Using the ARM Embedded Tools

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Manual Purpose and Structure

Windows Users

The documentation explains and describes how to use the TASKING ARM toolchain to program an ARM processor.

You can use the tools either with the graphical EDE or from the command line in a command prompt window.

Structure

The toolchain documentation consists of a user's manual (this manual), which includes a Getting Started section, and a separate reference manual (*ARM Embedded Tools Reference*).

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

After installation you are ready 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 TASKING toolchain.

Short Table of Contents

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
	carm [**-?**]
	Both **carm** and **carm -?** are valid commands.
|	Separates items in a list. Read it as OR.
...	You can repeat the preceding item zero or more times.

Example

carm [*option*]... *filename*

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

```
carm test.c
carm -g test.c
carm -g -s test.c
```

Not valid is:

```
carm -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

- ISO/IEC 9899:1999(E), Programming languages – C [ISO/IEC]
  More information on the standards can be found at `http://www.ansi.org`

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

- ARM Embedded Tools Reference
  [Altium, MB101–024–00–00]
- ARM CrossView Pro Debugger User's Manual
  [Altium, MA101–043–00–00]

ARM

- ARM Architecture Reference Manual – second edition
  [2000, ARM Limited]

1 Software Installation and Configuration

Summary

This chapter guides you through the procedures to install the software on a Windows system.
The software for Windows has two faces: a graphical interface (Embedded Development Environment) and 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.

1.1 Software Installation

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.
7. License the software product as explained in section 1.3, Licensing TASKING Products.

1.2 Software Configuration

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

1.2.1 Configuring the Embedded Development Environment

After installation on Windows, 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.

1.2.2 Configuring the Command Line Environment

To facilitate the invocation of the tools from the command line (Windows command prompt), 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 (for example: `c:\carm\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.
CARMINC	With this variable you specify one or more additional directories in which the C compiler **carm** looks for include files. The compiler first looks in these directories, then always looks in the default `include` directory relative to the installation directory.
ASARMINC	With this variable you specify one or more additional directories in which the assembler **asarm** looks for include files. The assembler first looks in these directories, then always looks in the default `include` directory relative to the installation directory.
CCARMBIN	With this variable you specify the directory in which the control program **ccarm** looks for the executable tools. The path you specify here should match the path that you specified for the PATH variable.
LIBARM	With this variable you specify one or more alternative directories in which the linker **lkarm** looks for library files for a specific core. The linker first looks in these directories, then always looks in the default `lib` directory.
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:\carm\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:\carm\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:\carm\bin`.

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

1.3 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.

1.3.1 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 1.3.5, How to Determine the Host ID and section 1.3.6, 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.

1.3.2 Installing Node–Locked Licenses

If you do not have received your license key, read section 1.3.1, Obtaining License Information, before continuing.

1. Install the TASKING software product following the installation procedure described in section 1.1, Software Installation, 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 1.3.4, 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 1.3.4, Modifying the License File Location, for additional information.

The software product and license file are now properly installed.

1.3.3 Installing Floating Licenses

If you do not have received your license key, read section 1.3.1, 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 1.3.4, 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 1.3.4, 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 part of the TASKING product installation and is present in the `flexlm` subdirectory of the toolchain. This file is also 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.

1.3.4 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.

1.3.5 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
Linux	**hostid**	11ac5702
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`.

1.3.6 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

2 Getting Started with Embedded Software

Summary

This tutorial shows how to create an embedded software project with EDE.

2.1 Introduction

This tutorial presumes you are familiar with programming in C/assembly and have basic knowledge of embedded programming. It contains an overview of the TASKING tools available in the Embedded Development Environment (EDE). It describes how you can add, create and edit source files in an embedded project and how to build an embedded application.

The example used in this tutorial is a Hello World program in C. Other examples are supplied in the `\Program Files\Tasking\carm\examples\` folder.

2.2 Embedded Software Tools

With the TASKING embedded software tools in EDE you can write, compile, assemble and link applications for ARM. Figure 2–1 shows all components of the TASKING toolchain with their input and output files.

The **bold** names in the figure are the executable names of the tools.

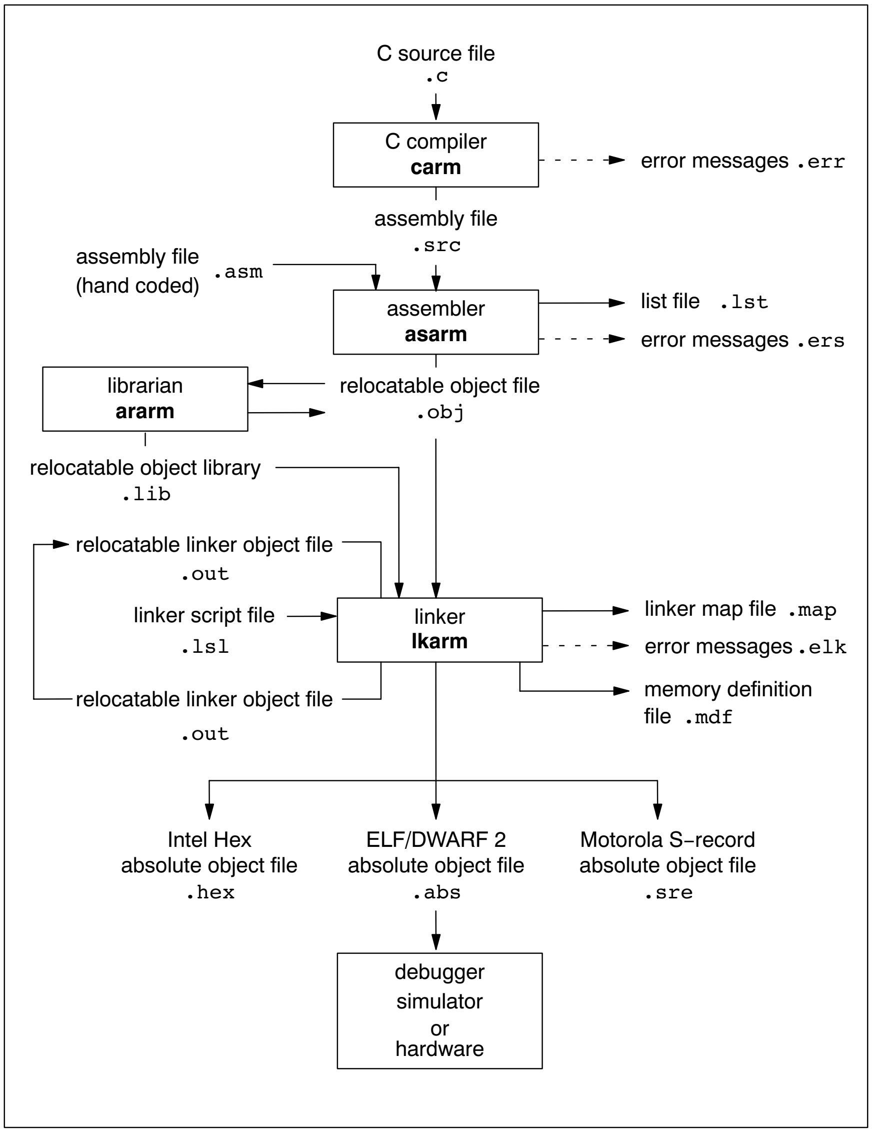


Figure 2–1: Toolchain overview

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

Extension	Description
Source files	
.c	C source file, input for the C compiler
.asm	Assembler source file, hand coded
.lsl	Linker script file
Generated source files	
.src	Assembler source file, generated by the C compiler, does not contain macros
Object files	
.obj	ELF/DWARF 2 relocatable object file, generated by the assembler
.lib	Archive with ELF/DWARF 2 object files
.out	Relocatable linker output file
.abs	ELF/DWARF 2 absolute object file, generated by the locating part of the llinker
.hex	Absolute Intel Hex object file
.sre	Absolute Motorola S−record object file
List files	
.lst	Assembler list file
.map	Linker map file
.mcr	MISRA−C report file
.mdf	Memory definition file
Error list files	
.err	Compiler error messages file
.ers	Assembler error messages file
.elk	Linker error messages file

Table 2−1: File extensions

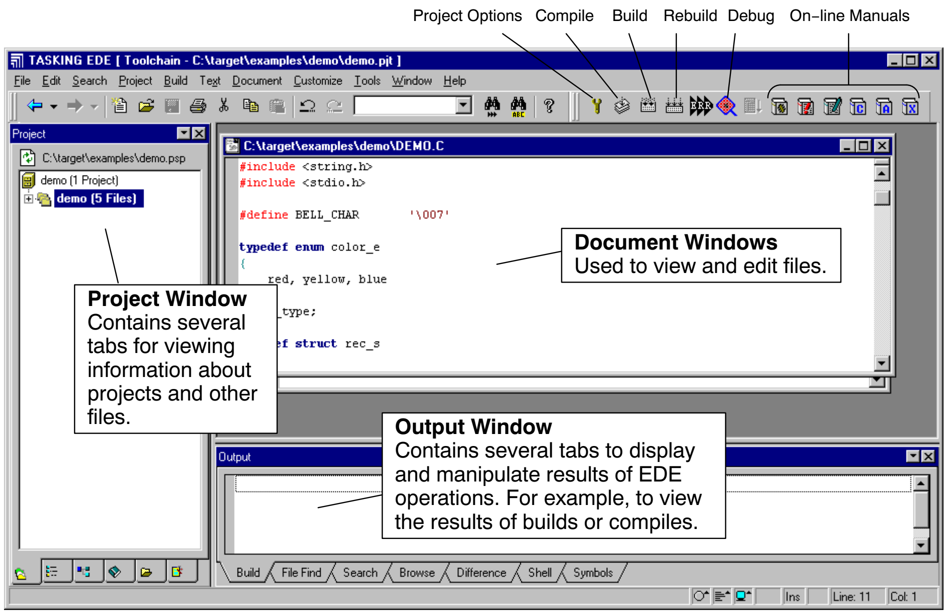
2.3 Embedded Development Environment

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.

To start EDE, double−click on the EDE shortcut on your desktop or launch EDE via the program folder create by the installation program (**Start** » **Programs** » **TASKING *toolchain*** » **EDE**).

Figure 2−2: 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;
 f 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 2−3: EDE desktop

2.4 Creating an Embedded Project

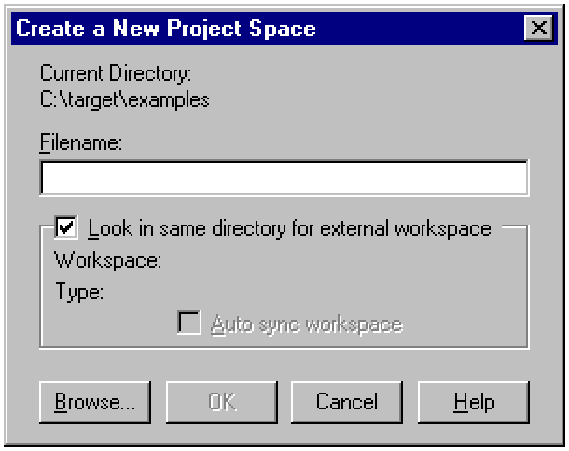
To start working with EDE, you first need a project space and a project. A *project space* holds a set of projects and must always contain at least one project. Before you can create a project you have to setup a project space. All information of a project space is saved in a *project space file* (`.psp`). Within a project space you can create projects. A *project* makes managing your source documents and any generated outputs much easier. All information of a project is saved in a *project file* (`.pjt`).

To create a new Embedded Software project:

Create a new project space

1. Select **File » New Project Space...** form the menu.

   The Create a New Project Space dialog appears.



Create a New Project Space

Current Directory:
C:\target\examples

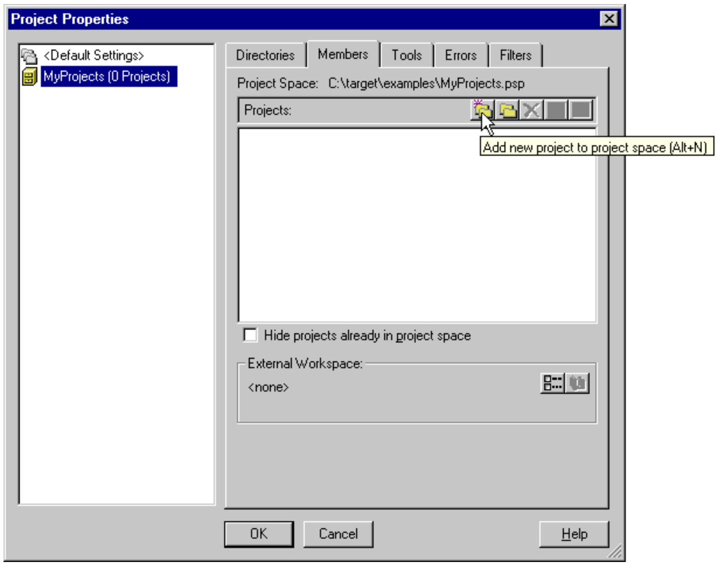
Filename:

☑ Look in same directory for external workspace
Workspace:
Type:
☐ Auto sync workspace

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

Projects:

Add new project to project space (Alt+N)

☐ Hide projects already in project space

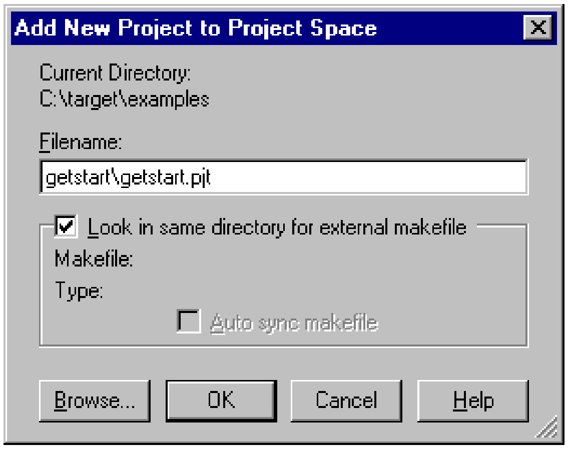
External Workspace:

<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

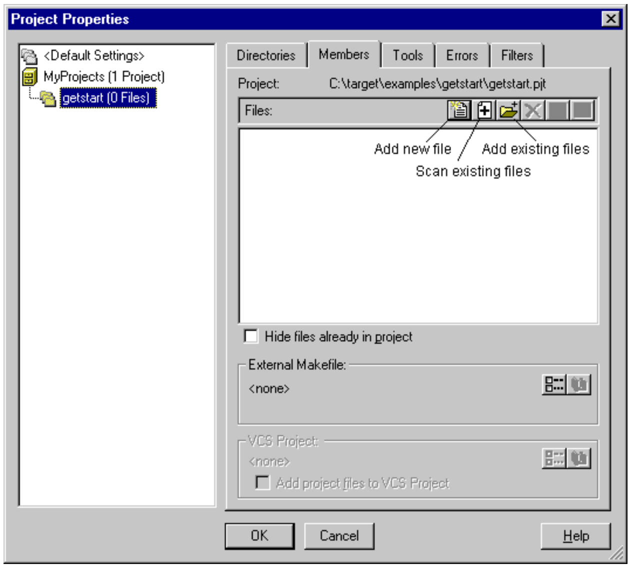
Makefile:

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

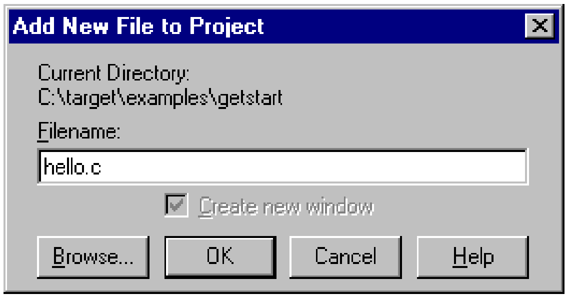
Now you can add all the files you want to be part of your project.

2.4.1 Adding a new source file to the project

If you want to add a new source file (C or assembly or text file) to your project, proceed as follows:

1. In the Project Properties dialog, click on the **Add new file to project** button.
   Alternatively: In the Project Window, right-click on `getstart` and select **Add New File...**

   The Add New File to Project dialog appears.



Current Directory:
C:\target\examples\getstart
Filename: hello.c

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

   A new empty file is created and added to the project. Repeat steps 1 and 2 if you want to add more files.

3. 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.

4. Enter the source code required. For this tutorial enter the following code:

```
#include <stdio.h>

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

Save the source file:

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

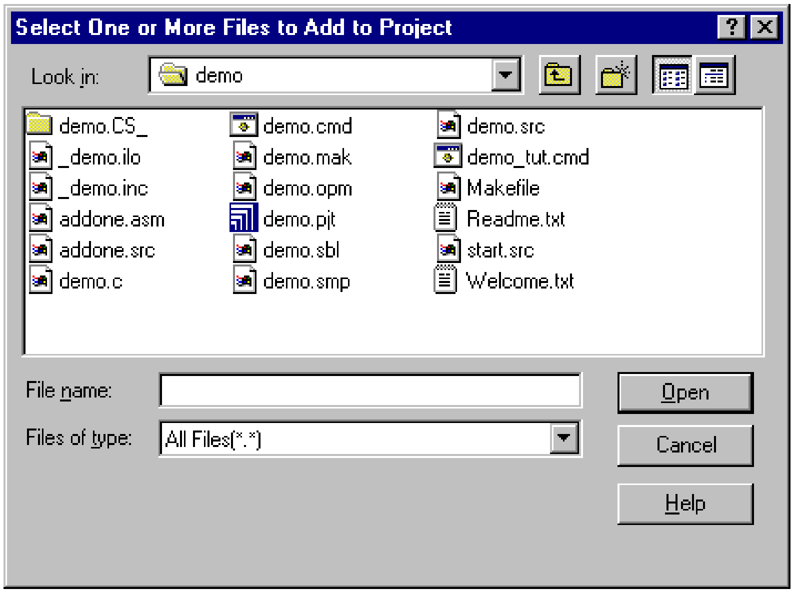
EDE saves the file.

2.4.2 Adding an existing source file to the project

If you want to add an exisiting source file to your project, proceed as follows:

1. In the Project Properties dialog, click on the **Add existing files to project** button.
   Alternatively: In the Project Window, right–click on `getstart` and select **Add Existing Files » Browse...**

   The Select One or More Files to Add to Project dialog appears.



2. In the **Look in** box, select the directory that contains the files you want to add to your project.
3. Select the files you want to add (hold down the **Ctrl**–key to select more than one file) and click **Open**.

   All the selected files will be added to your project.

2.5 Setting the Embedded Project Options

An embedded project in EDE has a set of embedded options associated with it. After you have added files to your project, and have written your application (`hello.c` in our example), the next steps in the process of building your embedded application are:

- selecting a target processor architecture
- specifying the options of the tools in the toolchain, such as the C compiler, assembler and linker options. (Different toolchain configurations may have different sets of options.)

2.5.1 Selecting a target processor

For an embedded project, you must specify the configuration and processor type first:

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

   The Project Options dialog appears.

2. Select **Processor Definition**.

3. In the **Target processor** list select a target processor. If you select **(Other)**, select an **Architecture**.

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

2.5.2 Setting the tool options

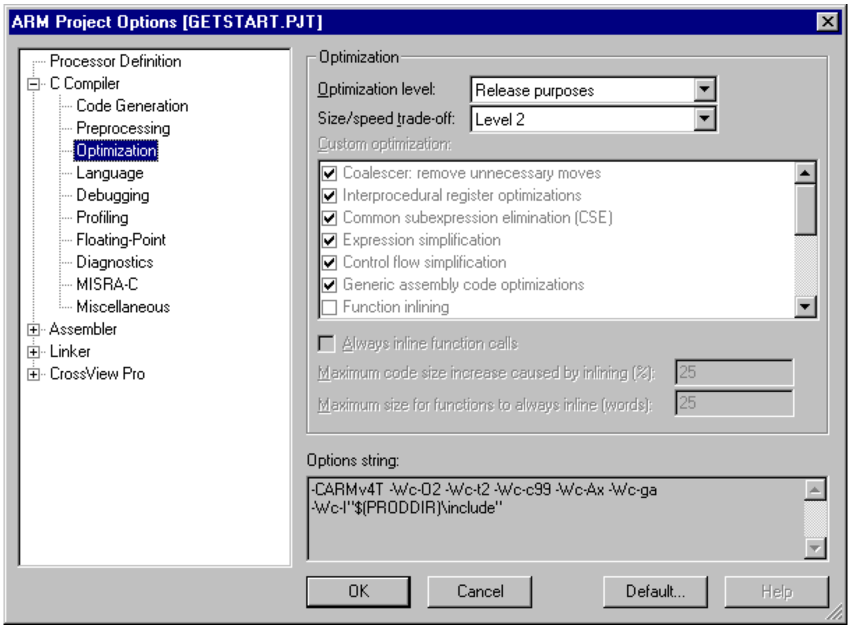
You can set embedded options commonly for all files in the project and you can set file specific options.

Setting project wide options

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

   The Project Options dialog appears.

2. In the left pane, expand the **C Compiler** entry.
   This entry contains several pages where you can specify C compiler settings.



Optimization

Optimization level: Release purposes

Size/speed trade-off: Level 2

Custom optimization:

- [✓] Coalescer: remove unnecessary moves
- [✓] Interprocedural register optimizations
- [✓] Common subexpression elimination (CSE)
- [✓] Expression simplification
- [✓] Control flow simplification
- [✓] Generic assembly code optimizations
- [ ] Function inlining

[ ] Always inline function calls

Maximum code size increase caused by inlining (%): 25

Maximum size for functions to always inline (words): 25

Options string:

```
-CARMv4T -Wc-O2 -Wc-t2 -Wc-c99 -Wc-Ax -Wc-ga
-Wc-I"$(PRODDIR)\include"
```

3. In the right pane, set the options to the values you want. Do this for all pages. If you want to debug the absolute file, set the **Optimization level** to **Debug purposes**. For your final application you can select **Release purposes**.

4. Repeat steps 2 and 3 for the other tools like assembler, linker and CrossView Pro.

5. Click **OK** to confirm the new settings.

Based on the embedded project options, EDE creates a so−called *makefile* which it uses to build your embedded application.

With the **Default...** button you can restore the default project options (for the current page, or for all pages). If available, the **Options string** field shows how your settings are translated to command line options.

Setting options for an individual document

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

   The File Options dialog appears.

Steps 2 to 5 are the same as the steps for setting project wide options.

2.6 Building your Embedded Application

You are now ready to build your embedded application.

1. Select **Build** » **Build** or click on the **Execute 'Make' command** button.

   The TASKING program builder compiles, assembles, links and locates the files in the embedded project that are out-of-date or that have been changed during a previous build. The resulting file is the absolute object file `getstart.abs` in the ELF/DWARF format.

2. You can view the results of the build in the **Build** tab of the Output window (**Window** » **Output**).

2.6.1 Compiling a single source file

If you want to compile a single source file:

1. Select the window (`hello.c`) containing the file you want to compile or assemble.
2. Select **Build** » **Compile** or click on the **Execute 'Compile' command** button.

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

2.6.2 Rebuiling your entire application

If you want to build your embedded application from scratch, regardless of their date/time stamp, you can perform a recompile:

1. Select **Build** » **Rebuild** or click on the **Execute 'Rebuild' command** button.
2. The TASKING program builder compiles, assembles, links and locates all files in the embedded project unconditionally.

You can now debug the resulting absolute object file `getstart.abs`.

2.7 Debugging your Embedded Application

When you have built your embedded application, you can start debugging the resulting absolute object file with the simulator.

To start the debugger:

- Select **Build** » **Debug** or click on the **Debug application** button.

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

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

3 C Language

Summary

This chapter describes the target specific features of the C language, including language extensions that are not standard in ISO−C. For example, pragmas are a way to control the compiler from within the C source.

3.1 Introduction

The TASKING compiler(s) fully support the ISO C standard and add extra possibilities to program the special functions of the targets.

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

- intrinsic (built−in) functions that result in target 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
- attribute to specify absolute addresses
- keywords for inlining functions and programming interrupt routines
- libraries

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

In this chapter the target specific characteristics of the C language are described, including the above mentioned extensions.

3.2 Data Types

The TASKING C compiler for the ARM architecture (**carm**) supports the following fundamental data types:

Type	C Type	Size (bit)	Align (bit)	Limits
Boolean	`_Bool`	8	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`
		16	16	-2^{15} .. $2^{15}-1$

	`unsigned short`	16	16	0 .. $2^{16}-1$
	`enum`	32	32	-2^{31} .. $2^{31}-1$

	`int`
	`signed int`
	`long`
	`signed long`
		32	32	-2^{31} .. $2^{31}-1$

	`unsigned int`
	`unsigned long`
		32	32	0 .. $2^{32}-1$

	`long long`
	`signed long long`
		64	64	-2^{63} .. $2^{63}-1$

	`unsigned long long`	64	64	0 .. $2^{64}-1$
Pointer	pointer to function or data	32	32	0 .. $2^{32}-1$
Floating–Point	`float`	32	32	$-3.402e^{38}$ .. $-1.175e^{-38}$ $1.175e^{-38}$ .. $3.402e^{38}$

	`double`
	`long double`
		64	64	$-1.798e^{308}$ .. $-2.225e^{-308}$
				$2.225e^{-308}$ .. $1.798e^{308}$

Table 3–1: Data Types for the ARM

3.2.1 Changing the Alignment: __unaligned and __packed__

Normally data, pointers and structure members are aligned according to the table in the previous section. With the type qualifier `__unaligned` you can specify to suppress the alignment of objects or structure members. This can be useful to create compact data structures. In this case the alignment will be one bit for bit–fields or one byte for other objects or structure members.

At the left side of a pointer declaration you can use the type qualifier `__unaligned` to mark the pointer value as potentially unaligned. This can be useful to access externally defined data. However the compiler can generate less efficient instructions to dereference such a pointer, to avoid unaligned memory access. You can convert a normal pointer to an unaligned pointer, but not vice versa.

