool Options* of the *Reference Manual*.

Instruction alignment *(option* ***–Oa****/****–OA****)*

When this option is enabled, the assembler aligns instructions with an even size on even addresses. Odd sized instructions are not aligned.

Allow generic instructions *(option* ***–Og****/****–OG****)*

When this option is enabled, you can use generic instructions in your assembly source. The assembler tries to replace the generic instructions by faster or smaller instructions. For example, the generic instruction `jeq _label1` is replaced by `jne __T1; jz _label1; __T1:`. By default this option is enabled. Because shorter instructions may influence the number of cycles, you may want to disable this option when you have written timed code. In that case the assembler encodes all instructions as they are.

Optimize instruction size *(option* ***–Os****/****–OS****)*

When this option is enabled, the assembler tries to find the shortest possible operand encoding for instructions. By default this option is enabled.

7.4 CALLING THE ASSEMBLER

EDE uses a *makefile* to build your entire project. You can set options specific for the assembler. After you have built your project, the output files of the assembling step are available in your project directory.

To assemble your program, click either one of the following buttons:

Assembles the currently selected assembly file (`.asm` or `.src`). This results in a relocatable object file (`.obj`).

Builds your entire project but looks whether there are already files available that are needed in the building process. If so, these files will not be generated again, which saves time.

Builds your entire project unconditionally. All steps necessary to obtain the final `.elf` file are performed.

To only check for syntax errors, click the following button:

Checks the currently selected assembly file for syntax errors, but does not generate code.

Select a target processor (core)

Because the toolchain supports several processor cores, you need to choose a processor type first.

To access the M16C processor options:

1. From the **Project** menu, select **Project Options...**

   The Project Options dialog box appears.

2. Expand the **Processor** entry, fill in the **Processor Definition** page and optionally the **Startup Code** page and click **OK** to accept the processor options.

   Processor options affect the invocation of all tools in the toolchain. In EDE you only need to set them once. The corresponding options for the assembler are listed in table 7–1.

Based on the target processor, the assembler includes a *special function register file* `regcpu.sfr`. This is an include file written in C syntax which is shared by the compiler, assembler and debugger. Once the assembler reads an SFR file you can reference the special function registers (SFR) and bits within an SFR using symbols defined in the SFR file.

To access the assembler options

1. From the **Project** menu, select **Project Options...**

   The Project Options dialog box appears.

2. Expand the **Assembler** entry, fill in the various pages and click **OK** to accept the project options.

   *The assembler command line equivalences of your EDE selections are shown simultaneously in the **Options string** box.*

The following processor options are available:

EDE options	Command line
Processor Definition	
Select processor Target R8C/tiny instead of M16C/60	**–C***cpu* **––r8c**
Memory	
Internal memory	*EDE only*
Startup Code	
Add <project>_cstart.src to your project	*EDE only*

Table 7–1: Processor options

The following assembler options are available:

EDE options	Command line
Preprocessing	
Define user *macro* Include this *file* before source	**–D***macro*[=*def*] **–H***file*
Optimization	
Optimize speed by means of instruction alignment Allow generic instructions Optimize instruction size	**–Oa**/**–OA** (= on/off) **–Og**/**–OG** **–Os**/**–OS**
Debug	
No debug information Automatic HLL or assembly level debug information Custom debug information	**–gAHLS** **–gs** **–g***flag*

EDE options	**Command line**
List File	
Generate list file	**–l**
Custom list file generation options	**–L***flags*
Generate section summary in list file	**–tl**
Diagnostics	
Report all warnings Suppress all warnings Suppress specific warnings	*no option –w* **–w** **–w***num*[,*num*]...
Treat warnings as errors	**––warnings–as–errors**
Miscellaneous	
Generate section summary	**–tc**
Case sensitive identifiers	*no option* ***–c***
Additional assembler options	*options*

Table 7–2: Assembler options

The following options are available on the command line, and you can set them in EDE through the **Additional assembler options** field in the **Miscellaneous** page:

Description	**Command line**
Display invocation syntax	**–?**
Emit local symbols	**––emit–locals**
Redirect diagnostic messages to a file	**––error–file**[=*file*]
Read options from file	**–f** ***file***
Labels are by default: local (default) global	 **–il** **–ig**
Keep output file after errors	**–k**
Select TASKING preprocessor or no preprocessor	**–m**{**t**|**n**}
Specify name of output file	**–o** *file*
Verbose information	**–v**
Display version header only	**–V**

Table 7–3: Assembler command line options

The invocation syntax on the command line is:

```
asm16c [option]... [file]
```

The input file must be an assembly source file (`.asm` or `.src`).

```
asm16c test.asm
```

This assembles the file `test.asm` for and generates the file `test.o` which serves as input for the linker.

For a complete overview of all options with extensive description, see section 4.2, *Assembler Options*, of Chapter *Tool Options* of the *Reference Manual*.

7.5 HOW THE ASSEMBLER SEARCHES INCLUDE FILES

When you use include files, you can specify their location in several ways. The assembler searches the specified locations in the following order:

1. The absolute pathname, if specified in the `INCLUDE` directive. Or, if no path or a relative path is specified, the same directory as the source file.

2. The directories that are specified in the **Project | Directories** dialog (**–I** option).

3. The paths which were set during installation. You can still change these paths.

See section 1.3.1, *Configuring the Embedded Development Environment* and environment variable ASM16CINC in section 1.3.2, *Configuring the Command Line Environment*, in Chapter *Software Installation*.

4. The default `include` directory relative to the installation directory.

7.6 GENERATING A LIST FILE

The list file is an additional output file that contains information about the generated code. You can also customize the amount and form of information.

If the assembler generates errors or warnings, these are reported in the list file just below the source line that caused the error or warning.

To generate a list file

1. From the **Project** menu, select **Project Options...**

   The Project Options dialog appears.

2. Expand the **Assembler** entry and select **List File**.

3. In the **List file generation** box, select **Enable default list file generation** or **Custom list file generation options**.

4. If you selected Custom, enable the options you want to include in the list file.

   EDE generates a list file for each source file in your project. A list file gets the same basename as the source file but with extension .lst.

Example on the command line

The following command generates the list file `test.lst`.

```
asm16c -l test.src
```

See section 5.1, *Assembler List File Format*, in Chapter *List File Formats* of the *Reference Manual* for an explanation of the format of the list file.

7.7 ASSEMBLER ERROR MESSAGES

The assembler produces error messages of the following types:

F Fatal errors

After a fatal error the assembler immediately aborts the assembling process.

E Errors

Errors are reported, but the assembler continues assembling. No output files are produced unless you have set the assembler option **––keep–output–files** (the resulting output file may be incomplete).

W ***Warnings***

Warning messages do not result into an erroneous assembly output file. They are meant to draw your attention to assumptions of the assembler for a situation which may not be correct. You can control warnings in the **Assembler | Diagnostics** page of the **Project | Project Options...** menu (assembler option **–w**).

Display detailed information on diagnostics

1. In the **Help** menu, enable the option **Show Help on Tool Errors**.
2. In the **Build** tab of the **Output** window, double–click on an error or warning message.

   A description of the selected message appears.

```
asm16c --diag=[format:]{all | number,...}
```

See assembler option **––diag** in section 4.2, *Assembler Options* in Chapter *Tool Options* of the *Reference Manual*.

CHAPTER 8

USING THE LINKER

TASKING

CHAPTER 8

8.1 INTRODUCTION

The linker **lkm16c** is a combined linker/locator. The linker phase combines relocatable object files (`.obj` files, generated by the assembler), and libraries into a single *relocatable linker object file* (`.eln`). The locator phase assigns absolute addresses to the linker object file and creates an absolute object file which you can load into a target processor. From this point the term *linker* is used for the combined linker/locator.

The linker takes the following files for input and output:

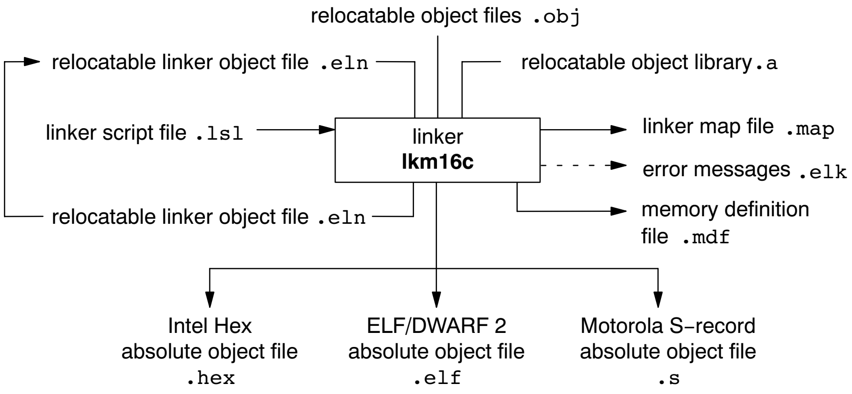

relocatable object files .obj
relocatable linker object file .eln
relocatable object library.a
linker script file .lsl
linker
lkm16c
linker map file .map
error messages .elk
relocatable linker object file .eln
memory definition file .mdf
Intel Hex absolute object file .hex
ELF/DWARF 2 absolute object file .elf
Motorola S–record absolute object file .s

Figure 8–1: Linker

This chapter first describes the linking process. Then it describes how to call the linker and how to use its options. An extensive list of all options and their descriptions is included in section 4.3, *Linker Options*, of the *Reference Manual*.

To gain even more control over the link process, you can write a script for the linker. This chapter shortly describes the purpose and basic principles of the *Linker Script Language* (LSL) on the basis of an example. A complete description of the LSL is included in Chapter 7, *Linker Script Language*, of the *Reference Manual*.

The end of the chapter describes how to generate a map file and contains an overview of the different types of messages of the linker.

8.2 LINKING PROCESS

The linker combines and transforms relocatable object files (.obj) into a single absolute object file. This process consists of two phases: the linking phase and the locating phase.

In the first phase the linker combines the supplied relocatable object files and libraries into a single relocatable object file. In the second phase, the linker assigns absolute addresses to the object file so it can actually be loaded into a target.

Glossary of terms

Term	Definition
Absolute object file	Object code in which addresses have fixed absolute values, ready to load into a target.
Address	A specification of a location in an address space.
Address space	The set of possible addresses. A core can support multiple spaces, for example in a Harvard architecture the addresses that identify the location of an instruction refer to code space, whereas addresses that identify the location of a data object refer to a data space.
Architecture	A description of the characteristics of a core that are of interest for the linker. This encompasses the logical address space(s) and the internal bus structure. Given this information the linker can convert logical addresses into physical addresses.
Copy table	A section created by the linker. This section contains data that specifies how the startup code initializes the data sections. For each section the copy table contains the following fields: – action: defines whether a section is copied or zeroed – destination: defines the section's address in RAM – source: defines the sections address in ROM – length: defines the size of the section in MAUs of the destination space
Core	An instance of a core architecture.
Derivative	The design of a processor. A description of one or more cores including internal memory and any number of buses.
Library	Collection of relocatable object files. Usually each object file in a library contains one symbol definition (for example, a function).