Example:

```
struct
{
    char c;
    __unaligned  int i;   /* aligned at offset 1 ! */
} s;

__unaligned int * up = & s.i;
```

Packed structures

To prevent alignment gaps in structures, you can use the attribute `__packed__`. When you use the attribute `__packed__` directly after the keyword `struct`, all structure members are marked `__unaligned`. For example the following two declarations are the same:

```
struct __packed__
{
    char c;
    int i;
} s1;

struct
{
    __unaligned char c;
    __unaligned int i;
} s2;
```

The attribute `__packed__` has the same effect as adding the type qualifier `__unaligned` to the declaration to suppress the standard alignment.

You can also use `__packed__` in a pointer declaration. In that case it affects the alignment of the pointer itself, not the value of the pointer. The following two declarations are the same:

```
int * __unaligned p;
int * p __packed__;
```

3.3 Placing an Object at an Absolute Address: __at()

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 i __at(0x1000) = 1;
```

The variable `i` is placed at address 0x1000 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 global variables 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 allocated within another module but on a different address, the compiler, assembler or linker will not notice, because an assembler external object cannot specify an absolute address.
- When the variable is declared `static`, no public symbol will be generated (normal C behavior).
- You cannot place structure members at an absolute address.
- Absolute variables cannot overlap each other. If you declare two absolute variables at the same address, the assembler and / or linker issues an error. The compiler does not check this.
- When you declare the same absolute variable within two modules, this produces conflicts during link time (except when one of the modules declares the variable ’extern’).

3.4 Using Assembly in the C Source: __asm()

With the `__asm` keyword you can use assembly instructions in the C source. 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*
%*parm_nr*[*.regnum*]	Parameter number in the range 0 .. 9. With the optional *.regnum* you can access an individual register from a register pair.
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*.
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:q	Name of the register you want to reserve.

```
char a, b;
int result;

void main(void)
{
    a = 3;
    b = 4;
    __asm( ”ADD %0,%1,%2” : ”=r”(result): ”r”(a), ”r”(b) );
}
```

`%0` corresponds with the first C variable, `%1` with the second and so on.

Generated assembly code:

```
main: .type func
    ldr    r1,L_2
    mov    r0,#3
    strb   r0,[r1,#0]
    mov    r2,#4
    strb   r2,[r1,#1]
    ADD    r0,r0,r2
    str    r0,[r1,#4]
    bx     lr
    .size  main,$-main
    .align 4
L_2:
    .dcw   a
```

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 saving and restoring instructions are placed around the inline assembly instructions.

Constraint character	Type	Operand	Remark
R	general purpose register (64 bits)	r0 .. r11	Thumb mode r0 .. r7 Based on the specified register, a register pair is formed (64–bit). For example r0r1.
r	general purpose register	r0 .. r11, lr	Thumb mode r0 .. r7
i	immediate value	#value	
l	label	*label*	
m	memory label	*variable*	stack or memory operand, a fixed address
number	other operand	same as %*number*	used when in– and output operands must be the same. Use %*number*.0 and %*number*.1 to indicate the first and second half of a register pair when used in combination with R.

Table 3–2: Available input/output operand constraints for the ARM

Loops and conditional jumps

The compiler does not detect loops that are coded 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 contained in the same statement.

Example 1: no input or output

A simple example without input or output parameters. You can use any instruction or label. Note that you can use standard C escape sequences.

```
__asm( "nop\n\t"
       "nop" );
```

Generated code:

```
    nop
    nop
```

Example 2: using output parameters

Assign the result of inline assembly to a variable. A register is chosen for the parameter because of the constraint `r`; the compiler decides which register is best to use. The `%0` in the instruction template is replaced with the name of this register. Finally, the compiler generates code to assign the result to the output variable.

```
char var1;

void main(void)
{
    __asm( ”mov %0,#0xff” : ”=r”(var1));
}
```

Generated assembly code:

```
      mov    r0,0xff
      ldr    r1,L_2
      strb   r0,[r1,#0]
      bx     lr
      .size  main,$-main
      .align 4
L_2:
      .dcw     var1
```

Example 3: using input and output parameters

Add two C variables and assign the result to a third C variable. Registers are used for the input parameters (constraint `r`, `%1` for `a` and `%2` for `b` in the instruction template) and for the output parameter (constraint `r`, `%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.

```
char a, b;
int result;

void main(void)
{
    a = 3;
    b = 4;
    __asm( ”ADD %0,%1,%2” : ”=r”(result): ”r”(a), ”r”(b) );
}
```

Generated assembly code:

```
main: .type func
    ldr    r1,L_2
    mov    r0,#3
    strb   r0,[r1,#0]
    mov    r2,#4
    strb   r2,[r1,#1]
    ADD    r0,r0,r2
    str    r0,[r1,#4]
    bx     lr
    .size  main,$-main
    .align 4
L_2:
    .dcw   a
```

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`).

```
char a, b;
int result;

void main(void)
{
    a = 3;
    b = 4;
    __asm( ″ADD %0,%1,%2″ : ″=r″(result): ″r″(a), ″r″(b) : ″R0″ );
}
```

Generated assembly code:

```
main: .type func
    ldr   r2,L_2
    mov   r1,#3
    strb  r1,[r2,#0]
    mov   r3,#4
    strb  r3,[r2,#1]
    ADD   r1,r1,r3
    str   r1,[r2,#4]
    bx    lr
    .size main,$-main
    .align    4
L_2:
    .dcw      a
```

3.5 Pragmas to Control the Compiler

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 (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
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 3.7.3, *Inlining Functions*.
macro nomacro	Specifies macro expansion
message "*message*" ...	Emits a message to standard output

Pragma name	Description
optimize *flags* endoptimize	Controls compiler optimizations. See section 5.3, *Compiler Optimizations* in Chapter *Using the Compiler*
runtime	Check for run–time errors. See compiler option **–r (––runtime)** in section 5.1, *Compiler Options* in Chapter *Tool Options* of the reference manual.

section [*name*=]{*suffix* |**–f**|**–m**|**–fm**}
endsection
	Changes section names
	See compiler option **–R** in section 5.1, *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 5.1, *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 5.1, *Compiler Options* in Chapter *Tool Options* of the reference manual.
warning [*number*,...]	Disables warning messages. See compiler option **–w** in section 5.1, *Compiler Options* in Chapter *Tool Options* of the reference manual.
weak *symbol*	Marks a symbol as 'weak'

Table 3–3: Overview of pragmas

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

3.6 Predefined Preprocessor Macros

In addition to the predefined macros required by the ISO C standard, such as `__DATE__` and `__FILE__`, the TASKING C compiler supports the predefined macros as defined in the table below. The macros are useful to create conditional C code.

Macro	Description
`__BIG_ENDIAN__`	Expands to 1 if the processor accesses data in big–endian. Expands to 0 if the processor accesses data in little–endian (ARM default).
`__CARM__`	Expands to 1 for the ARM toolchain, otherwise unrecognized as macro.
`__THUMB__`	Expands to 1 if you used option **--thumb**, otherwise unrecognized as macro.
`__CPU__`	Expands to the CPU core name (option **-C***cpu*).
`__SINGLE_FP__`	Expands to 1 if you used option **-F** (Treat 'double' as 'float'), otherwise unrecognized as macro.
`__DOUBLE_FP__`	Expands to 1 if you did *not* use option **-F** (Treat 'double' as 'float'), otherwise unrecognized as macro.
`__TASKING__`	Identifies the compiler as a TASKING compiler. Expands to 1 if a TASKING compiler is used.
`__VERSION__`	Identifies the version number of the compiler. For example, if you use version 1.0r2 of the compiler, __VERSION__ expands to 1000 (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 1.0r2 of the compiler, __REVISION__ expands to 2.
`__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 3–4: Predefined preprocessor macros

Example

```
#ifdef __CARM__
/* this part is only compiled for the ARM */
...

#endif
```

3.7 Functions

3.7.1 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 compiler pushes parameters on the stack. See the table below.

Parameter Type	Parameter Number			
	1	2	3	4
_Bool	r0	r1	r2	r3
char	r0	r1	r2	r3
short	r0	r1	r2	r3
int / long	r0	r1	r2	r3
float	r0	r1	r2	r3
32–bit pointer	r0	r1	r2	r3
32–bit struct	r0	r1	r2	r3
long long	r0r1	r1r2	r2r3	r3
double	r0r1	r1r2	r2r3	
64–bit struct	r0r1	r1r2	r2r3	

Table 3–5: Register usage for parameter passing

If a register corresponding to a parameter number is already in use the next register is used.

Example with three arguments

```
func1( int a, int b, int *c )
```

- `a` (first parameter) is passed in register r0.
- `b` (second parameter) is passed in register r1.
- `c` (third parameter) is passed in register r2.

Example with one long long/double arguments and one other argument

```
func2( long long d, char e )
```

- `d` (first parameter) is passed in register r0 and r1
- `e` (second parameter) is passed in register r2.

Example with two long long/double arguments and one other argument

```
func3( double f, long long g, char h )
```

- `f` (first parameter) is passed in register r0 and r1
- `g` (second parameter) is passed in register r2 and r3.
- `h` (third parameter) cannot be passed through registers anymore, and is passed via the stack.

3.7.2 Function Return Types

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

Return Type	Register
_Bool	r0
char	r0
short	r0
int / long	r0
float	r0
32–bit pointer	r0
32–bit struct	r0
long long	r0r1
double	r0r1
64–bit struct	r0r1

Table 3–6: Register usage for function return types

Objects larger than 64 bits are returned via the stack.

3.7.3 Inlining Functions: inline

During compilation, the C compiler automatically inlines small functions in order to reduce execution time (smart inlining). 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. The C compiler decides which functions will be inlined. You can overrule this behaviour with the two keywords `inline` (ISO–C) and `__noinline`.

With the `inline` keyword you force the compiler to inline the specified function, regardless of the optimization strategy of the compiler itself:

```
inline unsigned int abs(int val)
{
    unsigned int abs_val = val;
    if (val < 0) abs_val = -val;
    return abs_val;
}
```

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 a header file).

With the `__noinline` keyword, you prevent a function from being inlined:

```
__noinline unsigned int abs(int val)
{
    unsigned int abs_val = val;
    if (val < 0) abs_val = -val;
    return abs_val;
}
```

Using pragmas: inline, noinline, smartinline

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

```
#pragma inline
unsigned int abs(int val)
{
    unsigned int abs_val = val;
    if (val < 0) abs_val = -val;
    return abs_val;
}
#pragma noinline
void main( void )
{
    int i;
    i = abs(-1);
}
```

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

With the `#pragma noinline` / `#pragma smartinline` you can temporarily disable the default situation that the C compiler automatically inlines small functions.

3.7.4 Intrinsic Functions

Some specific assembly instructions have no equivalence in C. *Intrinsic functions* are predefined functions that are recognized by the compiler. The compiler generates the most efficient assembly code for these functions. Intrinsic functions this way enable the use of these specific assembly instructions.

The compiler always inlines the corresponding assembly instructions in the assembly source (rather than calling it as a function). This avoids parameter passing and register saving instructions which are normally necessary during function calls.

Intrinsic functions produce very efficient assembly code. Though it is possible to inline assembly code by hand, intrinsic functions use registers even more efficiently. At the same time your C source remains very readable.

You can use intrinsic functions in C as if they were ordinary C (library) functions. All intrinsics begin with a double underscore character.

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

3.7.5 Interrupt Functions / Exception Handlers

The TASKING C compiler supports a number of function qualifiers and keywords to program exception handlers. An *exception handler* (or: interrupt function) is called when an exception occurs.

The ARM supports seven types of exceptions. The next table lists the types of exceptions and the processor mode that is used to process that exception. When an exception occurs, execution is forced from a fixed memory address corresponding to the type of exception. These fixed addresses are called the exception vectors.

Exception type	**Mode**	**Normal address**	**High vector address**	**Function type qualifier**
Reset	Supervisor	0x00000000	0xFFFF0000	
Undefined instructions	Undefined	0x00000004	0xFFFF0004	`__interrupt_und`
Software interrupt (SWI)	Supervisor	0x00000008	0xFFFF0008	`__interrupt_swi`
Prefetch abort	Abort	0x0000000C	0xFFFF000C	`__interrupt_iabt`
Data abort	Abort	0x00000010	0xFFFF0010	`__interrupt_dabt`
IRQ (interrupt)	IRQ	0x00000018	0xFFFF0018	`__interrupt_irq`
FIQ (fast interrupt)	FIQ	0x0000001C	0xFFFF001C	`__interrupt_fiq`

Table 3−7: Exception processing modes

3.7.5.1 Defining an Exception Handler: __interrupt keywords

You can define six types of exception handlers with the function type qualifiers `__interrupt_und`, `__interrupt_swi`, `__interrupt_iabt`, `__interrupt_dabt`, `__interrupt_irq` and `__interrupt_fiq`.

Interrupt functions and other exception handlers cannot return anything and must have a **void** argument type list:

```
void __interrupt_xxx
isr( void )
{
...
}
```

Example

```
void __interrupt_irq serial_receive( void )
{
  ...
}
```

Vector symbols

When you use one or more of these `__interrupt_xxx` function qualifiers, the compiler generates a corresponding vector symbol to designate the start of an execption handler function. The linker uses this symbol to automatically generate the exception vector.

Function type qualifier	Vector symbol
`__interrupt_und`	`_vector_1`
`__interrupt_swi`	`_vector_2`
`__interrupt_iabt`	`_vector_3`
`__interrupt_dabt`	`_vector_4`
`__interrupt_irq`	`_vector_6`
`__interrupt_fiq`	`_vector_7`

Note that the reset handler is designated by the symbol `_START` instead of `_vector_0`.

You can prevent the compiler from generating the `_vector_n` symbol by specifying the function qualifier `__novector`. This can be necessary if you have more than one interrupt handler for the same exception, for example for different IRQ's or for different run-time phases of your application. Without the `__novector` function qualifier the compiler generates the `_vector_n` symbol multiple times, which results in a link error.