Term	Definition
Logical address	An address as encoded in an instruction word, an address generated by a core (CPU).
LSL file	The set of linker script files that are passed to the linker.
MAU	Minimum Addressable Unit. For a given processor the number of bits loaded between an address and the next address. This is not necessarily a byte or a word.
Object code	The binary machine language representation of the C source.
Physical address	An address generated by the memory system.
Processor	An instance of a derivative. Usually implemented as a (custom) chip, but can also be implemented in an FPGA, in which case the derivative can be designed by the developer.
Relocatable object file	Object code in which addresses are represented by symbols and thus relocatable.
Relocation	The process of assigning absolute addresses.
Relocation information	Information about how the linker must modify the machine code instructions when it relocates addresses.
Section	A group of instructions and/or data objects that occupy a contiguous range of addresses.
Section attributes	Attributes that define how the section should be linked or located.
Target	The hardware board on which an application is executing. A board contains at least one processor. However, a complex target may contain multiple processors and external memory that may be shared between processors.
Unresolved reference	A reference to a symbol for which the linker did not find a definition yet.

Table 8–1: Glossary of terms

8.2.1 PHASE 1: LINKING

The linker takes one or more relocatable object files and/or libraries as input. A relocatable object file, as generated by the assembler, contains the following information:

- *Header information*: Overall information about the file, such as the code size, name of the source file it was assembled from, and creation date.
- *Object code*: Binary code and data, divided into various named sections. Sections are contiguous chunks of code or data that have to be placed in specific parts of the memory. The program addresses start at zero for each section in the object file.
- *Symbols*: Some symbols are exported – defined within the file for use in other files. Other symbols are imported – used in the file but not defined (external symbols). Generally these symbols are names of routines or names of data objects.
- *Relocation information*: A list of places with symbolic references that the linker has to replace with actual addresses. When in the code an external symbol (a symbol defined in another file or in a library) is referenced, the assembler does not know the symbol's size and address. Instead, the assembler generates a call to a preliminary relocatable address (usually 0000), while stating the symbol name.
- *Debug information*: Other information about the object code that is used by a debugger. The assembler optionally generates this information and can consist of line numbers, C source code, local symbols and descriptions of data structures.

The linker resolves the external references between the supplied relocatable object files and/or libraries and combines the supplied relocatable object files into a single relocatable linker object file.

The linker starts its task by scanning all specified relocatable object files and libraries. If the linker encounters an unresolved symbol, it remembers its name and continues scanning. The symbol may be defined elsewhere in the same file, or in one of the other files or libraries that you specified to the linker. If the symbol is defined in a library, the linker extracts the object file with the symbol definition from the library. This way the linker collects all definitions and references of all of the symbols.

With this information, the linker combines the object code of all relocatable object files. The linker combines sections with the same section name and attributes into single sections, starting each section at address zero. The linker also substitutes (external) symbol references by (relocatable) numerical addresses where possible. At the end of the linking phase, the linker either writes the results to a file (a single relocatable object file) or keeps the results in memory for further processing during the locating phase.

The resulting file of the linking phase is a single relocatable object file (`.eln`). If this file contains unresolved references, you can link this file with other relocatable object files (`.obj`) or libraries (`.a`) to resolve the remaining unresolved references.

With the linker command line option **--link–only**, you can tell the linker to only perform this linking phase and skip the locating phase. The linker complains if any unresolved references are left.

8.2.2 PHASE 2: LOCATING

In the locating phase, the linker assigns absolute addresses to the object code, placing each section in a specific part of the target memory. The linker also replaces references to symbols by the actual address of those symbols. The resulting file is an absolute object file which you can actually load into a target memory. Optionally, when the resulting file should be loaded into a ROM device the linker creates a so–called copy table section which is used by the startup code to initialize the data sections.

Code modification

When the linker assigns absolute addresses to the object code, it needs to modify this code according to certain rules or *relocation expressions* to reflect the new addresses. These relocation expressions are stored in the relocatable object file. Consider the following snippet of x86 code that moves the contents of variable `a` to variable `b` via the `eax` register:

```
A1 3412 0000 mov a,%eax   (a defined at 0x1234, byte reversed)
A3 0000 0000 mov %eax,b   (b is imported so the instruction refers to
                                0x0000 since its location is unknown)
```

Now assume that the linker links this code so that the section in which `a` is located is relocated by 0x10000 bytes, and `b` turns out to be at 0x9A12. The linker modifies the code to be:

```
A1 3412 0100 mov a,%eax   (0x10000 added to the address)
A3 129A 0000 mov %eax,b   (0x9A12 patched in for b)
```

These adjustments affect instructions, but keep in mind that any pointers in the data part of a relocatable object file have to be modified as well.

Output formats

The linker can produce its output in different file formats. The default ELF/DWARF2 format (`.elf`) contains an image of the executable code and data, and can contain additional debug information. The Intel–Hex format (`.hex`) and Motorola S–record format (`.s`) only contain an image of the executable code and data. You can specify a format with the options **–o** (**––output**) and **–c** (**––chip–output**).

Controlling the linker

Via a so–called *linker script file* you can gain complete control over the linker. The script language used to describe these features is called the *Linker Script Language* (LSL). You can define:

- The types of memory that are installed in the embedded target system:

  To assign locations to code and data sections, the linker must know what memory devices are actually installed in the embedded target system. For each physical memory device the linker must know its start–address, its size, and whether the memory is read–write accessible (RAM) or read–only accessible (ROM).

- How and where code and data should be placed in the physical memory:

  Embedded systems can have complex memory systems. If for example on–chip and off–chip memory devices are available, the code and data located in internal memory is typically accessed faster and with dissipating less power. To improve the performance of an application, specific code and data sections should be located in on–chip memory. By writing your own LSL file, you gain full control over the locating process.

- The underlying hardware architecture of the target processor.

To perform its task the linker must have a model of the underlying hardware architecture of the processor you are using. For example the linker must know how to translate an address used within the object file (a logical address) into an offset in a particular memory device (a physical address). In most linkers this model is hard coded in the executable and can not be modified. For the **lkm16c** linker this hardware model is described in the linker script file. This solution is chosen to support configurable cores that are used in system–on–chip designs.

When you want to write your own linker script file, you can use the standard linker script files with architecture descriptions delivered with the product.

See also section 8.6, *Controlling the Linker with a Script*.

8.2.3 LINKER OPTIMIZATIONS

During the linking and locating phase, the linker looks for opportunities to optimize the object code. Both code size and execution speed can be optimized. To enable or disable optimizations:

1. From the **Project** menu, select **Project Options...**

   The Project Options dialog box appears.

2. Expand the **Linker** entry and select **Optimization**.

You can enable or disable the optimizations described below. The command line option for each optimization is given in brackets.

See also option **–O** (**––optimize**) in section 4.3, *Linker Options*, in Chapter *Tool Options* of the *Reference Manual*.

First fit decreasing *(option* ***–Ol/–OL****)*

When the physical memory is fragmented or when address spaces are nested it may be possible that a given application cannot be located although the size of the available physical memory is larger than the sum of the section sizes. Enable the first–fit–decreasing optimization when this occurs and re–link your application.

The linker's default behavior is to place sections in the order that is specified in the LSL file. This also applies to sections within an unrestricted group. If a memory range is partially filled and a section must be located that is larger than the remainder of this range, then the section and all subsequent sections are placed in a next memory range. As a result of this gaps occur at the end of a memory range.

When the first–fit–decreasing optimization is enabled the linker will first place the largest sections in the smallest memory ranges that can contain the section. Small sections are located last and can likely fit in the remaining gaps.

Copy table compression *(option* ***–Ot/–OT****)*

The startup code initializes the application's data areas. The information about which memory addresses should be zeroed and which memory ranges should be copied from ROM to RAM is stored in the copy table.

When this optimization is enabled the linker will try to locate sections in such a way that the copy table is as small as possible thereby reducing the application's ROM image.

This optimization reduces both memory and startup speed.

Compress ROM image *(option* ***–Oz/–OZ****)*

Reduce the size of the application's ROM image by compressing the ROM image of initialized data sections. At application startup time the ROM image is decompressed and copied to RAM.

Delete unreferenced sections *(option* ***–Oc/–OC****)*

This optimization removes unused sections from the resulting object file. Because debug information normally refers to all sections, this optimization has no effect until you compile your project without debug information or use linker option **––strip–debug** to remove the debug information.

Delete duplicate code sections *(option* ***–Ox/–OX****)*

Delete duplicate data sections *(option* ***–Oy/–OY****)*

These two optimizations remove code and constant data that is defined more than once, from the resulting object file.

8.3 CALLING THE LINKER

EDE uses a *makefile* to build your entire project. This means that you cannot run only the linker. However, you can set options specific for the linker. After you have build your project, the output files of the linking step are available in your project directory, unless you specified an alternative output directory in the Build Options dialog.

To link your program, click either one of the following buttons:

Builds your entire project but only updates files that are out–of–date or have been changed since the previous build, which saves time.

Builds your entire project unconditionally. All steps necessary to obtain the final `.elf` file are performed.

To get access to the linker options:

1. From the **Project** menu, select **Project Options...**

   The Project Options dialog box appears.

2. Expand the **Linker** entry. Select the subentries and set the options in the various pages.

   The command line variant is shown simultaneously.

The following linker options are available:

EDE options	Command line
Output Format	
Output formats	**−o**[*filename*][**:***format* [**:***addr_size*][,*space*]] **−c**[*basename*]**:***format* [**:***addr_size*]
Libraries	
Link default C libraries Rescan libraries to solve unresolved exernals Link case sensitive (required for C language)	**−l***x* **−−no−rescan** *no option* **−−case−insensitive**
Optimization	
Use a 'first fit decreasing' algorithm Use copy table compression Compress ROM image Delete unreferenced sections Delete duplicate code Delete duplicate constant data	**−Ol**/**−OL** (= on/off) **−Ot**/**−OT** **−Oz**/**−OZ** **−Oc**/**−OC** **−Ox**/**−OX** **−Oy**/**−OY**
Map File	
Generate a map file (.map) *Suboptions for the* ***Generate a map file*** *option*	**−M** **−m***flags*
Warnings	
Report all warnings Suppress all warnings Suppress specific warnings Treat warnings as errors	*no option −w* **−w** **−w***num*[,*num*]... **−−warnings−as−errors**
Miscellaneous	
Use standard copy−table for initialization Strip symbolic debug information Dump processor and memory info from LSL file Select linker script file Additional linker options	*no option −***i** **−S** **−−lsl−dump**[=*file*] **−d***file*,... *options*

Table 8−2: Linker options

The following options are only available on the command line:

Description	Command line
Display invocation syntax	**–?**
Define preprocessor *macro*	**–D***macro*[=*def*]
Specify a symbol as unresolved external	**–e***symbol*
Redirect errors to a file with extension `.elk`	**––error–file**[=*file*]
Read options from file	**–f** *file*
Scan libraries in given order	**––first–library–first**
Search only in **–L** directories, not in default path	**––ignore–default–library–path**
Keep output files after errors	**–k**
Link only, do not locate	**––link–only**
Check LSL file(s) and exit	**––lsl–check**
Activate muncher in pre locate phase	**––munch**
Do not generate ROM copy	**–N**
Locate all ROM sections in RAM	**––non–romable**
Link incrementally	**–r**
Display version header only	**–V**
Print the name of each file as it is processed	**–v**

Table 8–3: Linker command line options

The invocation syntax on the command line is:

```
lkm16c [option]... [file]... ]...
```

When you are linking multiple files (either relocatable object files (`.obj`) or libraries (`.a`), it is important to specify the files in the right order. This is explained in Section 8.4.1, *Specifying Libraries to the Linker*

Example:

```
lkm16c -otest.elf -dm16c.lsl test.obj
```

This links and locates the file `test.obj` and generates the file `test.elf`.

For a complete overview of all options with extensive description, see section 4.3, *Linker Options*, of the *Reference Manual*.

8.4 LINKING WITH LIBRARIES

There are two kinds of libraries: system libraries and user libraries.

System library

The `lib` directory of the toolchain contains subdirectories with separate system libraries for the M16C and the R8C. An overview of the system libraries is given in the following tables.

Library to link	Description
libcs.a libcm.a libcl.a	C library for small, medium or large memory model (Some functions require the floating–point library. Also includes the startup code.)
libcss.a libcms.a libcls.a	Single precision C library for small, medium or large memory model (compiler option **–F**) (Some functions require the floating–point library. Also includes the startup code.)
libfps.a libfpm.a libfpl.a	Floating–point library (non–trapping) for each model
libfpst.a libfpmt.a libfplt.a	Floating–point library (trapping) for each model (Control program option **––fp–trap**)
librts.a librtm.a librtl.a	Run–time library for each model

Table 8–4: Overview of M16C libraries

Library to link	Description
libc.a	C library (Some functions require the floating–point library. Also includes the startup code.)
libcs.a	Single precision C library (compiler option **–F**) (Some functions require the floating–point library. Also includes the startup code.)
libfp.a	Floating–point library (non–trapping)
libfpt.a	Floating–point library (trapping) (Control program option **––fp–trap**)
librt.a	Run–time library

Table 8–5: Overview of R8C libraries

For more information on these libraries see section 3.14, *Libraries*, in Chapter *C Language*.

User library

You can also create your own libraries. Section 9.4, *Archiver*, in Chapter *Using the Utilities*, describes how you can use the archiver to create your own library with object modules. To link user libraries, specify their filenames on the command line.

8.4.1 SPECIFYING LIBRARIES TO THE LINKER

In EDE you can specify both system and user libraries.

Link a system library with EDE

To specify to link the default C libraries:

1. From the **Project** menu, select **Project Options...**

   The Project Options dialog box appears.

2. Expand the **Linker** entry and select **Libraries**.

3. Select **Link default C libraries**.

4. Click **OK** to accept the linker options.

When you want to link system libraries from the command line, you must specify this with the linker option **–l**. With the option **–lcl** you specify the system library `libcl.a`. For example:

```
lkm16c -lcl start.obj
```

Link a user library in EDE

To specify your own libraries, you have to add the library files to your project:

1. From the **Project** menu, select **Properties...**

   The Project Properties dialog box appears.

2. In the **Members** tab, click on the **Add existing files to project** button.

3. Select the libraries you want to add and click **Open**.

4. Click **OK** to accept the new project settings.

The invocation syntax on the command line is for example:

```
lkm16c start.obj mylib.a
```

If the library resides in a subdirectory, specify that directory with the library name:

```
lkm16c start.obj mylibs\mylib.a
```

Library order

The order in which libraries appear on the command line is important. By default the linker processes object files and libraries in the order in which they appear on the command line. Therefore, when you use a weak symbol construction, like `printf`, in an object file or your own library, you must position this object/library before the C library.

With the option **––first–library–first** you can tell the linker to scan the libraries from left to right, and extract symbols from the first library where the linker finds it. This can be useful when you want to use newer versions of a library routine.

Example:

```
lkm16c --first-library-first a.a test.obj b.a
```

If the file `test.obj` calls a function which is both present in `a.a` and `b.a`, normally the function in `b.a` would be extracted. With this option the linker first tries to extract the symbol from the first library `a.a`.

8.4.2 HOW THE LINKER SEARCHES LIBRARIES

System libraries

You can specify the location of system libraries (specified with option **–l**) in several ways. The linker searches the specified locations in the following order:

1. The linker first looks in the directories that are specified in the **Directories** dialog (**–L** option). If you specify the **–L** option without a pathname, the linker stops searching after this step.

2. When the linker did not find the library (because it is not in the specified library directory or because no directory is specified), it looks which paths were set during installation. You can still change these paths if you like.

See environment variables LIBM16C in section 1.3.2, *Configuring the Command Line Environment*, in Chapter *Software Installation*.

3. When the linker did not find the library, it tries the default `lib` directory relative to the installation directory.

User library

If you use your own library, the linker searches the library in the current directory only.

8.4.3 HOW THE LINKER EXTRACTS OBJECTS FROM LIBRARIES

A library built with **arm16c** always contains an index part at the beginning of the library. The linker scans this index while searching for unresolved externals. However, to keep the index as small as possible, only the defined symbols of the library members are recorded in this area.

When the linker finds a symbol that matches an unresolved external, the corresponding object file is extracted from the library and is processed. After processing the object file, the remaining library index is searched. If after a complete search of the library unresolved externals are introduced, the library index will be scanned again. After all files and libraries are processed, and there are still unresolved externals and you did not specify the linker option **--no-rescan**, all libraries are rescanned again. This way you do not have to worry about the library order. However, this rescanning does not work for 'weak symbols'. If you use a weak symbol construction, like `printf`, in an object file or your own library, you must position this object/library before the C library

The **-v** option shows how libraries have been searched and which objects have been extracted.

Resolving symbols

If you are linking from libraries, only the objects that contain symbol definition(s) to which you refer, are extracted from the library. This implies that if you invoke the linker like:

```
lkm16c mylib.a
```

nothing is linked and no output file will be produced, because there are no unresolved symbols when the linker searches through `mylib.a`.

It is possible to force a symbol as external (unresolved symbol) with the option **–e**:

```
lkm16c –e main mylib.a
```

In this case the linker searches for the symbol `main` in the library and (if found) extracts the object that contains `main`. If this module contains new unresolved symbols, the linker looks again in `mylib.a`. This process repeats until no new unresolved symbols are found.

8.5 INCREMENTAL LINKING

With the M16C linker **lkm16c** it is possible to link *incrementally*. Incremental linking means that you link some, but not all `.obj` modules to a relocatable object file `.eln`. In this case the linker does not perform the locating phase. With the second invocation, you specify both new `.obj` files and the `.eln` file you had created with the first invocation.

Incremental linking is only possible on the command line.

```
lkm16c –r test1.obj –otest.eln
lkm16c test2.obj test.eln
```

This links the file `test1.obj` and generates the file `test.eln`. This file is used again and linked together with `test2.obj` to create the file `task1.elf` (the default name if no output filename is given in the default ELF/DWARF 2 format).

With incremental linking it is normal to have unresolved references in the output file until all `.obj` files are linked and the final `.eln` or `.elf` file has been reached. The option **–r** for incremental linking also suppresses warnings and errors because of unresolved symbols.

8.6 CONTROLLING THE LINKER WITH A SCRIPT

With the options on the command line you can control the linker's behavior to a certain degree. From EDE it is also possible to determine where your sections will be located, how much memory is available, which sorts of memory are available, and so on. EDE passes these locating directions to the linker via a script file. If you want even more control over the locating process you can supply your own script.

The language for the script is called the *Linker Script Language*, or shortly LSL. You can specify the script file to the linker, which reads it and locates your application exactly as defined in the script. If you do not specify your own script file, the linker always reads a standard script file which is supplied with the toolchain.

8.6.1 PURPOSE OF THE LINKER SCRIPT LANGUAGE

The Linker Script Language (LSL) serves three purposes:

1. It provides the linker with a definition of the target's core architecture. This definition is supplied with the toolchain.
2. It provides the linker with a specification of the memory attached to the target processor.
3. It provides the linker with information on how your application should be located in memory. This gives you, for example, the possibility to create overlaying sections.

The linker accepts multiple LSL files. You can use the specifications of the M16C and R8C architectures that Altium has supplied in the `include.lsl` directory. Do not change these files.

If you use a different memory layout than described in the LSL file supplied for the target core, you must specify this in a separate LSL file and pass both the LSL file that describes the core architecture and your LSL file that contains the memory specification to the linker. Next you may want to specify how sections should be located and overlaid. You can do this in the same file or in another LSL file.

LSL has its own syntax. In addition, you can use the standard ANSI C preprocessor keywords because the linker sends the script file first to the C preprocessor before it starts interpreting the script.

The complete syntax is described in Chapter 7, *Linker Script Language*, in the *Reference Manual*.

8.6.2 EDE AND LSL

In EDE you can specify the size of the stack and heap; the physical memory attached to the processor; identify that particular address ranges are reserved; and specify which sections are located where in memory. EDE translates your input into an LSL file that is stored in the project directory under the name *`project`*`.lsl` and passes this file to the linker.

If you want to learn more about LSL you can inspect the generated file *`project`*`.lsl`.

To change the LSL settings

1. From the **Project** menu, select **Project Options...**

   The Project Options dialog box appears.

2. Expand the **Processor** entry and select **Memory**.

3. Make your changes.

4. Also make your changes, if necessary, in the pages **Sections**, **Reserved Areas** and/or **Stack/Heap** in the **Linker** entry.

Each time you close the Project Options dialog the file *`project`*`.lsl` is updated and you can immediately see how your settings are encoded in LSL.

Note that EDE supports ChromaCoding (applying color coding to text) and template expansion when you edit LSL files.

Specify your own LSL file

If you want to write your own linker script file, you can use the EDE generated file *`project`*`.lsl` as an example. Specify this file to EDE as follows:

1. From the **Project** menu, select **Project Options...**

   The Project Options dialog box appears.

2. Expand the **Linker** entry and select **Miscellaneous**.

3. Select **Use project specific linker script file** and add your own file in the edit field.

8.6.3 STRUCTURE OF A LINKER SCRIPT FILE

A script file consists of several definitions. The definitions can appear in any order.