```
void __interrupt_irq __novector another_handler( void )
{
  ... // used __novector to prevent multiple _vector_6 symbols
}
```

3.7.5.2 Interrupt Frame: __frame()

With the function type qualifier `__frame()` can specify which registers and SFRs must be saved for a particular interrupt function. Only the specified registers will be pushed and popped from the stack. If you do not specify the function qualifier `__frame()`, the C compiler determines which registers must be pushed and popped. The syntax is:

```
void __interrupt_xxx
     __frame(reg[, reg]...) isr( void )
{
...
}
```

where, *reg* can be any register defined as an SFR. The compiler generates a warning if some registers are missing which are normally required to be pushed and popped in an interrupt function prolog and epilog to avoid run–time problems.

Example

```
__interrupt_irq __frame(R4,R5,R6) void alarm( void )
{
...
}
```

3.8 Libraries

The TASKING compilers come with standard C libraries (ISO/IEC 9899:1999) and header files with the appropriate prototypes for the library functions. All 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 (too much code). These operations are implemented as *run–time* library functions to save code.

Libraries are stored in the directory:

```
\Program Files\Tasking\carm\lib\v4T\le
\Program Files\Tasking\carm\lib\v4T\be
\Program Files\Tasking\carm\lib\v5T\le
\Program Files\Tasking\carm\lib\v5T\be
```

Depending on your target settings in **Project » Project Options...** the appropriate libraries are selected.

3.8.1 Overview of Libraries

An overview of the available libraries is given in Table 3–8:

Libraries	Description
carm.lib cthumb.lib	C library, for ARM and Thumb instructions repectively (some functions also need the floating–point library)
carms.lib cthumbs.lib	Single precision C library (some functions also need the floating–point library)
fparm.lib fpthumb.lib	Floating–point library (non trapping)
fparmt.lib fpthumbt.lib	Floating–point library (trapping)
rtarm.lib	Run–time library

Table 3–8: Overview of libraries

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

3.8.2 Printf and Scanf 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.

See also the description of `#pragma weak` in section 1.6, *Pragmas*, in Chapter *C Language* of the reference manual.

4 Assembly Language

Summary

This chapter describes the most important aspects of the TASKING assembly language. For a complete overview of the architecture you are using, refer to the target's *Core Reference Manual*.

4.1 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 4.3, *Operands of an Assembly Instruction*. The instructions are described in the target's *Core Reference Manual*.

	The instruction can also be a so–called 'generic instruction'. Generic instructions are pseudo instructions (no instructions from the instruction set). Depending on the situation in which a generic instruction is used, the assembler replaces the generic instruction with appropriate real assembly instruction(s). For a complete list, see section 3.3, *Generic Instructions* in the reference manual.
directive	With directives you can control the assembler from within the assembly source. Except for preprocessing directives, these must not start in the first column. Directives are described in section 4.8, *Assembler Directives*.
macro_call	A call to a previously defined macro. It must not start in the first column. See section 4.9 *Macro Operations*.
comment	Comment, preceded by a ; (semicolon).

You can use empty lines or lines with only comments.

4.2 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
[ ]	Substring delimiter

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

4.3 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 4.4, *Symbol Names*. Symbols can also occur in expressions.
register	Any valid register as listed in section 4.5, *Registers*.
expression	Any valid expression as described in section 4.6, *Assembly Expressions*.
address	A combination of *expression*, *register* and *symbol*.

4.4 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

Symbol names and other identifiers beginning with a period (.) are reserved for the system (for example for directives or section names). Instructions are also reserved. The case of these built–in symbols is insignificant.

Examples

Valid symbol names:

```
loop_1
ENTRY
a_B_c
_aBC
```

Invalid symbol names:

`1_loop`	(starts with a number)
`.DEFINE`	(reserved directive name)

4.5 Registers

The following register names, either upper or lower case, should not be used for user–defined symbol names in an assembly language source file:

ARM registers

```
R0 .. R15
IP (alias for R12)   SP (alias for R13)
LR (alias for R14)   PC (alias for R15)
```

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 may contain user–defined labels (and their associated integer values), and any combination of integers 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 evaluated by the linker.

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

The syntax of 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, by default the assembler assumes the number is a decimal number.

Base	Description	Example

Binary	A **0b** prefix followed by binary digits (0,1). Or use a **b** suffix	`0b1101`
		`11001010b`

Hexadecimal	A **0x** prefix followed by a hexadecimal digits (0–9, A–F, a–f). Or use a **h** suffix	`0x12FF`
		`0x45`
		`0fa10h`

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

Table 4–1: Numeric constants

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 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 is used in a `.DB`, `.DH`, `.DW` or `.DD` assembler directive; in that case all characters result in a constant value of the specified size. 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

['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. Parenthetical expressions have the highest priority (innermost first).

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

Type	Operator	Name	Description
	( )	parenthesis	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	Returns: an integer 1 if the indicated condition is TRUE. an integer 0 if the indicated condition is FALSE.
	<=	less or equal	
	>	greater than	
	>=	greater or equal	
	==	equal	
	!=	not equal	
Bitwise	&	AND	Integer only: yields bitwise AND
	|	OR	Integer only: yields bitwise OR
	^	exclusive OR	Integer only: yields bitwise exlusive OR

Type	Operator	Name	Description
Logical	&&	logical AND	Returns an integer 1 if both operands are non−zero; otherwise, it returns an integer 0.
	||	logical OR	Returns an integer 1 if either of the operands is non−zero; otherwise, it returns an integer 1

Table 4−2: Assembly expression operators

4.7 Built−in Assembly Functions

The TASKING assemblers have several built−in functions to support data conversion, string comparison, and math computations. You can use functions as terms in any expression.

Syntax of an assembly function

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

Functions start with '@' 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.

Overview of assembly functions

The following table provides an overview of all built−in assembly functions. For a detailed description of these functions, refer to section 3.1, *Built−in Assembly Functions* in Chapter *Assembly Language* of the reference manual.

Function	Description
`@ALUPCREL(`*`expr`*`,`*`group`*`[,`*`check`*`])`	PC−relative ADD/SUB with operand split
`@ARG('`*`symbol`*`'`|*`expr`*`)`	Test whether macro argument is present
`@BIGENDIAN()`	Test if assembler generates code for big−endian mode
`@CNT()`	Return number of macro arguments
`@CPU(`*`string`*`)`	Test if current CPU matches *string*
`@DEFINED('`*`symbol`*`'`|*`symbol`*`)`	Test whether *symbol* exists
`@LSB(`*`expr`*`)`	Least significant byte of the expression
`@LSH(`*`expr`*`)`	Least significant half word of the absolute expression
`@LSW(`*`expr`*`)`	Least significant word of the expression
`@MSB(`*`expr`*`)`	Most significant byte of the expression
`@MSH(`*`expr`*`)`	Most significant half word of the absolute expression
`@MSW(`*`expr`*`)`	Most significant word of the expression
`@STRCAT(`*`str1`*`,`*`str2`*`)`	Concatenate *str1* and *str2*
`@STRCMP(`*`str1`*`,`*`str2`*`)`	Compare *str1* with *str2*

Function	Description
`@STRLEN(`*`str`*`)`	Return length of string
`@STRPOS(`*`str1`*`,`*`str2`*`[,`*`start`*`])`	Return position of *str1* in *str2*
`@THUMB()`	Test if assembler runs in Thumb mode or in ARM mode

4.8 Assembler Directives

An assembler directive is simply a message to the assembler. Assembler directives are not translated into machine instructions, but can produce data. There are three types 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
  - HLL 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. Unlike other directives, preprocesssor directives can start in the first column.
- 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. A typical example is to tell the assembler with an option to generate a list file while with the directives `.NOLIST` and `.LIST` you overrule this option for a part of the code that you do *not* want to appear in the list file. Directives of this kind sometimes are called *controls*.

Each assembler directive has its own syntax. Some assembler directives can be preceded with a label. If you do not precede an assembler directive with a label, you must use white space instead (spaces or tabs). You can use assembler directives in the assembly code as pseudo instructions.

The following tables provide an overview of all assembler directives. For a detailed description of these directives, refer to section 3.2, *Assembler Directives* in Chapter *Assembly Language* of the reference manual.

Overview of assembly control directives

Directive	Description
`.END`	Indicates the end of an assembly module
`.INCLUDE`	Include file
`.MESSAGE`	Programmer generated message

Overview of symbol definition directives

Directive	Description
`.EQU`	Set permanent value to a symbol
`.EXTERN`	Import global section symbol
`.GLOBAL`	Declare global section symbol
`.SECTION/.ENDSEC`	Start a new section
`.SET`	Set temporary value to a symbol
`.SIZE`	Set size of symbol in the ELF symbol table
`.SOURCE`	Specify name of original C source file
`.TYPE`	Set symbol type in the ELF symbol table
`.WEAK`	Mark a symbol as 'weak'

Overview of data definition / storage allocation directives

Directive	Description
`.ALIGN`	Align location counter
`.BS/.BSB/.BSH/` `.BSW/.BSD`	Define block storage (initialized)
`.DB`	Define byte
`.DH`	Define half word
`.DW`	Define word
`.DD`	Define double–word
`.DS/.DSB/.DSH/` `.DSW/.DSD`	Define storage
`.OFFSET`	Move location counter forwards

Overview of macro and conditional assembly directives

Directive	Description
`.DEFINE`	Define substitution string
`.BREAK`	Break out of current macro expansion
`.REPEAT/.ENDREP`	Repeat sequence of source lines
`.FOR/.ENDFOR`	Repeat sequence of source lines *n* times
`.IF/.ELIF/.ELSE`	Conditional assembly directive
`.ENDIF`	End of conditional assembly directive
`.MACRO/.ENDM`	Define macro
`.UNDEF`	Undefine `.DEFINE` symbol or macro

Overview of listing control assembly directives

Directive	Description
`.LIST/.NOLIST`	Print / do not print source lines to list file
`.PAGE`	Set top of page/size of page
`.TITLE`	Set program title in header of assembly list file

Overview of HLL directives

Directive	Description
`.CALLS`	Pass call tree information

ARM specific directives

Directive	Description
`.CODE16/.CODE32`	Treat instructions as Thumb or ARM instructions, respectively
`.LTORG`	Assembly current literal pool immediately

4.9 Macro Operations

Macros provide a shorthand method for inserting a repeated pattern of code or group of instructions. You 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 on 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.

4.9.1 Defining a Macro

The first step in using a macro is to define it.

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

A macro definition takes the following form:

macro_name **.MACRO** [*arg*[,*arg*]...]   [; *comment*]

   .
   source statements
   .
   .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

Consider the following macro definition:

```
RESERV  .MACRO  val   ; reserve space
        .DS val
        .ENDM
```

After the following macro call:

```
.section .text
RESERV 8
```

The macro expands to:

```
.DS 8
```

4.9.2 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.

4.9.3 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	Prevents name mangling on labels in macros.

***Example: Argument Concatenation Operator* – \**

Consider the following macro definition:

```
MAC_A .MACRO reg,val
   sub   r\reg,r\reg,#val
   .ENDM
```

The macro is called as follows:

```
   MAC_A 2,1
```

The macro expands as follows:

```
   sub r2,r2,#1
```

The macro preprocessor substitutes the character ’2’ for the argument `reg`, and the character ’1’ for the argument `val`. The concatenation operator (\) indicates to the macro preprocessor that the substitution characters for the arguments are to be concatenated with the characters ’r’.

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

```
   sub rreg,rreg,#1
```

which results in an assembler error (invalid operand).

Example: 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 `MAC_A` after the argument `AVAL` has been set to 1.