The architecture definition (required)

In essence an *architecture definition* describes how the linker should convert logical addresses into physical addresses for a given type of core. If the core supports multiple address spaces, then for each space the linker must know how to perform this conversion. In this context a physical address is an offset on a given internal or external bus. Additionally the architecture definition contains information about items such as the (hardware) stack and the interrupt vector table.

This specification is normally written by Altium. For the M16C core architecture, a separate LSL file is provided `m16c.lsl`. For the R8C core architecture, a separate LSL file is provided `r8c.lsl`.

The architecture definition of the LSL file should not be changed by you unless you also modify the core's hardware architecture. If the LSL file describes a multi–core system an architecture definition must be available for each different type of core.

The derivative definition (required)

The *derivative definition* describes the configuration of the internal (on–chip) bus and memory system. Basically it tells the linker how to convert offsets on the buses specified in the architecture definition into offsets in internal memory. A derivative definition must be present in an LSL file. Microcontrollers and DSPs often have internal memory and I/O sub–systems apart from one or more cores. The design of such a chip is called a *derivative*.

When you design an FPGA together with a PCB, the components on the FPGA become part of the board design and there is no need to distinguish between internal and external memory. For this reason you probably do not need to work with derivative definitions at all. There are, however, two situations where derivative definitions are useful:

1. When you re–use an FPGA design for several board designs it may be practical to write a derivative definition for the FPGA design and include it in the project LSL file.

2. When you want to use multiple cores of the same type, you must instantiate the cores in a derivative definition, since the linker automatically instantiates only a single core for an unused architecture.

The processor definition

The *processor definition* describes an instance of a derivative. A processor definition is only needed in a multi–processor embedded system. It allows you to define multiple processors of the same type.

If for a derivative 'A' no processor is defined in the LSL file, the linker automatically creates a processor named 'A' of derivative 'A'. This is why for single–processor applications it is enough to specify the derivative in the LSL file, for example with **–dm16c.lsl**.

The memory and bus definitions (optional)

Memory and bus definitions are used within the context of a derivative definition to specify internal memory and on–chip buses. In the context of a board specification the memory and bus definitions are used to define external (off–chip) memory and buses. Given the above definitions the linker can convert a logical address into an offset into an on–chip or off–chip memory device.

The board specification

The processor definition and memory and bus definitions together form a *board specification*. LSL provides language constructs to easily describe single–core and heterogeneous or homogeneous multi–core systems. The board specification describes all characteristics of your target board's system buses, memory devices, I/O sub–systems, and cores that are of interest to the linker. Based on the information provided in the board specification the linker can for each core:

- convert a logical address to an offset within a memory device
- locate sections in physical memory
- maintain an overall view of the used and free physical memory within the whole system while locating

The section layout definition (optional)

The optional *section layout definition* enables you to exactly control where input sections are located. Features are provided such as: the ability to place sections at a given address, to place sections in a given order, and to overlay code and/or data sections.

Example: Skeleton of a Linker Script File

A linker script file that defines a derivative "X" based on the M16C architecture, its external memory and how sections are located in memory, may have the following skeleton:

```
architecture M16C
{
    // Specification of the M16C core architecture.
    // Written by Altium.
}

derivative X           // derivative name is arbitrary
{
    // Specification of the derivative.
    // Written by Altium.
    core M16C            // always specify the core
    {
       architecture = M16C;
    }

    bus data_bus       // internal bus
    {
       // maps to data_bus in "M16C" core
    }

    // internal memory
}

processor proc1        // processor name is arbitrary
{
    derivative = X;

    // You can omit this part, except if you use a
    // multi-core system.
}
```

```
memory ext_name
{
    // external memory definition
}

section_layout proc1:M16C:near    // section layout
{
    // section placement statements

    // sections are located in address space 'near'
    // of core 'M16C' of processor 'proc1'
}
```

8.6.4 THE ARCHITECTURE DEFINITION

Although you will probably not need to program the architecture definition (unless you are building your own processor core) it helps to understand the Linker Script Language and how the definitions are interrelated.

Within an architecture definition the characteristics of a target processor core that are important for the linking process are defined. These include:

- space definitions: the logical address spaces and their properties
- bus definitions: the I/O buses of the core architecture
- mappings: the address translations between logical address spaces, the connections between logical address spaces and buses and the address translations between buses

Address spaces

A logical address space is a memory range for which the core has a separate way to encode an address into instructions. Most microcontrollers and DSPs support multiple address spaces. For example, the M16C has separate spaces for byte–addressable data and bit–addressable data. Normally, the size of an address space is to 2^N, with N the number of bits used to encode the addresses.

The relation of an address space with another address space can be one of the following:

- one space is a subset of the other. These are often used for "small" absolute, and relative addressing.

- the addresses in the two address spaces represent different locations so they do not overlap. This means the core must have separate sets of address lines for the address spaces. For example, in Harvard architectures we can identify at least a code and a data memory space.

Address spaces (even nested) can have different minimal addressable units (MAU), alignment restrictions, and page sizes.

The M16C architecture in LSL notation

The best way to program the architecture definition, is to start with a drawing. The following figure shows a part of the M16C architecture:

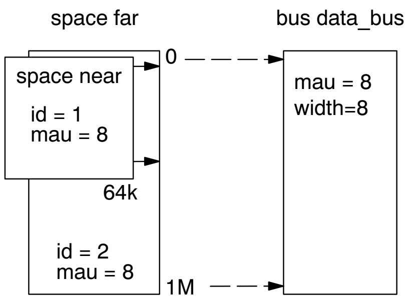


Figure 8–2: Scheme of (part of) the M16C architecture

The figure shows two address spaces called `near`, and `far`. The address space `near` is a subset of the address space `far`. All address spaces have attributes like a number that identifies the logical space (id), a MAU size and an alignment. In LSL notation the definition of these address spaces looks as follows:

```
space near
{
     id = 1;
     mau = 8;

     map (src_offset=0x00000, dest_offset=0x00000,
          size=64k, dest=space:far);
}

space far
{
     id = 2;
     mau = 8;

     map (src_offset=0x00000, dest_offset=0x00000,
          size=1M, dest=bus:data_bus);
}
```

The keyword **map** corresponds with the arrows in the drawing. You can map:

• address space	=> address space	
• address space	=> bus	
• memory	=> bus	(not shown in the drawing)
• bus	=> bus	(not shown in the drawing)

Next the internal bus, named **data_bus** must be defined in LSL:

```
bus data_bus
{
     mau = 8;
     width = 8;  // there are 8 data lines on the bus
}
```

This completes the LSL code in the architecture definition. Note that all code above goes into the architecture definition, thus between:

```
architecture M16C
{
    All code above goes here.
}
```

8.6.5 THE DERIVATIVE DEFINITION

Although you will probably not need to program the derivative definition (unless you are using multiple cores) the description below helps to understand the Linker Script Language and how the definitions are interrelated.

A derivative is the design of a processor, as implemented on a chip (or FPGA). It comprises one or more cores and on–chip memory. The derivative definition includes:

- core definition: an instance of a core architecture
- bus definition: the I/O buses of the core architecture
- memory definitions: internal (or on–chip) memory

Core

Each derivative must have at least one core and each core must have a specification of its core architecture. This core architecture must be defined somewhere in the LSL file(s).

```
core M16C
{
   architecture = M16C;
}
```

Bus

Each derivative can contain a bus definition for connecting external memory. In this example, the bus `data_bus` maps to the bus `data_bus` defined in the architecture definition of core `M16C`:

```
bus data_bus
{
   mau = 8;
   width = 8;
   map (dest=bus:M16C:data_bus, dest_offset=0, size=256);
}
```

Memory

Memory is usually described in a separate memory definition, but you can specify on–chip memory for a derivative. For example:

```
memory internal_ram
{
     type = ram;
     size = 16k;
     mau = 8;
     map(src_offset=0x0000, dest_offset=0x0000,
         size=16k, dest=bus:M16C:data_bus);
}
```

This completes the LSL code in the derivative definition. Note that all code above goes into the derivative definition, thus between:

```
derivative X    // name of derivative
{
   All code above goes here.
}
```

If you want to create a custom derivative and you want to use EDE to select sections, the derivative must be called "M16C", since EDE uses this name in the generated LSL file. If you want to specify external memory in EDE, the custom derivative must contain a bus named "data_bus" for the same reason. In EDE you have to define a target processor in the **Processor** pages of the **Project | Project Options** dialog.

8.6.6 THE MEMORY DEFINITION

Once the core architecture is defined in LSL, you may want to extend the processor with memory. You need to specify the location and size of the physical external memory devices in the target system.

The principle is the same as defining the core's architecture but now you need to fill the memory definition:

```
memory name
{
    memory definitions.
}
```

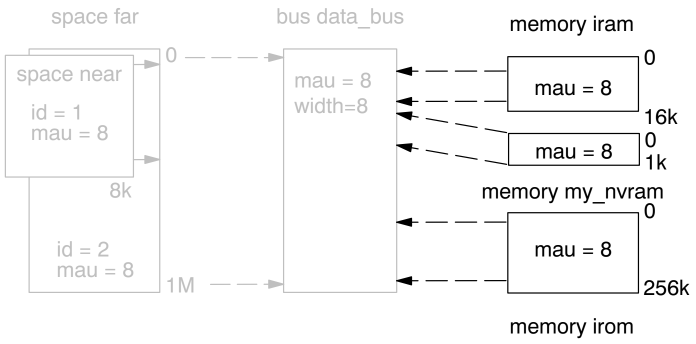


Figure 8–3: Adding external memory to the M16C architecture

Suppose your embedded system has 16k of RAM, named **iram**., 1k of non–volatile RAM called **my_nvram** and 256k of ROM, named **irom** (see figure above). The memories are connected to the bus **data_bus**. In LSL this looks like:

```
memory iram
{
     type = ram;
     size = 16k;
     mau = 8;
     map(src_offset=0x0000, dest_offset=0x0400,
         size=16k, dest=bus:M16C:data_bus);
}
```

The memory **`my_nvram`** is connected to the bus with an offset of 0x5000:

```
memory my_nvram
{
     type = ram;
     size = 1k;
     mau = 8;
     map(src_offset=0x0000, dest_offset=0x5000,
         size=1k, dest=bus:M16C:data_bus);
}
```

The memory **`irom`** is connected to the bus with an offset of 0xC0000:

```
memory irom
{
     type = rom;
     size = 256k;
     mau = 8;
     map(src_offset=0x0000, dest_offset=0xc0000,
         size=256k, dest=bus:M16C:data_bus);
}
```

If you use a different memory layout than described in the LSL file supplied for the target core, you can specify this in EDE or you can specify this in a separate LSL file and pass both the LSL file that describes the core architecture and your LSL file that contains the memory specification to the linker.

In order to bypass the default memory setup, your memory LSL file must contain a **`#define __NODEFAULTMEM`**, and you must specify this file before the core architecture LSL file.

Adding memory using EDE

In EDE you can only specify external memory if the processor does not run in single chip mode.