```
AVAL .SET  1
     MAC_A 2,AVAL
```

If you want to replace the argument `val` with the value of `AVAL` rather than with the literal string `'AVAL'`, you can use the **?** operator and modify the macro as follows:

```
MAC_A .MACRO reg,val
   sub   r\reg,r\reg,?val
   .ENDM
```

Example: 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
```

The macro is called after `NUM` has been set to 10:

```
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`.

Example: 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 `.DEFINE` expansion occurs before macro substitution, any `.DEFINE` symbols are replaced first within a macro argument string:

```
    .DEFINE LONG  'short'
STR_MAC    .MACRO  STRING
    .MESSAGE I 'This is a LONG STRING'
    .MESSAGE I "This is a LONG STRING"
    .ENDM
```

If the macro is called as follows:

```
    STR_MAC  sentence
```

it expands as:

```
   .MESSAGE I 'This is a LONG STRING'
   .MESSAGE I 'This is a short sentence'
```

Macro Local Label Override Operator – ^

If you use labels in macros, the assembler normally generates another unique name for the labels (such as `LOCAL__M_L000001`).

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

Consider the following macro definition:

```
INIT  .MACRO  addr
LOCAL:  ldr   r0,^addr
      .ENDM
```

The macro is called as follows:

```
LOCAL:
       INIT LOCAL
```

The macro expands as:

```
LOCAL__M_L000001: ldr   r0,LOCAL
```

If you would not have used the ^ operator, the macro preprocessor would choose another name for `LOCAL` because the label already exists. The macro would expand like:

```
LOCAL__M_L000001: ldr   r0,LOCAL__M_L000001
```

4.9.4 Using the .FOR and .REPEAT Directives as Macros

The `.FOR` and `.REPEAT` 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 `.FOR` and `.ENDFOR` directives and `.REPEAT` and `.ENDREP` directives follow the same rules as macro definitions.

For a detailed description of these directives, see section 3.2, *Assembler Directives* in Chapter *Assembly Language* of the reference manual.

4.9.5 Conditional Assembly

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 range of allowable values. In this way macros become self–checking and can generate error messages to any desired level of detail.

The conditional assembly directive `.IF/.ENDIF` has the following form:

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

A section of a program that is to be conditionally assembled must be bounded by an `.IF–.ENDIF` directive pair. If the optional `.ELSE` and/or `.ELIF` directives are not present, then the source statements following the `.IF` directive and up to the next `.ENDIF` directive will be included as part of the source file being assembled only if the *expression* had a non–zero result.

If the *expression* has a value of zero, the source file will be assembled as if those statements between the `.IF` and the `.ENDIF` directives were never encountered.

If the `.ELSE` directive is present and *expression* has a nonzero result, then the statements between the `.IF` and `.ELSE` directives will be assembled, and the statement between the `.ELSE` and `.ENDIF` directives will be skipped. Alternatively, if *expression* has a value of zero, then the statements between the `.IF` and `.ELSE` directives will be skipped, and the statements between the `.ELSE` and `.ENDIF` directives will be assembled.

5 Using the Compiler

Summary

This chapter describes the compilation process and explains how to call the compiler.

5.1 Introduction

EDE uses a *makefile* to build your entire embedded project, from C source till the final ELF/DWARF 2 object file which serves as input for the debugger.

Although in EDE you cannot run the compiler separately from the other tools, this section 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 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:

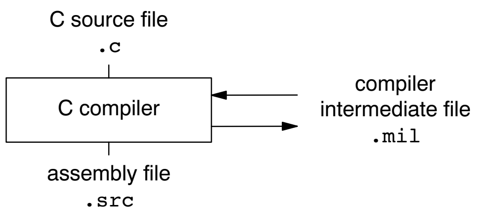


Figure 5–1: C compiler

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 reference manual. Finally, a few important basic tasks are described.

5.2 Compilation Process

During the compilation of a C program, the compiler ***ctarget*** 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.

The compiler requires only one pass over the input file which results in relative fast compilation.

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 a processor instruction, with an opcode, operands and information used within the compiler.

2. Peephole optimizer/instruction scheduler/software pipelining 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 assebmly language output.

5.3 Compiler Optimizations

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

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

   The Project Options dialog 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.

- **No optimization**: 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.
- **Debug purposes optimization**: Enables optimizations that do not affect the debug−ability of the source code. Use this level when you are developing/debugging new source code.
- **Release purposes optimization**: 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.
- **Aggressive optimization**: 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 optimization**: 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 compiler option **–O** (**––optimize**) in section 5.1, *Compiler Options*, of Chapter *Tool Options* of the reference manual.

5.3.1 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 value is replaced by that value.

Function Inlining *(option –Oi/–OI)*

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

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 the 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 pointers 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.

5.3.2 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.

Instruction Scheduler *(option –Ok/–OK)*

Instructions are rearranged to avoid structural hazards, for example by inserting another non-related instruction.

Loop unrolling *(option –Ou/–OU)*

To reduce the number of branches, short loops are eliminated by replacing them with a number of copies.

Software pipelining *(option –Ow/–OW)*

A number of techniques to optimize loops. For example, within a loop the most efficient order of instructions is chosen by the *pipeline scheduler* and it is examined what instructions can be executed parallel.

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

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

5.3.3 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 focusses 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 appears.

2. Expand the **C Compiler** entry and select **Optimization**.
3. Enable one of the options **Optimize for size** or **Optimize for speed**.

See also compiler option **–t** (**––tradeoff**) in section 5.1, *Compiler Options*, of 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 separately. If you compile a single C source file from within EDE, the file is also assembled. However, you can set options specific for the compiler. After you have built your project, the output files of the compilation step are available in your project directory, unless you specified an alternative output directory in the **Build Options** dialog (**Build » Options**).

To compile and assemble 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 only updates files that are out-of-date or have been changed since the last build, which saves time.

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

To check your program for syntax errors

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 (architecture)

If you have a toolchain that supports several processor architectures, you need to choose a processor type first.

To access the processor options:

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

   The Project Options dialog box appears.

2. Select **Processor Definition**.

3. In the **Target processor** list select a target processor. If you select **(Other)**, select an **Architecture**.

Processor options affect the invocation of all tools in the toolchain. In EDE you only need to set them once.

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.

3. Select the sub–entries and set the options in the various pages.

   The command line variant is shown simultaneously.

Assembler options do not apply to compiler generated assembly. If you want to add assembler options for compiler generated assembly, you can add them to the **Additional assembler options** field in the **C Compiler** » **Miscellaneous** page.

Invocation syntax on the command line (Windows Command Prompt)

The invocation syntax on the command line is:

```
carm [ [option]... [file]... ]...
```

The input *file* must be a C source file (`.c`).

Example:

```
carm test.c
```

This compiles the file `test.c` and generates the file `test.src` which serves as input for the assembler.

5.4.1 Overview of C Compiler Options

You can set the following C compiler options in EDE.

Menu entry	Command line
Processor Definition	
Target processor Architecture	**–C[ARMv4** | **ARMv4T**| **ARMv5** | **ARMv5T** | **ARMv5TE** | **XS**]
C Compiler » **Code Generation**	
Use Thumb instruction set	**––thumb**
Compile for ARM/Thumb interworking	**––interwork**
Alignment of composite types: natural or optimal	**––align–composites=**[**n**|**o**]
C Compiler » **Preprocessing**	
Include this file before source	**–H***file*
Define user macros	**–D***macro*[=*value*]
Store the C compiler preprocess output (*file*`.pre`)	**–E**
C Compiler » **Optimization**	
Optimization level	**–O**[**0**|**1**|**2**|**3**]
Size / speed trade–off (default: size)	**–t**{**0**|**4**}
Maximum code size increase caused by inlining	**––inline–max–incr**
Maximum size for functions to always inline	**––inline–max–size**

Menu entry	**Command line**
C Compiler » Language	
ISO C standard: C 90 or C 99 (default: 99)	**−c**{**90**|**99**}
Treat 'char' variables as unsigned	**−u**
Single precision floating−point only	**−F**
Treat 'int' bit−fields as signed	**−−signed−bitfields**
Language extensions:	**−A***flag*
Allow C++ style comments in C source Allow relaxed const check for string literals	**−Ap** **−Ax**
C Compiler » Debugging	
Generate symbolic debug information	**−g**
Run−time checks	**−r**[*flags*]
C Compiler » Profiling	
Profiling	**−p**[*flags*]
C Compiler » Floating−Point	
Use single precision floating−point only	**−F**
Floating−point trap/exception handling	*n.a*
C Compiler » Diagnostics	
Report all warnings Suppress all warnings Suppress specific warnings	*no option* **−w** **−w** **−w***num*[,*num*]...
Treat warnings as errors	**−−warnings−as−errors**
C Compiler » MISRA−C	
MISRA−C standard: 1998 or 2004	**−−misrac−version=***year*
MISRA−C rules	**−−misrac=**{**all**|*nr*[−*nr*] **,**...}
MISRA−C configuration file	*n.a*
Generate warnings instead of errors for required rules	**−−misrac−required−warnings**
Generate warnings instead of errors for advisory rules	**−−misrac−advisory−warnings**
Produce MISRA−C report	*n.a*
C Compiler » Miscellaneous	
Merge C source code with assembly in output file (`.src`)	**−s**
Additional C compiler options	*options*
Additional assembler options	*options*

Table 5−1: C compiler options in EDE

The following C compiler options are only available on the command line:

Description	**Command line**
Display invocation syntax	**––help**[=*item*,...]
Generate information for call graph	**––call–info**
Check source (check syntax without generating code)	**––check**
Show description of diagnostic(s)	**––diag=**[*fmt*:]{**all**|*nr*,...}
Redirect diagnostic messages to a file	**––error–file**[=*file*]
Read options from *file*	**–f** *file*
Always inline function calls	**––inline**
Keep output file after errors	**–k**
Send output to standard output	**–n**
Specify name of output file	**–o** *file*
Rename default section name	**–R**[*name*]={*suffix* | **–f** | **–m** | **–fm**}
Treat external definitions as ”static”	**––static**
Remove preprocessor *macro*	**–U***macro*
Display version header only	**–V**

Table 5–2: Additional C compiler options

For a complete overview of all options with extensive description, see section 5.1, *Compiler Options*, of Chapter *Tool Options* of the reference manual.

5.5 How the Compiler Searches Include Files

When you use include files (with the `#include` statement), you can specify their location in several ways. The compiler searches the specified locations in the following order:

1. If the `#include` statement contains an absolute pathname, the compiler looks for this file. If no path or a relative path is specified, the compiler looks in 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. When the compiler did not find the include file, it looks in the directories that are specified in the **Project » Directories** dialog (equivalent to the **–I** command line option).
3. When the compiler did not find the include file (because it is not in the specified include directory or because no directory is specified), it looks in the path(s) specified in the environment variable `CARMINC`.

See section 1.2.1, Configuring the Embedded Development Environment and environment variable `CARMINC` in section 1.2.2, Configuring the Command Line Environment, in Chapter *Software Installation and Configuration*.

4. When the compiler still did not find the include file, it finally tries the default `include` directory relative to the installation directory.

Example

Suppose that the C source file `test.c` contains the following lines:

```
#include <stdio.h>
#include "myinc.h"
```

You can call the compiler as follows:

```
carm -Imyinclude test.c
```

First the compiler looks for the file `stdio.h` in the directory `myinclude` relative to the current directory. If it was not found, the compiler searches in the environment variable and then in the default `include` directory.

The compiler now looks for the file `myinc.h`, in the directory where `test.c` is located. If the file is not there the compiler searches in the directory `myinclude`. If it was still not found, the compiler searches in the environment variable and then in the default `include` 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 **Debugging**.

3. Enable the option **Generate symbolic debug information**.

Debugging 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 purposes** optimizations (**–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 purposes**.

Invocation syntax on the command line (Windows Command Prompt)

The invocation syntax on the command line is:

```
carm -g -O1 file...
```

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 in *MISRA-C:2004, Guidelines for the Use of the C Language in Critical Systems* (Motor Industry Research Association (MIRA), 2004).

The compiler also supports MISRA-C:1998, the first version of MISRA-C. 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 9, *MISRA-C Rules*, in the reference manual.

Implementation issues

The MISRA-C implementation in the compiler supports nearly all rules. Only a 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 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.

To 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 have a project team work with a MISRA–C configuration common to the whole project. In this case the MISRA–C configuration can be read from an external settings file.

4. (Optional) In the **MISRA–C Rules** entry, specify the individual rules.

On the command line you can use the **––misrac** option.