1. From the **Project** menu, select **Project Options...**

   The Project Options dialog box appears.

2. Expand the **Processor** entry and select **Processor Definition**.

3. Select **Memory Expansion mode** or **Microprocessor mode** or select **–– User Defined ––** in the **Select processor** box for a user defined processor.
4. Open the **Memory** page.
5. In the **External Memory** box add your memory (for example `my_nvram`), by specifying the type, name, start address and size.

8.6.7 THE SECTION LAYOUT DEFINITION: LOCATING SECTIONS

Once you have defined the internal core architecture and optional memory, you can actually define where your application must be located in the physical memory.

During compilation, the compiler divides the application into sections. Sections have a name, an indication in which address space it should be located and attributes like writable or read–only.

In the section layout definition you can exactly define how input sections are placed in address spaces, relative to each other, and what their absolute run–time and load–time addresses will be. To illustrate section placement the following example of a C program is used:

Example: section propagation through the toolchain

To illustrate section placement, the following example of a C program (`bat.c`) is used. The program saves the number of times it has been executed in battery back–upped memory, and prints the number.

```
#define BATTERY_BACKUP_TAG  0xa5f0
#include <stdio.h>

int  uninitialized_data;
int  initialized_data = 1;
#pragma renamesect DA ”non_volatile” noclear
int  battery_backup_tag;
int  battery_backup_invok;
#pragma endrenamesect DA
```

```
void main (void)
{
     if (battery_backup_tag != BATTERY_BACKUP_TAG )
     {
         // battery back-upped memory area contains invalid data
         // initialize the memory
         battery_backup_tag = BATTERY_BACKUP_TAG;
         battery_backup_invok = 0;
     }
     printf( ”This application has been invoked %d times\n”,
              battery_backup_invok++);
}
```

The compiler assigns names and attributes to sections. With the `#pragma renamesect DA ”name”` the compiler's default section naming convention is overruled and a section with the name `non_volatile_CLR_DA` is defined. In this section the battery back–upped data is stored.

By default the compiler creates the section `bat_CLR_DA, data, clear` (a section with the name `bat_CLR_DA` carrying section attributes ”data” and ”clear”) to store uninitialized data objects. The section attributes tell the linker to locate the section in address space data and that the section content should be filled with zeros at startup.

As a result of the `#pragma renamesect DA ”non_volatile” noclear`, the data objects between the pragma pair are placed in `non_volatile_CLR_DA, data, noclear`. Note that because battery back–upped sections should not be cleared we used the ”noclear” attribute.

The generated assembly may look like:

```
extern   (code)_printf
extern   (code)___printf_int
extern   (code)__START

defsect ”bat_CO”, code
sect    ”bat_CO”
global  _main
```

```
; Function _main
_main:  type    func
        cmp.w   #42480, _battery_backup_tag
        jeq     _2
        .
        .
        jsr     _printf
        rts
        size    _main, $-_main
        ; End of function
        ; End of section

        defsect ”bat_CLR_DA”, data, clear
        sect    ”bat_CLR_DA”
        global  _uninitialized_data
_uninitialized_data:    type    object
        size    _uninitialized_data, 2
        ds      2
        ; End of section

        defsect ”bat_INI_DA”, data, init
        sect    ”bat_INI_DA”
        global  _initialized_data
_initialized_data:  type    object
        size    _initialized_data, 2
        dw      1
        ; End of section

        defsect ”non_volatile_CLR_DA”, data, noclear
        sect    ”non_volatile_CLR_DA”
        global  _battery_backup_tag
_battery_backup_tag:  type    object
        size    _battery_backup_tag, 2
        ds      2
        global  _battery_backup_invok
_battery_backup_invok:  type    object
        size    _battery_backup_invok, 2
        ds      2
        ; End of section

        sect    ”bat_INI_DA”
__1_ini:        type    object
        size    __1_ini, 44
        db      84,  104, 105, 115, 32,  97,  112, 112, 108, 105
        db      99,  97,  116, 105, 111, 110, 32,  104, 97,  115
        db      32,  98,  101, 101, 110, 32,  105, 110, 118, 111
        db      107, 101, 100, 32,  37,  100, 32,  116, 105, 109
        db      101, 115, 10,  0
        ; This application has been invoked %d times\n

        ; Module end
```

Section placement

The number of invocations of the example program should be saved in *non–volatile* (battery back–upped) memory. This is the memory `my_nvram` from the example in the previous section.

To control the locating of sections, you need to write one or more section definitions in the LSL file. At least one for each address space where you want to change the default behavior of the linker. In our example, we need to locate sections in the address space `near`:

```
section_layout ::near
{
    Section placement statements
}
```

To locate sections, you must create a group in which you select sections from your program. For the battery back–up example, we need to define one group, which contains the section `non_volatile_CLR_DA`. All other sections are located using the defaults specified in the architecture definition. Section `non_volatile_CLR_DA` should be placed in non–volatile ram. To achieve this, the run address refers to our non–volatile memory called `my_nvram`:

```
group ( ordered, run_addr = mem:my_nvram )
{
     select "non_volatile_CLR_DA";
}
```

Section placement from EDE

To specify the above settings using EDE, follow these steps:

1. From the **Project** menu, select **Project Options...**

   The Project Options dialog box appears.

2. Expand the **Linker** entry and select **Sections**.

   Here you can specify where sections are located in memory.

3. In the **Section type** field, select **Near Data**.

4. In the **Section name** field, enter `non_volatile_CLR_DA`.

5. In the **Absolute address** field, enter `mem:my_nvram`

6. In the **Section attr** field, select **Code/Data part**.

7. Click **OK**.

This completes the LSL file for the sample architecture and sample program. You can now call the linker with this file and the sample program to obtain an application that works for this architecture.

For a complete description of the Linker Script Language, refer to Chapter 7, *Linker Script Language*, in the *Reference Manual*.

8.6.8 THE PROCESSOR DEFINITION: USING MULTI-PROCESSOR SYSTEMS

The processor definition is only needed when you write an LSL file for a multi–processor embedded system. The processor definition explicitly instantiates a derivative, allowing multiple processors of the same type.

```
processor proc_name
{
   derivative = deriv_name
}
```

If no processor definition is available that instantiates a derivative, a processor is created with the same name as the derivative.

8.7 LINKER LABELS

The linker creates labels that you can use to refer to from within the application software. Some of these labels are real labels at the beginning or the end of a section. Other labels have a second function, these labels are used to address generated data in the locating phase. The data is only generated if the label is used.

Linker labels are labels starting with **__lc_**. The linker assigns addresses to the following labels when they are referenced:

Label	Description
`__lc_cp`	Start of copy table. Same as `__lc_ub_table`. The copy table gives the source and destination addresses of sections to be copied. This table will be generated by the linker only if this label is used.
`__lc_bh`	Begin of heap. Same as `__lc_ub_heap`.
`__lc_eh`	End of heap. Same as `__lc_ue_heap`.
`__lc_bs`	Begin of stack. Same as `__lc_ub_sp`.
`__lc_es`	End of stack. Same as `__lc_ue_sp`.
`__lc_u_`*name*	User defined label. The label must be defined in the LSL file. For example, `"__lc_u_int_tab" = (INTTAB);`
`__lc_ub_`*name* `__lc_b_`*name*	Begin of section *name*. Also used to mark the begin of the stack or heap or copy table.
`__lc_ue_`*name* `__lc_e_`*name*	End of section *name*. Also used to mark the begin of the stack or heap.
`__lc_cb_`*name*	Start address of an overlay section in ROM.
`__lc_ce_`*name*	End address of an overlay section in ROM.
`__lc_gb_`*name*	Begin of group *name*. This label appears in the output file even if no reference to the label exist in the input file.
`__lc_ge_`*name*	End of group *name*. This label appears in the output file even if no reference to the label exist in the input file.

Table 8–6: Linker labels

The linker only allocates space for the stack and/or heap when a reference to either of the section labels exists in one of the input object files.

At C level, all linker labels start with one leading underscore (the compiler adds an extra underscore).

Example

Suppose in an LSL file you have defined a user stack section with the name "`ustack`" (with the keyword **`stack`**). You can refer to the begin and end of the stack from your C source as follows (labels have one leading underscore):

```
#include <stdio.h>
extern char *_lc_ub_ustack;
extern char *_lc_ue_ustack;
void main()
{
  printf( "Size of user stack is %d\n",
          _lc_ue_ustack - _lc_ub_ustack );
}
```

From assembly you can refer to the end of the user stack with:

```
extern __lc_ue_ustack   ; user stack end
```

8.8 GENERATING A MAP FILE

The map file is an additional output file that contains information about the location of sections and symbols. You can customize the type of information that should be included in the map file.

To generate a map file

1. From the **Project** menu, select **Project Options...**

   The Project Options dialog box appears.

2. Expand the **Linker** entry and select **Map File**.

3. Select **Generate a linker map file (.map)**

4. (Optional) Enable the options to include that information in the map file.

Example on the command line

```
lkm16c -Mtest.map test.obj
```

With this command the list file `test.map` is created.

See section 5.2, *Linker Map File Format*, in Chapter *List File Formats* of the *Reference Manual* for an explanation of the format of the map file.

8.9 LINKER ERROR MESSAGES

The linker produces error messages of the following types:

F Fatal errors

After a fatal error the linker immediately aborts the link/locate process.

E Errors

Errors are reported, but the linker continues linking and locating. No output files are produced unless you have set the linker option **––keep–output–files**.

W Warnings

Warning messages do not result into an erroneous output file. They are meant to draw your attention to assumptions of the linker for a situation which may not be correct. You can control warnings in the **Linker | Diagnostics** page of the **Project | Project Options...** menu (linker option **–w**).

I Information

Verbose information messages do not indicate an error but tell something about a process or the state of the linker. To see verbose information, use the linker option **–v**.

S System errors

System errors occur when internal consistency checks fail and should never occur. When you still receive the system error message

```
S6##: message
```

please report the error number and as many details as possible about the context in which the error occurred. The following helps you to prepare an e–mail using EDE:

1. From the **Help** menu, select **Technical Support –> Prepare Email...**

   The Prepare Email form appears.

2. Fill out the the form. State the error number and attach relevant files.

3. Click the **Copy to Email client** button to open your email application.

   A prepared e–mail opens in your e–mail application.

4. Finish the e–mail and send it.

Display detailed information on diagnostics

1. In the **Help** menu, enable the option **Show Help on Tool Errors**.
2. In the **Build** tab of the **Output** window, double–click on an error or warning message.

   A description of the selected message appears.

```
lkm16c --diag=[format:]{all | number,...}
```

See linker option **--diag** in section 4.3, *Linker Options* in Chapter *Tool Options* of the *Reference Manual*.