```
carm --misrac={all | number [-number],...]
```

See compiler option **––misrac** in section 5.1, *Compiler Options* in Chapter *Tool Options* of the reference manual.
See linker option **––misra–c–report** in section 5.3, *Linker Options* in Chapter *Tool Options* of the reference manual.

5.8 C Compiler Error Messages

The C 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.

Report problems to Technical Support

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 form. State the error number and attach relevant files.

3. Click the **Copy to Email client** button to open your e−mail 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. From 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.

On the command line you can use the compiler option **−−diag** to see an explanation of a diagnostic message:

```
carm --diag=[format:]{all | number,...]
```

See compiler option **−−diag** in section 5.1, *Compiler Options* in Chapter *Tool Options* of the reference manual.

6 Profiling

Summary

Profiling is the process of collecting statistical data about a running application. With these data you can analyze which functions are called, how often they are called and what their execution time is. This chapter describes the TASKING profiling method with code instrumentation techniques.

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.

<u>Advantages</u>

– it gives (cycle) accurate information with extreme fine granularity
– the executed code is identical to the non–profiled code

<u>Disadvantages</u>

– 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.

<u>Advantages</u>

– the executed code is identical to the non–profiled code

<u>Disadvantage</u>

– 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 applications 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.

<u>Advantages</u>

– 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

<u>Disadvantage</u>

– 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 pieces 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 lead to 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.

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 profile data
3. Display the profile

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:

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

   The Project Options dialog box appears.

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

3. Enable one or more of the following options to select which profiles should be obtained.

   - **Block counters** (not in combination with with ***Call graph*** or ***Function timers***)
   - **Call graph**
   - **Function counters**
   - **Function timers**

Note that the more detailed information you request, the larger the overhead in terms of execution time, code size and heap space needed. The option **Generate Debug information** (**−g** or **−−debug**) does not affect profiling, execution time or code size.

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 only 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 associates the caller with 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. By 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.

For the command line, see the compiler option **−p (−−profile)** in section 5.1, *Compiler Options* in Chapter *Tool Options* of the reference manual.

Rebuild your application:

4. From the **Build** menu select **Rebuild**.

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 will link your program with the standard version of the C library `carm.lib`. 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 the corresponding profile library. EDE (or the control program) 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 will run somewhat slower that 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 in a 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 **Script File**

3. Select **Generated LSL file based on EDE settings**

4. Expand the **Script File** entry, and select **Defines**/**Stack**/**Heap**

5. Enter a new value in the **Heap size (bytes)**, field and/or enable the option **Expand heap if space left**.

After execution

When the program has finished (returning from `main()`), the exit code calls the function `__prof_cleanup(void)`. 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**, or click on the **Show profile** button.

   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 profiling data may be present and some may be not. 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.

7 Using the Assembler

Summary

This chapter describes the assembly process and explains how to call the assembler.

7.1 Introduction

The assembler converts hand–written or compiler–generated assembly language programs into machine language, resulting in object files in the ELF/DWARF object format.

The assembler takes the following files for input and output:

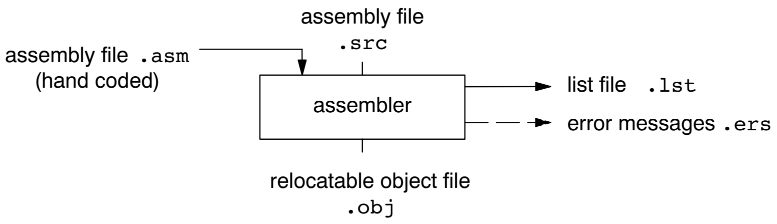


Figure 7–1: Assembler

The following information is described:

- The assembly process.
- The various assembler optimizations.
- 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.
- How to generate a list file
- Types of assmbler messages

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 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 4.9, *Macro Operations*, in Chapter *Assembly Language* for more information.

7.3 Assembler Optimizations

The assembler performs various optimizations to reduce the size of assembled applications. There are two options available to influence the degree of optimization.

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 5.2, *Assembler Options*, in Chapter *Tool Options* of the reference manual.

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 instructions by faster or smaller instructions.

By default this option is enabled. If you turn off this optimization, generic instructions are not allowed. In that case you have to use hardware instructions.

Optimize jump chains *(option* ***–Oj***/***–OJ****)*

When this option is enabled, the assembler replaces chained jumps by a single jump instruction. For example, a jump from *a* to *b* immediately followed by a jump from *b* to *c*, is replaced by a jump from *a* to *c*. By default this option is disabled.

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 assembly step are available in your project directory, unless you specified an alternative output directory in the **Build Options** dialog (**Build** » **Options**).

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 only updates files that are out-of-date or have been changed since the last build, which saves time.

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

To check your program for syntax errors

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 (architecture)

If you have a toolchain that supports several processor architectures, you need to choose a processor type first.

To access the processor options:

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

   The Project Options dialog box appears.

2. Select **Processor Definition**.
3. In the **Target processor** list select a target processor. If you select **(Other)**, select an **Architecture**.

Processor options affect the invocation of all tools in the toolchain. In EDE you only need to set them once.

To access the assembler options

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

   The Project Options dialog box appears.

2. Expand the **Assembler** entry.

3. Select the sub–entries and set the options in the various pages.

   The command line variant is shown simultaneously.

The assembler options you enter here only apply to handwritten assembly. They do not apply to compiler generated assembly. If you want to add assembler options for compiler generated assembly, you can add them to the **Additional assembler options** field in the **C Compiler** » **Miscellaneous** page.

Invocation syntax on the command line (Windows Command Prompt)

The invocation syntax on the command line is:

```
asarm [ [option]... [file]... ]...
```

The input *file* must be an assembly source file (`.asm` or `.src`).

Example:

```
asarm test.asm
```

This assembles the file `test.asm` and generates the file `test.obj` which serves as input for the linker.

7.4.1 Overview of Assembler Options

You can set the following assembler options in EDE.

Menu entry	Command line
Processor Definition	
Target processor Architecture	**–C[ARMv4** | **ARMv4T**| **ARMv5** | **ARMv5T** | **ARMv5TE** | **XS]**
Assembler » Preprocessing	
Enable the assember preprocessor	**–m**{**t**|**n**}
Define user macros	**–D***macro*[=*value*]
Include this file before source	**–H***file*
Assembler » Optimization	
Generic instructions	**–Og**
Jump chains	**–Oj**
Instruction size	**–Os**

Menu entry	**Command line**
Assembler » Debug Information	
No debug information Automatic HLL or assembly level debug information	**−gAHLS** **−gs**
Custom debug information Assembler source line information Pass HLL debug information	**−g***flags* **−ga** **−gh**
Assembler local symbols information	**−gl**
Assembler » List File	
Generate list file	**−l**
Display section information	**−tl**
List file format	**−L***flags*
Assembler » Diagnostics	
Report all warnings Suppress all warnings Suppress specific warnings	*no option* ***−w*** **−w** **−w***num*[,*num*]...
Treat warnings as errors	**−−warnings−as−errors**
Assembler » Miscellaneous	
Assemble Thumb instructions by default	**−T**
Assemble case sensitive (required for C language)	**−c** (case *insensitive*)
Allow 2−operand form for 3−operand instructions	**−−relaxed**
Emit local symbols	**−−emit−locals**
Labels are by default: local (default) global	 **−il** **−ig**
Additional assembler options	*options*

Table 7−1: EDE assembler options

The following assembler options are only available on the command line:

Description	**Command line**
Display invocation syntax	**––help**[=*item*,...]
Check source (check syntax without generating code)	**––check**
Show description of diagnostic(s)	**––diag=**[*fmt*:]{**all**|*nr*,...}
Preprocess only	**–E**
Redirect diagnostic messages to a file	**––error–file**[=*file*]
Set the maximum *number* of emitted errors	**––error–limit**=*number*
Read options from *file*	**–f** *file*
Keep output file after errors	**–k**
Specify name of output file	**–o** *file*
Verbose information	**–v**
Display version header only	**–V**

Table 7–2: Additional assembler options

For a complete overview of all options with extensive descriptions, see section 5.2, *Assembler Options*, of Chapter *Tool Options* of the reference manual.

7.5 How the Assembler Searches Include Files

When you use include files (with the `.INCLUDE` directive), you can specify their location in several ways. The assembler searches the specified locations in the following order:

1. If the `.INCLUDE` directive contains a path name, the assembler looks for this file. If no path is specified, the assembler looks in the same directory as the source file.

2. When the assembler did not find the include file, it looks in the directories that are specified in the **Project » Directories** dialog (equivalent to the **–I** command line option).

3. When the assembler did not find the include file (because it is not in the specified include directory or because no directory is specified), it looks in the path(s) specified in the environment variable `ASARMINC`.

See section 1.2.1, Configuring the Embedded Development Environment and environment variable `ASARMINC` in section 1.2.2, Configuring the Command Line Environment, in Chapter *Software Installation and Configuration*.

4. When the assembler still did not find the include file, it finally tries the default `include` directory relative to the installation directory.

Example

Suppose that the assembly source file `test.asm` contains the following lines:

```
.INCLUDE 'myinc.inc'
```

You can call the assembler as follows:

```
asarm -Imyinclude test.asm
```

First the assembler looks for the file `myinc.inc` in the directory where `test.asm` is located. If the file is not there the assembler searches in the directory `myinclude`. If it was still not found, the assembler searches in the environment variable and then in the default `include` directory.

7.6 Generating a List File

The list file is an additional output file that contains information about the generated code. You can 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 box appears.

2. Expand the **Assembler** entry and select **List File**.
3. Select **Generate list file**.
4. (Optional) Enable the options to include that information in the list file.

Example on the command line (Windows Command Prompt)

The following command generates the list file `test.lst`:

```
asarm -l test.asm
```

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 assembly 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. From 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.

On the command line you can use the assembler option **--diag** to see an explanation of a diagnostic message:

```
asarm --diag=[format:]{all | number,...]
```

See assembler option **--diag** in section 5.2, *Assembler Options* in Chapter *Tool Options* of the reference manual.

8 Using the Linker

Summary

This chapter describes the linking process, how to call the linker and how to control the linker with a script file.

8.1 Introduction

The TASKING linker 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* (`.out`). 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 can simultaneously link and locate all programs for all cores available on a target board. The target board may be of arbitrary complexity. A simple target board may contain one standard processor with some external memory that executes one task. A complex target board may contain multiple standard processors and DSPs combined with configurable IP–cores loaded in an FPGA. Each core may execute a different program, and external memory may be shared by multiple cores.

The linker takes the following files for input and output:

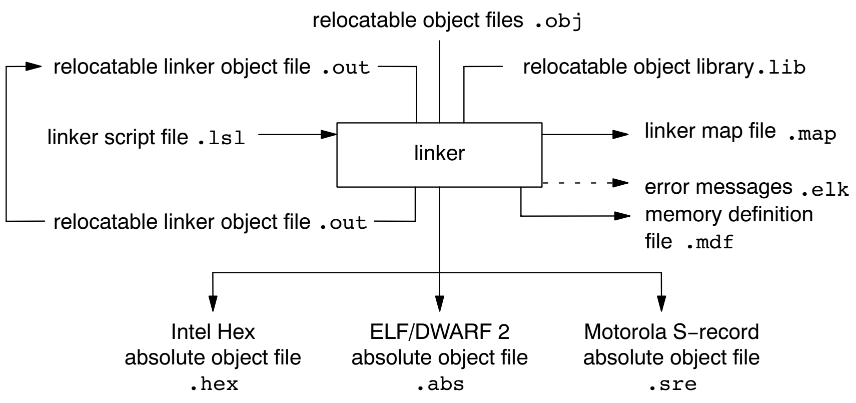

relocatable object files .obj
relocatable linker object file .out
relocatable object library .lib
linker script file .lsl
linker
linker map file .map
error messages .elk
memory definition file .mdf
relocatable linker object file .out
Intel Hex absolute object file .hex
ELF/DWARF 2 absolute object file .abs
Motorola S–record absolute object file .sre

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 5.3, *Linker Options*, of the reference manual.

To control 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 8, *Linker Script Language*, of the reference manual.

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 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 an 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).
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 between an address and the next address. This is not necessarily a byte or a word.

Term	Definition
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 and 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 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 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.

Next, the linker combines sections with the same section name and attributes into single sections. 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 (`.out`). If this file contains unresolved references, you can link this file with other relocatable object files (`.obj`) or libraries (`.lib`) 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/DWARF 2 format (`.abs`) 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 (`.sre`) 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 is called the *Linker Script Language* (LSL). Using LSL you can define:

- The memory 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 TASKING 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 8.7, *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 5.3, *Linker Options*, in Chapter *Tool Options* of the reference manual.

Delete unreferenced sections (option **–Oc**/**–OC**)

This optimization removes unused sections from the resulting object file. Because debug information normally refers to all sections, the optimization has no effect until you compile your project without debug information or use linker option **––strip–debug** to remove the debug information.

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 (that is, working from low to high memory addresses or vice versa). 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.

Delete duplicate code (option **–Ox**/**–OX**)
Delete duplicate constant data (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

In EDE you can set options specific for the linker. EDE creates and uses a *makefile* to build your entire project. 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 (**Build » Options**).

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 last build, which saves time.

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

To access the linker options

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

   The Project Options dialog box appears.

2. Expand the **Linker** entry.

3. Select the sub−entries and set the options in the various pages.

   The command line variant is shown simultaneously.

Invocation syntax on the command line (Windows Command Prompt)

The invocation syntax on the command line is:

```
lkarm [ [option]... [file]... ]...
```

When you are linking multiple files, either relocatable object files (`.obj`) or libraries (`.lib`), it is important to specify the files in the right order. This is explained in Section 8.4, *Linking with Libraries*.

Example:

```
lkarm −darm.lsl test.obj
```

This links and locates the file `test.obj` and generates the file `test.abs`.

8.3.1 Overview of Linker Options

You can set the following linker options in EDE.

Menu entry	**Command line**
Linker » Output Format	
ELF/DWARF for debuggers and loaders (.abs) Library for TASKING ARM linker (.lib)	**–o**[*file*][**:***format*[**:***addr_size*]]...
Intel Hex records for EPROM programmers (.hex) Motorola S–records for EPROM programmers (.sre)	**–c**[*basename*]**:IHEX**[**:***addr_size*]**,**... **–c**[*basename*]**:SREC**[**:***addr_size*]**,**...
Linker » Libraries	
Link default C libraries	**–l***x*
Rescan libraries to solve unresolved externals	**––no–rescan** (disables rescan)
Libraries	**–l***x*
Linker » Script File	
Select LSL file with memory and section description	**–d***file*
Dump processor and memory info from LSL file	**––lsl–dump**[=*file*]
Linker » Optimization	
Delete unreferenced sections Use 'first fit decreasing' algorithm Copy table compression Delete duplicate code Delete duplicate constant data	**–Oc**/**–OC** (= on/off) **–Ol**/**–OL** **–Ot**/**–OT** **–Ox**/**–OX** **–Oy**/**–OY**
Linker » Map File	
Generate a map file (`.map`)	**–M**
Map file format	**–m***flags*
Linker » Diagnostics	
Report all warnings Suppress all warnings Suppress specific warnings	*no option* **–w** **–w** **–w***num*[,*num*]...
Treat warnings as errors	**––warnings–as–errors**
Linker » Miscellaneous	
Include symbolic debug information	**–S** (strips debug information)
Print the name of each file as it is processed	**–v** / **–vv**
Link case sensitive (required for C language)	**––case–insensitive**
Use standard copy table for initialization	*no option* **–i**
Generate long–branch veneers	**––long–branch–veneers**
Additional linker options	*options*

Table 8–2: EDE Linker options

The following linker options are only available on the command line:

Description	**Command line**
Display invocation syntax	**−−help**[=*item*,...]
Define preprocessor *macro*	**−D***macro*[=*def*]
Show description of diagnostic(s)	**−−diag**=[*fmt*:]{**all**|*nr*,...}
Specify a symbol as unresolved external	**−e***symbol*
Redirect diagnostic messages to a file with extension `.elk`	**−−error−file**[=*file*]
Read options from *file*	**−f** *file*
Scan libraries in given order	**−−first−library−first**
Add *dir* to LSL include file search path	**−I***dir*
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**
Do not generate ROM copy	**−N**
Locate all ROM sections in RAM	**−−non−romable**
Link incrementally	**−r**
Display version header only	**−V**

Table 8−3: Additional Linker options

For a complete overview of all options with extensive description, see section 5.3, *Linker Options*, of the reference manual.

8.4 Linking with Libraries

There are two kinds of libraries: system libraries and user libraries.

System library

System libraries are stored in the directory:

```
\Program Files\Tasking\carm\lib\v4T\le
\Program Files\Tasking\carm\lib\v4T\be
\Program Files\Tasking\carm\lib\v5T\le
\Program Files\Tasking\carm\lib\v5T\be
```

An overview of the system libraries is given in the following table:

Libraries	Description
carm.lib cthumb.lib	C library, for ARM and Thumb instructions repectively (some functions also need the floating–point library)
carms.lib cthumbs.lib	Single precision C library (some functions also need the floating–point library)
fparm.lib fpthumb.lib	Floating–point library (non trapping)
fparmt.lib fpthumbt.lib	Floating–point library (trapping)
rtarm.lib	Run–time library

Table 8–4: Overview of libraries

For more information on these libraries see section 3.8, *Libraries*, in Chapter *C Language*.

To link the default C (system) 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. Expand the **C Compiler** entry and select **Floating–Point**.
5. Enable or disable **Floating–point trap/exception handling**.
6. Click **OK** to accept the linker options.

When you want to link system libraries from the command line, you must specify this with the option **–l**. For example, to specify the system library `carm.lib`, type:

```
lkarm –lcarm test.obj
```

User library

You can create your own libraries. Section 9.4, *Librarian*, in Chapter *Using the Utilities*, describes how you can use the librarian to create your own library with object modules.

To link user libraries

To specify your own libraries you have to add the library files to your project:

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

   The Project Poperties 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.

When you want to link user libraries from the command line, you must specify their filenames on the command line:

```
lkarm start.obj mylib.lib
```

If the library resides in a sub–directory, specify that directory with the library name:

```
lkarm start.obj mylibs\mylib.lib
```

If you do not specify a directory, the linker searches the library in the current directory only.

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 at 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:

```
lkarm --first-library-first a.lib test.obj b.lib
```

If the file `test.obj` calls a function which is both present in `a.lib` and `b.lib`, normally the function in `b.lib` would be extracted. With this option the linker first tries to extract the symbol from the first library `a.lib`.

Note that routines in `b.lib` that call other routines that are present in both `a.lib` and `b.lib` are now also resolved from `a.lib`.

8.4.1 How the Linker Searches Libraries

System libraries

You can specify the location of system libraries 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 **Project » Directories** dialog (equivalent to the **-L** command line 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 in the path(s) specified in the environment variable `LIBARM`.
3. When the linker did not find the library, it tries the default `lib` directory relative to the installation directory (or a processor specific sub-directory).

User library

If you use your own library, the linker searches the library in the current directory only.

8.4.2 How the Linker Extracts Objects from Libraries

A library built with the TASKING librarian **ararm** 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 on the command line and the order of the object files in the libraries. 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 symbols to which you refer, are extracted from the library. This implies that if you invoke the linker like:

```
lkarm mylib.lib
```

nothing is linked and no output file will be produced, because there are no unresolved symbols when the linker searches through `mylib.lib`.

It is possible to force a symbol as external (unresolved symbol) with the option **-e**:

```
lkarm -e main mylib.lib
```

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.lib`. This process repeats until no new unresolved symbols are found.

8.5 Incremental Linking

With the TASKING linker it is possible to link *incrementally*. Incremental linking means that you link some, but not all `.obj` modules to a relocatable object file `.out`. In this case the linker does not perform the locating phase. With the second invocation, you specify both new `.obj` files as the `.out` file you had created with the first invocation.

Incremental linking is only possible on the command line.

```
lkarm -darm.lsl -r test1.obj -otest.out
lkarm -darm.lsl test2.obj test.out
```

This links the file `test1.obj` and generates the file `test.out`. This file is used again and linked together with `test2.obj` to create the file `test.abs` (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 `.out` or `.abs` file has been reached. The option **-r** for incremental linking also suppresses warnings and errors because of unresolved symbols.

8.6 Linking the C Startup Code

You need the run–time startup code to build an executable application. The default startup code consists of the following components:

- *Initialization code*. This code is executed when the program is initiated and before the function `main()` is called.
- *Exit code*. This controls the closedown of the application after the program's main function terminates.

The startup code is part of the C library, and the source is present in the file `cstart.asm` (for ARM) or `cstart_thumb.asm` (for Thumb) in the directory `lib\src`. If the default run–time startup code does not match your configuration, you need to modify the startup code accordingly.

To link the default startup code

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**.

To use your own startup code

1. Make a copy (backup) of the file `lib\src\cstart.asm`, for example *`project_cstart.asm`*, and place it in your project directory.

2. Right-click on your project name in EDE, select **Add Existing Files** » **Browse** and add the file *`project_cstart.asm`* to your project.

3. Modify the file *`project_cstart.asm`* to match your configuration.

   EDE adds the startup code to your project, before the libraries. So, the linker finds your startup code first.

8.7 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.

8.7.1 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 core 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 C preprocessor keywords, such as `#include` and `#define`, 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 8, *Linker Script Language*, in the reference manual.

8.7.2 EDE and LSL

In EDE you can specify the size of the stack and heap and the physical memory attached to the processor. 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. Select **Script File** and select **Generated File based on EDE settings**.
3. Expand **Script File** entry and select **Memory**.
4. Make your changes to the memory layout.

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.

Specify your own LSL file

If you want to write your own linker script file, you can make a copy of the file `arm.lsl` or the EDE generated file `project.lsl` and use it 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. Select **Script File** and select **User–defined LSL file**.
3. Enter the name of your own LSL file.

Note that EDE supports ChromaCoding (applying color coding to text) and template expansion when you edit LSL files.

8.7.3 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 vector table.

This specification is normally written by Altium. 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 linker uses the architecture name in the LSL file to identify the target. For example, the default library search path can be different for each core architecture.

The derivative definition

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. 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.

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 ARM architecture, its external memory and how sections are located in memory, may have the following skeleton:

```
architecture ARM
{
    // Specification of the ARM core architecture.
    // Written by Altium.
}

derivative X            // derivative name is arbitrary
{
    // Specification of the derivative.
    // Written by Altium.
    core ARM        // always specify the core
    {
       architecture = ARM;
    }

    bus local_bus        // local bus
    {
       // maps to local_bus in "ARM" 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:ARM:linear    // section layout
{
    // section placement statements

    // sections are located in address space 'linear'
    // of core 'ARM' of processor 'proc1'
}
```

8.7.4 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, separate spaces for code and data. Normally, the size of an address space is 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. All address spaces have a number that identifies the logical space (id). The following table lists the different address spaces.

Space	Id	MAU	Description
linear	1	8	Address space

Table 8–5: ARM address space

The ARM architecture in LSL notation

The best way to program the architecture definition, is to start with a drawing. The figure below shows a part of the `ARM` architecture:

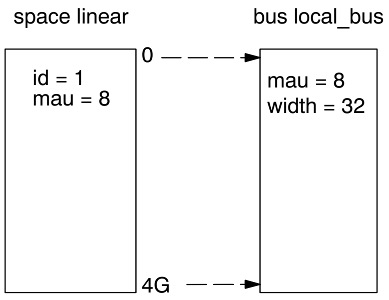


Figure 8–2: Scheme of the ARM architecture

The figure shows one address spaces called `linear`. The address space has attributes like a number that identifies the logical space (id), a MAU and an alignment. In LSL notation the definition of this address space looks as follows:

```
space linear
{
  id  = 1;
  mau = 8;
  map (size=4G, dest=bus:local_bus);
}
```

The keyword `map` corresponds with the arrows in the drawing. You can map:

• address space	=> address space (not shown in the drawing)
• address space	=> bus
• memory	=> bus (not shown in the drawing)
• bus	=> bus (not shown in the drawing)

Next the internal bus named `local_bus` must be defined in LSL:

```
bus local_bus
{
    mau = 8;
    width = 32;  // there are 32 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 ARM
{
    All code above goes here.
}
```

8.7.5 The Derivative Definition

When you are building a personal ASIC (using FPGAs) you will probably not need to program the derivative definition (unless you are using multiple cores), but 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 an 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 ARM
{
   architecture = ARM;
}
```

Bus

Each derivative can contain a bus definition for connecting external memory. In this example, the bus `local_bus` maps to the bus `local_bus` defined in the architecture definition of core `ARM`:

```
bus local_bus
{
   mau = 8;
   width = 32;
   map (dest=bus:ARM:local_bus, dest_offset=0, size=4G);
}
```

Memory

Memory is usually described in a separate memory definition, but you can specify on–chip memory for a derivative. For example:

```
memory internal_code_rom
{
     type = rom;
     size = 2k;
     mau = 8;
     map(dest = bus:local_bus, size=2k,
         dest_offset = 0x00100000);  // src_offset is zero by default)
}
```

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 create a derivative and you want to use EDE to select sections, the derivative must be called ”ARM” for the ARM, since EDE uses this name in the generated LSL file. If you want to specify memory in EDE, the custom derivative must contain the bus ”local_bus” for the same reasons.

8.7.6 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.
}
```

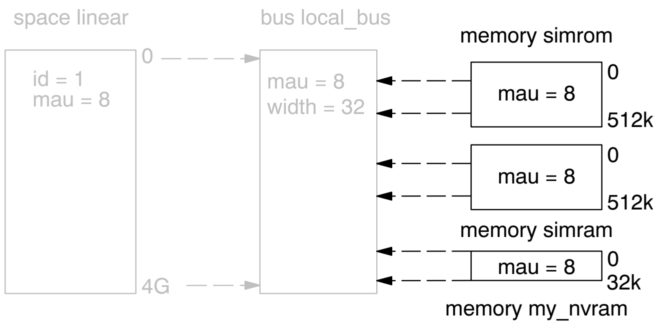


Figure 8–3: Adding external memory to the ARM architecture

Suppose your embedded system has 512kB of external ROM, named `simrom`, 512kB of external RAM, named `simram` and 32kB of external NVRAM, named `my_nvram` (see figure above.) All memories are connected to the bus `local_bus`. In LSL this looks like follows:

```
memory simrom
{
    mau = 8;
    type = rom;
    size = 512k;
    map ( size = 512k, dest_offset=0, dest=bus:X:local_bus);
}

memory simram
{
    mau = 8;
    type = ram;
    size = 512k;
    map ( size = 512k, dest_offset=512k, dest=bus:X:local_bus);
}

memory my_nvram
{
    mau = 8;
    type = ram;
    size = 32k;
    map ( size = 32k, dest_offset=1M, dest=bus:X:local_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 definition file must contain a `#define __MEMORY`, and you must specify this file *before* the core architecture LSL file.

Adding memory using EDE

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

   The Project Options dialog box appears.

2. Select **Script File** and select **Generated File based on EDE settings**.
3. Expand **Script File** entry and select **Memory**.
4. Specify a new physical memory device, for example `my_nvram`.

8.7.7 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 (section type) 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.