CHAPTER 9

USING THE UTILITIES

TASKING

CHAPTER 9

9.1 INTRODUCTION

The TASKING toolchain for the M16C processor family comes with a number of utilities that provide useful extra features.

ccm16c	A control program for the M16C toolchain. The control program invokes all tools in the toolchain and lets you quickly generate an absolute object file from C source input files.
mkm16c	A utility program to maintain, update, and reconstruct groups of programs. The make utility looks whether files are out of date, rebuilds them and determines which other files as a consequence also need to be rebuild.
arm16c	An ELF archiver. With this utility you create and maintain object library files.
flashm16c	A utility to flash an ELF, Intel Hex or Motorola S–Records file.

9.2 CONTROL PROGRAM

The control program **ccm16c** is a tool that invokes all tools in the toolchain for you. It provides a quick and easy way to generate the final absolute object file out of your C sources without the need to invoke the compiler, assembler and linker manually.

9.2.1 CALLING THE CONTROL PROGRAM

You can only call the control program from the command line. The invocation syntax is

```
ccm16c [ [option]... [file]... ]...
```

For example:

```
ccm16c –v test.c
```

The control program calls all tools in the toolchain and generates the absolute object file `test.elf`. With the control program option **–v** you can see how the control program calls the tools:

```
+ c:\cm16c\bin\cm16c –Ms –o test.src test.c
+ c:\cm16c\bin\asm16c –o test.obj test.src
+ c:\cm16c\bin\lkm16c test.obj –o test.elf ––map-file
–lcs –lfps –lrts
```

By default, the control program removes the intermediate output files (`test.src` and `test.obj` in the example above) afterwards, unless you specify the command line option **–t** (**––keep–temporary–files**).

Recognized input files

The control program recognizes the following input files:

- Files with a `.cc`, `.cxx` or `.cpp` suffix are interpreted as C++ source programs and are passed to the C++ compiler.
- Files with a `.c` suffix are interpreted as C source programs and are passed to the compiler.
- Files with a `.asm` suffix are interpreted as hand–written assembly source files which have to be passed to the assembler.
- Files with a `.src` suffix are interpreted as compiled assembly source files. They are directly passed to the assembler.

- Files with a `.a` suffix are interpreted as library files and are passed to the linker.
- Files with a `.obj` suffix are interpreted as object files and are passed to the linker.
- Files with a `.eln` suffix are interpreted as linked object files and are passed to the locating phase of the linker. The linker accepts only one `.eln` file in the invocation.
- An argument with a `.lsl` suffix is interpreted as a linker script file and is passed to the linker.

Options of the control program

The following control program options are available:

Description	Option
Information	
Display invocation options	**–?**
Display version header	**–V**
Check the source but do not generate code	**––check**
Show description of diagnostics	**––diag=**[*fmt*:]{**all**|*nr*}
Verbose option: show commands invoked Verbose option: show commands without executing	**–v** **–n**
Suppress all warnings	**–w**
Treat warnings as errors	**––warnings–as–errors**
Show C and assembly warnings for C++ compilations	**––show–c++–warnings**
C Language	
ISO C standard 90 or 99 (default: 99)	**––iso=**{**90**|**99**}
Language extensions Allow C++ style comments in C source Check assignment constant string to non constant string pointer	**–A***flag* **–Ap** **–Ax**
Treat external definitions as ”static”	**––static**
Single precision floating point	**–F**
C++ Language	
Treat C++ files as C files	**––force–c**
Force C++ compilation and linking	**––force–c++**

Description	**Option**
Force invocation of C++ muncher	**––force–munch**
Force invocation of C++ prelinker	**––force–prelink**
Show the list of object files handled by the C++ prelinker	**––list–object–files**
Copy C++ prelink (.ii) files from outside the current directory	**––prelink–copy–if–nonlocal**
Use only C++ prelink files in the current directory	**––prelink–local–only**
Remove C++ instantiation flags after prelinking	**––prelink–remove–instantiation–flags**
Enable C++ exception handling	**––exceptions**
C++ instantiation mode	**––instantiate=***type*
C++ instantiation directory	**––instantiation–dir=***dir*
C++ instantiation file	**––instantiation–file=***file*
Disable automatic C++ instantiation	**––no–auto–instantiation**
Allow multiple instantiations in a single object file	**––no–one–instantiation–per–object**
Preprocessing	
Define preprocessor *macro*	**–D***macro*[=*def*]
Remove preprocessor *macro*	**–U***macro*
Store the C compiler preprocess output (*file*`.pre`)	**–E***flag*
Memory models	
Select memory model	**–M**{**s**|**m**|**l**}
Code generation	
Select CPU type	**–C***cpu*
Generate symbolic debug information	**–g**
Target R8C instead of M16C/60	**––r8c**
Libraries	
Add library directory	**–L***dir*
Add library	**–l***lib*
Ignore the default search path for libraries	**––ignore–default–library–path**

Description	Option
Do not include default list of libraries	**––no–default–libraries**
Use trapped floating–point library	**––fp–trap**
Input files	
Specify linker script file	**–d** *file*
Read options from file	**–f** *file*
Add include directory	**–I***dir*
Output files	
Redirect diagnostic messages to a file	**––error–file**
Select final output file:	
relocatable output file	**–cl**
object file(s)	**–co**
assembly file(s)	**–cs**
Specify linker output format (ELF, IHEX, SREC)	**––format=***type*
Set the address size for linker IHEX/SREC files	**––address–size=***n*
Set linker output space name	**––space=***name*
Keep output file(s) after errors	**–k**
Do not generate linker map file	**––no–map–file**
Specify name of output file	**–o** *file*
Do not delete intermediate (temporary) files	**–t**

Table 9–1: Overview of control program options

For a complete list and description of all control program options, see section 4.4, *Control Program Options*, in Chapter *Tool Options* of the *Reference Manual*.

The options in table 9–1 are options that the control program interprets itself. The control program however can also pass an option directly to a tool. Such an option is not interpreted by the control program but by the tool itself. The next example illustrates how an option is passed directly to the linker to link a user defined library:

```
ccm16c –Wl–lmylib test.c
```

Use the following options to pass arguments to the various tools:

Description	Option
Pass argument directly to the C++ compiler	**–Wcp***arg*
Pass argument directly to the C++ pre–linker	**–Wpl***arg*
Pass argument directly to the C compiler	**–Wc***arg*
Pass argument directly to the assembler	**–Wa***arg*
Pass argument directly to the linker	**–Wl***arg*

Table 9–2: Control program options to pass an option directly to a tool

If you specify an unknown option to the control program, the control program looks if it is an option for a specific tool. If so, it passes the option directly to the tool. However, it is recommended to use the control program options for passing arguments directly to tools.

With the environment variable CCM16COPT you can define options and/or arguments that the control programs always processes *before* the command line arguments.

For example, if you use the control program always with the option **––no–map–file** (do not generate a linker map file), you can specify "––no–map–file" to the environment variable CCM16COPT.

See section 1.3.2, *Configuring the Command Line Environment*, in Chapter *Software Installation*.

9.3 MAKE UTILITY

If you are working with large quantities of files, or if you need to build several targets, it is rather time–consuming to call the individual tools to compile, assemble, link and locate all your files.

You save already a lot of typing if you use the control program **ccm16c** and define an options file. You can even create a batch file or script that invokes the control program for each target you want to create. But with these methods *all* files are completely compiled, assembled, linked and located to obtain the target file, even if you changed just one C source. This may demand a lot of (CPU) time on your host.

The make utility **mkm16c** is a tool to maintain, update, and reconstruct groups of programs. The make utility looks which files are out–of–date and only recreates these files to obtain the updated target.

Make process

In order to build a target, the make utility needs the following input:

- the target it should build, specified as argument on the command line
- the rules to build the target, stored in a file usually called `makefile`

In addition, the make utility also reads the file `mkm16c.mk` which contains predefined rules and macros. See section 9.3.2, *Writing a Makefile*.

The makefile contains the relationships among your files (called *dependencies*) and the commands that are necessary to create each of the files (called *rules*). Typically, the absolute object file (`.elf`) is updated when one of its dependencies has changed. The absolute file depends on `.obj` files and libraries that must be linked together. The `.obj` files on their turn depend on `.src` files that must be assembled and finally, `.src` files depend on the C source files (`.c`) that must be compiled. In the makefile `makefile` this looks like:

```
test.src  : test.c                      # dependency
            cm16c test.c                # rule

test.obj  : test.src
            asm16c test.src

test.elf  : test.obj
            lkm16c -otest.elf test.obj -lcs -lfps -lrts
```

You can use any command that is valid on the command line as a rule in the `makefile`. So, rules are not restricted to invocation of the toolchain.

Example

To build the target `test.elf`, call **mkm16c** with one of the following lines:

```
mkm16c test.elf

mkm16c –f mymake.mak test.elf
```

By default, the make utility reads `makefile` so you do not need to specify it on the command line. If you want to use another name for the makefile, use the option **–f** *my_makefile*.

If you do not specify a target, **mkm16c** uses the first target defined in the makefile. In this example it would build `test.src` instead of `test.elf`.

The make utility now tries to build `test.elf` based on the `makefile` and peforms the following steps:

1. From the makefile the make utility reads that `test.elf` depends on `test.obj`.
2. If `test.obj` does not exist or is out–of–date, the make utility first tries to build this file and reads from the makefile that `test.obj` depends on `test.src`.
3. If `test.src` does exist, the make utility now creates `test.obj` by executing the rule for it: `asm16c test.src`.
4. There are no other files necessary to create `test.elf` so the make utility now can use `test.obj` to create `test.elf` by executing the rule `lkm16c –otest.elf test.obj –lcs –lfps –lrts`.

The make utility has now built `test.elf` but it only used the assembler to update `test.obj` and the linker to create `test.elf`.

If you compare this to the control program:

```
ccm16c test.c
```

This invocation has the same effect but now *all* files are recompiled (assembled, linked and located).

9.3.1 CALLING THE MAKE UTILITY

You can only call the make utility from the command line. The invocation syntax is

```
mkm16c [ [options] [targets] [macro=def]... ]
```

For example:

```
mkm16c test.elf
```

target	You can specify any target that is defined in the makefile. A target can also be one of the intermediate files specified in the makefile.
macro=*def*	Macro definition. This definition remains fixed for the **mkm16c** invocation. It overrides any regular definitions for the specified macro within the makefiles and from the environment. It is inherited by subordinate **mkm16c**'s but act as an environment variable for these. That is, depending on the **–e** setting, it may be overridden by a makefile definition.

Exit status

The make utility returns an exit status of 1 when it halts as a result of an error. Otherwise it returns an exit status of 0.

Options of the make utility

The following make utility options are available:

Description	Option
Display options	**–?**
Display version header	**–V**
Verbose	
Print makefile lines while being read	**–D/–DD**
Display time comparisons which indicate a target is out of date	**–d/–dd**
Display current date and time	**–time**
Verbose option: show commands without executing (dry run)	**–n**
Do not show commands before execution	**–s**
Do not build, only indicate whether target is up–to–date	**–q**

Description	Option
Input files	
Use *makefile* instead of the standard makefile `makefile`	**–f** *makefile*
Change to directory before reading the makefile	**–G** *path*
Read options from file	**–m** *file*
Do not read the `mkm16c.mk` file	**–r**
Process	
Always rebuild target without checking whether it is out–of–date	**–a**
Run as a child process	**–c**
Environment variables override macro definitions	**–e**
Do not remove temporary files	**–K**
On error, only stop rebuilding current target	**–k**
Overrule the option **–k** (only stop rebuilding current target)	**–S**
Make all target files precious	**–p**
Touch the target files instead of rebuilding them	**–t**
Treat target as if it has just been reconstructed	**–W** *target*
Error messages	
Redirect error messages and verbose messages to a file	**–err** *file*
Ignore error codes returned by commands	**–i**
Redirect messages to standard out instead of standard error	**–w**
Show extended error messages	**–x**

Table 9–3: Overview of make utility options

For a complete list and description of all make utility options, see section 4.5, *Make Utility Options*, in Chapter *Tool Options* of the *Reference Manual*.

9.3.2 WRITING A MAKEFILE

In addition to the standard makefile `makefile`, the make utility always reads the makefile `mkm16c.mk` before other inputs. This system makefile contains implicit rules and predefined macros that you can use in the makefile `makefile`.

With the option **–r** (Do not read the `mkm16c.mk` file) you can prevent the make utility from reading `mkm16c.mk`.

The default name of the makefile is `makefile` in the current directory. If on a UNIX system this file is not found, the file `Makefile` is used as the default. If you want to use other makefiles, use the option **–f** *my_makefile*.

The makefile can contain a mixture of:

- targets and dependencies
- rules
- macro definitions or functions
- comment lines
- include lines
- export lines

To continue a line on the next line, terminate it with a backslash (\):

```
# this comment line is continued\
on the next line
```

If a line must end with a backslash, add an empty macro.

```
# this comment line ends with a backslash \$(EMPTY)
# this is a new line
```

Targets and dependencies

The basis of the makefile is a set of targets, dependencies and rules. A target entry in the makefile has the following format:

```
target ... : [dependency ...] [; rule]
       [rule]
        ...
```

Target lines must always start at the beginning of a line, leading white spaces (tabs or spaces) are not allowed. A target line consists of one or more targets, a semicolon and a set of files which are required to build the target (*dependencies*). The target itself can be one or more filenames or symbolic names.:

```
all:                    demo.elf final.elf

demo.elf final.elf:     test.obj demo.obj final.obj
```

You can now can specify the target you want to build to the make utility. The following three invocations all have the same effect:

```
mkm16c
mkm16c all
mkm16c demo.elf final.elf
```

If you do *not* specify a target, the first target in the makefile (in this example `all`) is build. The target `all` depends on `demo.elf` and `final.elf` so the second and third invocation have also the same effect and the files `demo.elf` and `final.elf` are built.

In MS–Windows you can normally use colons to denote drive letters. The following works as intended: `c:foo.obj : a:foo.c`

If a target is defined in more than one target line, the dependencies are added to form the target's complete dependency list:

```
all:  demo.elf   # These two lines are equivalent with:
all:  final.elf  # all: demo.elf final.elf
```

For target lines, macros and functions are expanded at the moment they are read by the make utility. Normally macros are not expanded until the moment they are actually used.

Special Targets

There are a number of special targets. Their names begin with a period.

.DEFAULT:	If you call the make utility with a target that has no definition in the make file, this target is build.
.DONE:	When the make utility has finished building the specified targets, it continues with the rules following this target.
.IGNORE:	Non–zero error codes returned from commands are ignored. Encountering this in a makefile is the same as specifying the option **–i** on the command line.
.INIT:	The rules following this target are executed before any other targets are build.
.SILENT:	Commands are not echoed before executing them. Encountering this in a makefile is the same as specifying the option **–s** on the command line.
.SUFFIXES:	This target specifies a list of file extensions. Instead of building a completely specified target, you now can build a target that has a certain file extension. Implicit rules to build files with a number of extensions are included in the system makefile `mkm16c.mk`.

If you specify this target with dependencies, these are added to the existing `.SUFFIXES` target in `mkm16c.mk`. If you specify this target without dependencies, the existing list is cleared.

.PRECIOUS: Dependency files mentioned for this target are never removed. Normally, if a command in a rule returns an error or when the target construction is interrupted, the make utility removes that target file. You can use the **–p** command line option to make all target files precious.

Rules

A line with leading white space (tabs or spaces) is considered as a rule and associated with the most recently preceding dependency line. A *rule* is a line with commands that are executed to build the associated target. A target–dependency line can be followed by one or more rules.

```
final.src : final.c            # target and dependency
            mv test.c final.c  # rule1
            cm16c final.c      # rule2
```

You can precede a rule with one or more of the following characters:

@ does not echo the command line, except if **–n** is used.

– the make utility ignores the exit code of the command (ERRORLEVEL in MS–DOS). Normally the make utility stops if a non–zero exit code is returned. This is the same as specifying the option **–i** on the command line or specifying the special `.IGNORE` target.

+ The make utility uses a shell or COMMAND.COM to execute the command. If the '+' is not followed by a shell line, but the command is a DOS command or if redirection is used (<, |, >), the shell line is passed to COMMAND.COM anyway. For UNIX, redirection, backquote (`) parentheses and variables force the use of a shell.

You can force **mkm16c** to execute multiple command lines in one shell environment. This is accomplished with the token combination ';\'. For example:

```
cd c:\cm16c\bin ;\
ccm16c –V
```

The ';' must always directly be followed by the '\' token. Whitespace is not removed when it is at the end of the previous command line or when it is in front of the next command line. The use of the ';' as an operator for a command (like a semicolon ';' separated list with each item on one line) and the '\' as a layout tool is not supported, unless they are separated with whitespace.

The make utility can generate inline temporary files. If a line contains `<<`*`LABEL`* (no whitespaces!) then all subsequent lines are placed in a temporary file until the line `LABEL` is encountered. Next, `<<`*`LABEL`* is replaced by the name of the temporary file.

Example:

```
lkm16c -o $@ -f <<EOF
     $(separate "\n" $(match .obj $!))
     $(separate "\n" $(match .a $!))
     $(LKFLAGS)
EOF
```

The three lines between `<<EOF` and `EOF` are written to a temporary file (for example `mkce4c0a.tmp`), and the rule is rewritten as `lkm16c -o $@ -f mkce4c0a.tmp`.

Instead of specifying a specific target, you can also define a general target. A general target specifies the rules to generate a file with extension *`.ex1`* to a file with extension *`.ex2`*. For example:

```
.SUFFIXES:   .c
.c.src    :
             lkm16c $<
```

Read this as: to build a file with extension `.src` out of a file with extension `.c`, call the compiler with `$<`. `$<` is a predefined macro that is replaced with the basename of the specified file. The special target `.SUFFIXES:` is followed by a list of file extensions of the files that are required to build the target.

Implicit Rules

Implicit rules are stored in the system makefile `mkm16c.mk` and are intimately tied to the `.SUFFIXES` special target. Each dependency that follows the `.SUFFIXES` target, defines an extension to a filename which must be used to build another file. The implicit rules then define how to actually build one file from another. These files share a common basename, but have different extensions.

If the specified target on the command line is not defined in the makefile or has not rules in the makefile, the make utility looks if there is an implicit rule to build the target.

Example

This makefile says that `prog.elf` depends on two files `prog.obj` and `sub.obj`, and that they in turn depend on their corresponding source files (`prog.c` and `sub.c`) along with the common file `inc.h`.

```
LIB   =     -lcs                                        # macro

prog.elf:  prog.obj sub.obj
     lkm16c prog.obj sub.obj $(LIB) -o prog.elf

prog.obj:  prog.c inc.h
     cm16c  prog.c
     asm16c prog.src

sub.obj:   sub.c inc.h
     cm16c  sub.c
     asm16c sub.src
```

The following makefile uses implicit rules (from `mkm16c.mk`) to perform the same job.

```
LKFLAGS = -lcs               # macro used by implicit rules
prog.elf: prog.obj sub.obj   # implicit rule used
prog.obj: prog.c inc.h       # implicit rule used
sub.obj:  sub.c inc.h        # implicit rule used
```

Files

makefile	Description of dependencies and rules.
Makefile	Alternative to makefile, for UNIX.
mkm16c.mk	Default dependencies and rules.

Diagnostics

mkm16c returns an exit status of 1 when it halts as a result of an error. Otherwise it returns an exit status of 0.

Macro definitions

A macros is a symbol names that is replaced with it's definition before the makefile is executed. Although the macro name can consist of lower case or upper case characters, upper case is an accepted convention. The general form of a macro definition is:

```
MACRO = text and more text
```

Spaces around the equal sign are not significant. To use a macro, you must access it's contents:

```
$(MACRO)       # you can read this as
${MACRO}       # the contents of macro MACRO
```

If the macro name is a single character, the parentheses are optional. Note that the expansion is done recursively, so the body of a macro may contain other macros. These macros are expanded when the macro is actually used, not at the point of definition:

```
FOOD = $(EAT) and $(DRINK)
EAT = meat and/or vegetables
DRINK = water
export FOOD
```

The macro `FOOD` is expanded as `meat and/or vegetables and water` at the moment it is used in the export line.

Predefined Macros

MAKE Holds the value `mkm16c`. Any line which uses `MAKE`, temporarily overrides the option **–n** (Show commands without executing), just for the duration of the one line. This way you can test nested calls to `MAKE` with the option **–n**.

MAKEFLAGS
Holds the set of options provided to **mkm16c** (except for the options **–f** and **–d**). If this macro is exported to set the environment variable `MAKEFLAGS`, the set of options is processed before any command line options. You can pass this macro explicitly to nested **mkm16c**'s, but it is also available to these invocations as an environment variable.

PRODDIR Holds the name of the directory where **mkm16c** is installed. You can use this macro to refer to files belonging to the product, for example a library source file.

```
DOPRINT = $(PRODDIR)/lib/src/_doprint.c
```

When **mkm16c** is installed in the directory `/cm16c/bin` this line expands to:

```
DOPRINT = /cm16c/lib/src/_doprint.c
```

SHELLCMD	Holds the default list of commands which are local to the SHELL. If a rule is an invocation of one of these commands, a SHELL is automatically spawned to handle it.
TMP_CCPROG	Holds the name of the control program: `ccm16c`. If this macro and the TMP_CCOPT macro are set and the command line argument list for the control program exceeds 127 characters, then **mkm16c** creates a temporary file with the command line arguments. **mkm16c** calls the control program with the temporary file as command input file.
TMP_CCOPT	Holds **–f**, the control program option that tells it to read options from a file. (This macro is only available for the Windows command prompt version of **mkm16c**.)
$	This macro translates to a dollar sign. Thus you can use ”$$” in the makefile to represent a single ”$”.