Example: section propagation through the toolchain

To illustrate section placement, the following example of a C program is used. The program prints the number of times it has been executed.

```
#define BATTERY_BACKUP_TAG  0xa5f0
#include <stdio.h>

int  uninitialized_data;
int  initialized_data = 1;

#pragma section  non_volatile
int  battery_backup_tag;
int  battery_backup_invok;
#pragma endsection

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 section` and `#pragma endsection` the compiler’s default section naming convention is overruled and a section with the name `non_volatile` appended is defined. In this section the battery back−upped data is stored.

As a result of the `#pragma section non_volatile`, the data objects between the pragma pair are placed in `.bss.non_volatile`. Note that `.bss` sections are cleared at startup. However, battery back−upped sections should not be cleared and therefore we will change this section attribute using the LSL.

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 section 8.7.6, *The Memory Definition*.

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 `linear`:

```
section_layout ::linear
{
    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 `.bss.non_volatile`. All other sections are located using the defaults specified in the architecture definition. Section `.bss.non_volatile` should be placed in non–volatile ram. To achieve this, the run address refers to our non–volatile memory called `my_nvram`. Furthermore, the section should not be cleared and therefore the attribute **s** (scratch) is assigned to the group:

```
group ( ordered, run_addr = mem:my_nvram, attributes = rws )
{
     select ".bss.non_volatile";
}
```

This completes the LSL file for the sample architecture and sample program. You can now invoke 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 8, *Linker Script Language*, in the reference manual.

8.7.8 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.

8.8 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_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 end 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 exists 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 exists 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.

If you want to use linker labels in your C source for sections that have a dot (.) in the name, you have to replace all dots by underscores.

See also section 8.9.4, *Creating Symbols*, in Chapter 8, *Linker Script Language* of the reference manual.

Example: refer to a label with section name with dots from C

Suppose a section has the name `.text`. When you want to refer to the begin of this section you have to replace all dots in the section name by underscores:

```
#include <stdio.h>
extern void *_lc_ub__text;

int main(void)
{
    printf("The function main is located at %X\n",
            &_lc_ub__text);
}
```

Example: refer to the stack

Suppose in an LSL file a stack section is defined with the name ”`stack`” (with the keyword **`stack`**). You can refer to the begin and end of the stack from your C source as follows:

```
#include <stdio.h>
extern char _lc_ub_stack[];
extern char _lc_ue_stack[];
void main()
{
  printf( ”Size of stack is %d\n”,
          _lc_ub_stack - _lc_ue_stack );
         /* stack grows from high to low */
}
```

From assembly you can refer to the end of the stack with:

```
.extern _lc_ue_stack   ; end of stack
```

8.9 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 map file (.map)**
4. (Optional) Enable the options to include that information in the map file.

Example on the command line (Windows Command Prompt)

```
lkarm -M test.obj
```

With this command the map file `test.map` is created.

See section 6.2, *Linker Map File Format*, in Chapter *List File Formats* of the reference manual for an explanation of the format of the map file.

Linker option **-M** (Generate task related map file)

Linker option **-m** (Map file formatting)

8.10 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.

Report problems to Technical Support

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 form. State the error number and attach relevant files.
3. Click the **Copy to Email client** button to open your e−mail 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. From 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.

On the command line you can use the linker option **−−diag** you can see an explanation of a diagnostic message:

```
lkarm --diag=[format:]{all | number,...]
```

See linker option **−−diag** in section 5.3, *Linker Options* in Chapter *Tool Options* of the reference manual.

9 Using the Utilities

Summary

This chapter describes the utilities that are delivered with the product.

9.1 Introduction

The TASKING toolchain comes with a number of utilities that are only available as command line tools.

ccarm	A control program. The control program invokes all tools in the toolchain and lets you quickly generate an absolute object file from C and/or assembly source input files.
mkarm	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 rebuilt.
ararm	A librarian. With this utility you create and maintain library files with relocatable object modules (`.obj`) generated by the assembler.

9.2 Control Program

The control program 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:

```
   ccarm [ [option]... [file]... ]...
```

where, *target* to specify the target you are building for.

Recognized input files

The control program recognizes the following input files:

- 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 `.lib` 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 `.out` suffix are interpreted as linked object files and are passed to the locating phase of the linker. The linker accepts only one `.out` file in the invocation.
- An argument with a `.lsl` suffix is interpreted as a linker script file and is passed to the linker.

Options

The control program accepts several command line options. 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 **–Wc**, **–Wa**, **–Wl** to pass arguments directly to tools.

Example with verbose output

```
   ccarm –v test.c
```

The control program calls all tools in the toolchain and generates the absolute object file `test.abs`. With option **–v** (verbose) you can see how the control program calls the tools:

```
   + path\carm –o cc1692a.src test.c
   + path\asarm –o cc1692b.obj cc1692a.src
   + path\lkarm cc1692b.obj –o test.abs –darm.lsl –M –lcarm –lfparm
```

The control program produces unique filenames for intermediate steps in the compilation process (such as `cc1692a.src` and `cc1692b.obj` in the example above) which are removed afterwards, unless you specify command line option **–t** (**––keep–temporary–files**).

Example with argument passing to a tool

```
ccarm -Wc-Oc test.c
```

The option **-Oc** is directly passed to the compiler.

9.2.2 Overview of Control Program Options

The following control program options are available:

Description	Option
Information	
Display invocation options	**-?** / **--help**
Display version header	**-V**
Show description of diagnostics	**--diag=**[*fmt*:]{**all**|*nr*}
Check the source, but do not generate code	**--check**
Profiling	**-p**[*flags*]
Verbose output	**-v**
Verbose output and suppress execution	**-n**
Suppress all or specific warnings	**-w**[*num*]
Treat warnings as errors	**--warnings-as-errors**
C Language	
ISO C standard 90 or 99 (default: 99)	**--iso=**{**90**|**99**}
Treat external definitions as "static"	**--static**
Single precision floating-point	**-F**
Preprocessing	
Define preprocessor *macro*	**-D***macro*[=*def*]
Remove preprocessor *macro*	**-U***macro*
Store the C compiler preprocess output (*file*`.pre`)	**-E***flag*
Code generation	
Select target CPU	**-C***cpu*
Generate symbolic debug information	**-g**
Pass arguments	
Pass arguments directly to the:	
C compiler	**-Wc***option*
Assembler	**-Wa***option*
Linker	**-Wl***option*

Description	**Option**
Libraries	
Add library directory	**–L***dir*
Add library	**–l***lib*
Ignore the default search path for libraries	**––ignore–default–library–path**
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*
Keep output file(s) after errors	**–k**
Generate assembler list files	**––list–files**[=*name*]
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 5.4, *Control Program Options*, in Chapter *Tool Options* of the reference manual.

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 **ccarm** 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 and linked 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 **mkarm** 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 `mkarm.mk` which contains predefined rules and macros. See section 9.3.3, *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 (`.abs`) 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
           carm test.c             # rule

test.obj : test.src
           asarm test.src

test.abs : test.obj
           lkarm test.obj −o test.abs −darm.lsl −M −lcarm −lfparm
```

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.abs`, call **mkarm** with one of the following lines:

```
mkarm test.abs

mkarm −f mymake.mak test.abs
```

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, **mkarm** uses the first target defined in the makefile. In this example it would build `test.src` instead of `test.abs`.

The make utility now tries to build `test.abs` based on the `makefile` and peforms the following steps:

1. From the `makefile` the make utility reads that `test.abs` 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: `carm test.src`.
4. There are no other files necessary to create `test.abs` so the make utility now can use `test.obj` to create `test.abs` by executing the rule `lkarm test.obj –o test.abs .....`

The make utility has now built `test.abs` but it only used the assembler to update `test.obj` and the linker to create `test.abs`.

If you compare this to the control program:

```
ccarm 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:

```
mkarm [ [option]... [target]... [macro=def]... ]
```

For example:

```
mkarm test.abs
```

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 **mkarm** invocation. It overrides any regular definitions for the specified macro within the makefiles and from the environment. It is inherited by subordinate **mkarm**'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

mkarm returns an exit status of 1 when it halts as a result of an error. Otherwise it returns an exit status of 0.

9.3.2 Overview of Make Utility Options

The following make utility options are available:

Description	**Option**
Information	
Display invocation options	**–?**
Display version header only	**–V**
Print makefile lines while being read	**–D**/**–DD**
Display time comparisons which indicate a target is out of date	**–d**/**–dd**
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**
Input files	
Use *makefile* instead of the standard `makefile`	**–f** *makefile*
Change to directory before reading the makefile	**–G** *path*
Read options from *file*	**–m** *file*
Do not read the `mkarm.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 building current target)	**–S**
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 9–2: Overview of control program options

For a complete list and description of all make utility options, see section 5.5, *Make Utility Options*, in Chapter *Tool Options* of the reference manual.

9.3.3 Writing a MakeFile

In addition to the standard makefile `makefile`, the make utility always reads the makefile `mkarm.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 `mkarm.mk` file) you can prevent the make utility from reading `mkarm.mk`.

The default name of the makefile is `makefile` in the current directory. 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.abs final.abs

demo.abs final.abs:     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:

```
mkarm
mkarm all
mkarm demo.abs final.abs
```

If you do *not* specify a target, the first target in the makefile (in this example `all`) is built. The target `all` depends on `demo.abs` and `final.abs` so the second and third invocation have the same effect and the files `demo.abs` and `final.abs` are built.

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.abs   # These two lines are equivalent with:
all:  final.abs  # all: demo.abs final.abs
```

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.

Target	Description
`.DEFAULT`	If you call the make utility with a target that has no definition in the makefile, this target is built.
`.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 built.
`.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.
`.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 `mkarm.mk`. If you specify this target with dependencies, these are added to the existing `.SUFFIXES` target in `mkarm.mk`. If you specify this target without dependencies, the existing list is cleared.

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
            move test.c final.c  # rule1
            carm 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.

You can force **mkarm** to execute multiple command lines in one shell environment. This is accomplished with the token combination ';\'. For example:

```
cd c:\Tasking\bin ;\
mkarm -V
```

Note that 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.

Inline temporary files

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:

```
lkarm -o $@ -f <<EOF
     $(separate "\n" $(match .obj $!))
     $(separate "\n" $(match .lib $!))
     $(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 `lkarm -o $@ -f mkce4c0a.tmp`.

Suffix targets

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   :
            carm $<
```

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 `mkarm.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.abs` 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  =     -lcarm -lfparm     # macro

prog.abs:  prog.obj sub.obj
     lkarm prog.obj sub.obj $(LIB) -darm.lsl -o prog.abs

prog.obj:  prog.c inc.h
     carm  prog.c
     asarm prog.src

sub.obj:   sub.c inc.h
     carm  sub.c
     asarm sub.src
```

The following makefile uses implicit rules (from `mkarm.mk`) to perform the same job.

```
LKFLAGS = -lcarm -lfparm             # macro used by implicit rules
prog.abs: 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
```

Macro definitions

A *macro* is a symbol name that is replaced with its 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 its 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 line and the environment variable `FOOD` is set accordingly.

Predefined macros

Macro	Description
`MAKE`	Holds the value `mkarm`. 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 **mkarm** (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 **mkarm**'s, but it is also available to these invocations as an environment variable.

`PRODDIR`	Holds the name of the directory where **mkarm** 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 **mkarm** is installed in the directory `c:/Tasking/bin` this line expands to:
	`DOPRINT = c:/Tasking/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.
`$`	This macro translates to a dollar sign. Thus you can use ”$$” in the makefile to represent a single ”$”.

Dynamically maintained macros

There are several dynamically maintained macros that are useful as abbreviations within rules. It is best not to define them explicitly.

Macro	Description
`$*`	The basename of the current target.
`$<`	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.

Makefile: 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.lib)
```

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 ccarm test.c)
```

When the file `test.c` exists, it yields:

```
ccarm 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 ccarm 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 5.5, *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
            ccarm 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 Librarian

The librarian **ararm** is a program to build and maintain your own library files. A library file is a file with extension `.lib` and contains one or more object files (`.obj`) that may be used by the linker.

The librarian 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 librarian takes the following files for input and output:

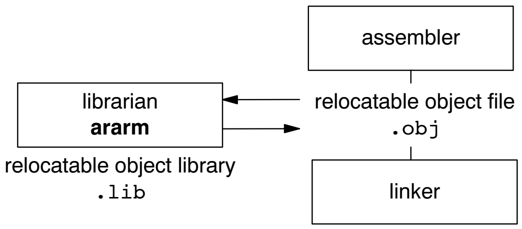


Figure 9–1: Librarian

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 Librarian

You can only call the librarian from the command line. The invocation syntax is:

```
ararm key_option [sub_option...] library [object_file]
```

key_option With a key option you specify the main task which the librarian should perform. You must *always* specify a key option.

sub_option Sub–options specify into more detail how the librarian 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 librarian 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.

9.4.2 Overview of Librarian Options

The following librarian 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**	
Miscellaneous		
Display options	**–?**	
Display version header	**–V**	
Read options from *file*	**–f** *file*	
Suppress warnings above level *n*	**–w***n*	

Table 9–3: Overview of librarian options and sub–options

For a complete list and description of all librarian options, see section 5.6, *Librarian Options*, in Chapter *Tool Options* of the reference manual.

9.4.3 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.lib` and add the object modules `cstart.obj` and `calc.obj` to it:

```
ararm -r mylib.lib 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.)

```
ararm -r mylib.lib mod3.obj
```

Print a list of object modules in the library

To inspect the contents of the library:

```
ararm -t mylib.lib
```

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`:

```
ararm -mb cstart.obj mylib.lib mod3.obj
```

Delete an object module from the library

To delete the object module `cstart.obj` from the library `mylib.lib`:

```
ararm -d mylib.lib cstart.obj
```

Extract all modules from the library

Extract all modules from the library `mylib.lib`:

```
ararm -x mylib.lib
```

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