There are several dynamically maintained macros that are useful as abbreviations within rules. It is best not to define them explicitly.

$*	The basename of the current target.
$<	The name of the current dependency file.
$@	The name of the current target.
$?	The names of dependents which are younger than the target.
$!	The names of all dependents.

The $< and $* macros are normally used for implicit rules. They may be unreliable when used within explicit target command lines. All macros may be suffixed with F to specify the Filename components (e.g. ${*F}, ${@F}). Likewise, the macros $*, $< and $@ may be suffixed by D to specify the directory component.

The result of the $* macro is always without double quotes (”), regardless of the original target having double quotes (”) around it or not.
The result of using the suffix F (Filename component) or D (Directory component) is also always without double quotes (”), regardless of the original contents having double quotes (”) around it or not.

Functions

A function not only expands but also performs a certain operation. Functions syntactically look like macros but have embedded spaces in the macro name, e.g. '$(match arg1 arg2 arg3)'. All functions are built–in and currently there are five of them: `match`, `separate`, `protect`, `exist` and `nexist`.

`match` The `match` function yields all arguments which match a certain suffix:

```
$(match .obj prog.obj sub.obj mylib.a)
```

yields:

```
prog.obj sub.obj
```

`separate` The `separate` function concatenates its arguments using the first argument as the separator. If the first argument is enclosed in double quotes then '\n' is interpreted as a newline character, '\t' is interpreted as a tab, '*ooo*' is interpreted as an octal value (where, *ooo* is one to three octal digits), and spaces are taken literally. For example:

```
$(separate "\n" prog.obj sub.obj)
```

results in:

```
prog.obj
sub.obj
```

Function arguments may be macros or functions themselves. So,

```
$(separate "\n" $(match .obj $!))
```

yields all object files the current target depends on, separated by a newline string.

`protect` The `protect` function adds one level of quoting. This function has one argument which can contain white space. If the argument contains any white space, single quotes, double quotes, or backslashes, it is enclosed in double quotes. In addition, any double quote or backslash is escaped with a backslash.

Example:

```
echo $(protect I’ll show you the ”protect”
function)
```

yields:

```
echo ”I’ll show you the \”protect\”
function”
```

`exist` The `exist` function expands to its second argument if the first argument is an existing file or directory.

Example:

```
$(exist test.c ccm16c test.c)
```

When the file `test.c` exists, it yields:

```
ccm16c test.c
```

When the file `test.c` does not exist nothing is expanded.

`nexist` The `nexist` function is the opposite of the exist function. It expands to its second argument if the first argument is not an existing file or directory.

Example:

```
$(nexist test.src ccm16c test.c)
```

Conditional Processing

Lines containing `ifdef`, `ifndef`, `else` or `endif` are used for conditional processing of the makefile. They are used in the following way:

`ifdef` *macro–name*
if–lines
`else`
else–lines
`endif`

The *if–lines* and *else–lines* may contain any number of lines or text of any kind, even other `ifdef`, `ifndef`, `else` and `endif` lines, or no lines at all. The `else` line may be omitted, along with the *else–lines* following it.

First the *macro–name* after the `if` command is checked for definition. If the macro is defined then the *if–lines* are interpreted and the *else–lines* are discarded (if present). Otherwise the *if–lines* are discarded; and if there is an `else` line, the *else–lines* are interpreted; but if there is no `else` line, then no lines are interpreted.

When using the `ifndef` line instead of `ifdef`, the macro is tested for not being defined. These conditional lines can be nested up to 6 levels deep.

See also *Defining Macros* in section 4.5, *Make Utility Options*, in Chapter *Tools Options* of the *Reference Manual*.

Comment lines

Anything after a "#" is considered as a comment, and is ignored. If the "#" is inside a quoted string, it is not treated as a comment. Completely blank lines are ignored.

```
test.src   : test.c        # this is comment and is
             cm16c test.c  # ignored by the make utility
```

Include lines

An *include* line is used to include the text of another makefile (like including a .h file in a C source). Macros in the name of the included file are expanded before the file is included. Include files may be nested.

```
include makefile2
```

Export lines

An *export* line is used to export a macro definition to the environment of any command executed by the make utility.

```
GREETING = Hello

export GREETING
```

This example creates the environment variable `GREETING` with the value `Hello`. The macros is exported at the moment the export line is read so the macro definition has to proceed the export line.

9.4 ARCHIVER

The archiver **arm16c** is a program to build and maintain your own library files. A library file is a file with extension `.a` and contains one or more object files (`.obj`) that may be used by the linker.

The archiver has five main functionalities:

- Deleting an object module from the library
- Moving an object module to another position in the library file
- Replacing an object module in the library or add a new object module
- Showing a table of contents of the library file
- Extracting an object module from the library

The archiver takes the following files for input and output:

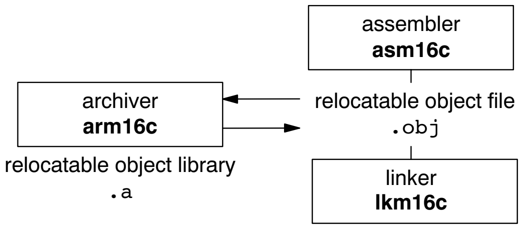


Figure 9–1: ELF/DWARF archiver and library maintainer

The linker optionally includes object modules from a library if that module resolves an external symbol definition in one of the modules that are read before.

9.4.1 CALLING THE ARCHIVER

You can only call the archiver from the command line. The invocation syntax is:

```
arm16c key_option [sub_option...] library [object_file]
```

key_option With a key option you specify the main task which the archiver should perform. You must *always* specify a key option.

sub_option	Sub–options specify into more detail how the archiver should perform the task that is specified with the key option. It is not obligatory to specify sub–options.
library	The name of the library file on which the archiver performs the specified action. You must always specify a library name, except for the option **–?** and **–V**. When the library is not in the current directory, specify the complete path (either absolute or relative) to the library.
object_file	The name of an object file. You must always specify an object file name when you add, extract, replace or remove an object file from the library.

Options of the archiver utility

The following archiver options are available:

Description	Option	Sub–option
Main functions (key options)		
Replace or add an object module	**–r**	**–a –b –c –u –v**
Extract an object module from the library	**–x**	**–v**
Delete object module from library	**–d**	**–v**
Move object module to another position	**–m**	**–a –b –v**
Print a table of contents of the library	**–t**	**–s0 –s1**
Print object module to standard output	**–p**	
Sub–options		
Append or move new modules after existing module *name*	**–a** *name*	
Append or move new modules before existing module *name*	**–b** *name*	
Create library without notification if library does not exist	**–c**	
Preserve last–modified date from the library	**–o**	
Print symbols in library modules	**–s{0|1}**	
Replace only newer modules	**–u**	
Verbose	**–v**	

Description	Option	Sub–option
Miscellaneous		
Display options	**–?**	
Display version header	**–V**	
Read options from *file*	**–f** *file*	
Suppress warnings above level *n*	**–w***n*	

Table 9–4: Overview of archiver options and sub–options

For a complete list and description of all archiver options, see section 4.6, *Archiver Options*, in Chapter *Tool Options* of the *Reference Manual*.

9.4.2 EXAMPLES

Create a new library

If you add modules to a library that does not yet exist, the library is created. To create a new library with the name **mylib.a** and add the object modules **cstart.obj** and **calc.obj** to it:

```
arm16c –r mylib.a cstart.obj calc.obj
```

Add a new module to an existing library

If you add a new module to an existing library, the module is added at the end of the module. (If the module already exists in the library, it is replaced.)

```
arm16c –r mylib.a mod3.obj
```

Print a list of object modules in the library

To inspect the contents of the library:

```
arm16c –t mylib.a
```

The library has the following contents:

```
cstart.obj
calc.obj
mod3.obj
```

Move an object module to another position

To move `mod3.obj` to the beginning of the library, position it just before `cstart.obj`:

```
arm16c –mb cstart.obj mylib.a mod3.obj
```

Delete an object module from the library

To delete the object module `cstart.obj` from the library **`mylib.a`**:

```
arm16c –d mylib.a cstart.obj
```

Extract all modules from the library

Extract all modules from the library **`mylib.a`**:

```
arm16c –x mylib.a
```

9.5 FLASH UTILITY

With the flash utility **flashm16c** you can load an ELF, Intel Hex or Motorola S–record file in a flash device.

Configure flash settings from EDE

You can configure all flash settings from EDE.

1. From the **Project** menu, select **Project Options...**

   The Project Options dialog appears.

2. Expand the **Flasher** entry and select **Flasher Settings**.
3. Select serial or USB communication.
4. Select the flash actions.

You can perform several actions with the flash tool:

Blank check

Select this to check if the flash device is properly erased.

Full erase

Select this to erase the entire flash memory.

Program

Select this to program the flash device with the specified file.

Verify

Select this to compare a Motorola S–record file (or other absolute file) with the content of the FLASH.

9.5.1 CALLING THE FLASH UTILITY

You can call the flash utitlity from the command line or from EDE. The invocation syntax is:

```
flashm16c [option]... [file]...
```

If you invoke **flashm16c** with the **–nodialog** command line option the absolute file is directly flashed into the target.

From EDE, you can start flashing with one click on the `Flash an ELF, Intel Hex or Motorola S–Rec file` button located in the toolbar.

Options of the flash utility

The following flash utility options are available:

Description	Option
Target selection	
Default: M16C20 – M16C60	*no option*
M16C10	**–M16C10**
R8C10 – R8C13	**–R8C10**
Flasher settings	
Flash actions: **B** – Blank check **F** – Erase all blocks **P** – Program file **V** – Verify programmed blocks	**–actions**=*flag*...
Flash ID code	
Use *id* to access the flash	**–id**=*id*
When IDs 00 or FF fail, do not retry with opposite	**–noidretry**
Communication settings	
Specify baud rate (default: 9600)	**–baudrate**=*baudrate*
Specify the serial port to use	**–com**{**1**|**2**|**3**|**4**}
Use USB connection	**–USB**
Set the target board and upload the hex file to the USB monitor board	**–set_USB_target**=*target*
Files	
Set working directory	**–dir** *dir*
Read options from file	**–f** *file*
Save original contents before overwriting	**–backup** *file*
Specify start/end address for backup (default: 0xC0000 – 0xFFFFF)	**–backup_range**=*start*, *end*

Description	Option
Append errors to file	**–err** *file*
Miscellaneous	
Do not use the Flash dialog	**–nodialog**
Log level (detail of warnings, 0=none, 3=all)	**–level=**{**0**|**1**|**2**|**3**}
Display short description of options	**–h**
Show on–board flash program version	**–version**

Example

To erase the flash device and flash the file **demo.s** at a baud rate of 38400 in a device connected at serial port COM2, using a command line interface, type:

```
flashm16c –actions=FP –baudrate=38400 –com2
      –id=00.00.00.00.00.00.00 –nodialog demo.s
```

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