ARM Cross Development with Eclipse Version 3

By: James P. Lynch

December 11, 2005

Preface to Version 3

When I revised this tutorial in September 2005, everything needed to provide a complete Eclipse/ARM cross-development package was in place. The only shortcoming was that the Eclipse debugger could not debug programs in FLASH. Now that issue has been resolved.

Macraigor Systems LLC updated their free **OCDRemote** utility to handle hardware breakpoints (GDB remote serial protocol "***Z1,addr,length***" commands).

The Macraigor **OCDRemote** utility has a monitor command (***monitor softbkpts off***) that forces the utility to convert all Eclipse software breakpoints (which don't work in FLASH) to hardware breakpoints (ARM7 cores allow two hardware breakpoints and they do, of course, work in FLASH). When you double-click on the "breakpoint" area on the left side of the source window in Eclipse, you are now setting an ARM hardware breakpoint.

You can only set two hardware breakpoints (a limitation of the ARM7 core). This is not much of a roadblock. You can single-step in and out of functions, inspect and change variables, view memory dumps, and work in assembler mode.

If you need more than two breakpoints, you can elect not to send the "monitor softbkpts off" command during GDB initialization and thus debug RAM-based applications with all the software breakpoints you desire.

James P. Lynch

1 Introduction

I credit my interest in science and electronics to science fiction movies in the fifties. Robbie the Robot in the movie “Forbidden Planet” especially enthralled me and I watched every episode of Rocky Jones, Space Ranger on television. In high school, I built a robot and even received a ham radio operator license at age 13.

Electronic kits were popular then and I built many Heath kits and Knight kits, everything from ham radio gear to televisions, personal computers and robots. These kits not only saved money at the time, but the extensive instruction manuals taught the basics of electronics.

Unfortunately, surface mount technology and pick-and-place machines obliterated any cost advantage to “building it yourself” and Heath and Allied Radio all dropped out of the kit business.

What of our children today? They have home computers to play with, don’t they? Do you learn anything by playing a Star Wars game or downloading music? I think not, while these pastimes may be fun they are certainly not intellectually creative.

A couple years ago, there were 5 billion microcomputer chips manufactured planet-wide. Only 300 million of these went into desktop computers. The rest went into toasters, cars, fighter jets and Roomba vacuum cleaners. This is where the real action is in the field of computer science and engineering. It’s called “embedded software development”.

Can today’s young student or home hobbyist tired of watching Reality Television dabble in microcomputer electronics? The answer is an unequivocal YES!

Most people start out with projects involving the Microchip **PIC** series of microcontrollers. You may have seen these in Nuts and Volts magazine or visited the plethora of web sites devoted to **PIC** computing. **PIC** microcomputer chips are very cheap (a couple of dollars) and you can get an IDE (Integrated Development Environment), compilers and emulators from Microchip and others for a very reasonable price.

Another inexpensive microcontroller for the hobbyist to work with is the **Rabbit** microcomputer. The **Rabbit** line is an 8-bit microcontroller with development packages (board and software) costing less that $140.

I’ve longed for a real, state-of-the-art microcomputer to play with. One that can do 32-bit arithmetic as fast as a speeding bullet and has all the on-board RAM and EPROM needed to build sophisticated applications. My prayers have been answered recently as big players such as Texas Instruments, Philips and Atmel have been selling inexpensive microcontroller chips based on the 32-bit ARM architecture. These chips have integrated RAM and FLASH memory, a rich set of peripherals such as serial I/O, PWM, I2C, SSI, Timers etc. and high performance at low power consumption.

A very good example from this group is the Philips LPC2000 family of microcontrollers. The LPC2106 has the following features, all enclosed in a 48-pin package costing about $11.88 (latest price from Digikey for one LPC2106).

Key features

- 16/32-bit ARM7TDMI-S processor.
- 64 kB on-chip Static RAM.
- 128 kB on-chip Flash Program Memory. In-System Programming (ISP) and In-Application Programming (IAP) via on-chip boot-loader software.
- Vectored Interrupt Controller with configurable priorities and vector addresses.
- JTAG interface enables breakpoints and watch points.
- Multiple serial interfaces including two UARTs (16C550), Fast I²C (400 kbits/s) and SPI™.
- Two 32-bit timers (7 capture/compare channels), PWM unit (6 outputs), Real Time Clock and Watchdog.
- Up to thirty-two 5 V tolerant general-purpose I/O pins in a tiny LQFP48 (7 x 7 mm^2) package.
- 60 MHz maximum CPU clock available from programmable on-chip Phase-Locked Loop with settling time of 100 us.
- On-chip crystal oscillator with an operating range of 1 MHz to 30 MHz.
- Two low power modes: Idle and Power-down.
- Processor wake-up from Power-down mode via external interrupt.
- Individual enable/disable of peripheral functions for power optimization.
- Dual power supply:
    - CPU operating voltage range of 1.65 V to 1.95 V (1.8 V +- 8.3 pct.).
    - I/O power supply range of 3.0 V to 3.6 V (3.3 V +- 10 pct.) with 5 V tolerant I/O pads.

Several companies have come forward with the LPC2000 microcontroller chips placed on modern surface-mount boards, ready to use. Olimex and New Micros have a nice catalog of inexpensive boards using the Philips ARM family. I wrote a similar tutorial for the New Micros **TiniARM** a year ago and you can see it on their web site www.newmicros.com.

Olimex, an up-and-coming electronics company in Bulgaria, offers a family of Philips LPC2100 boards. Specifically they offer three versions with the LPC2106 CPU. The Olimex web site is www.olimex.com. You can also buy these from Spark Fun Electronics in Colorado; their web site is www.sparkfun.com The Olimex boards are also carried by Microcontroller Pros in California, their web site is www.microcontrollershop.com

This is the Olimex LPC-H2106 header board. You can literally solder this tiny board onto Radio Shack perfboard, attach a power supply and serial cable and start programming. It costs about $49.95
Obviously, it requires some soldering to get started.

This is the Olimex LPC-P2106 prototype board. Everything is done for you. There's a power connector for a wall-wart power supply, a DB-9 serial connector and a JTAG port. It costs about $59.95 plus $2.95 for the wall-wart power supply.

This is the Olimex LPT-MT development board; it has everything the prototype board above includes plus a LCD display and four pushbuttons to experiment with. It costs about $79.95 plus $2.95 for the wall-wart power supply.

For starting out, I would recommend the **LPC-P2106** prototype board since it has an open prototype area for adding I2C chips and the like for advanced experimentation.

When you do design and develop something really clever, you could use the LPC-H2106 header board soldered into a nice Jameco or Digikey prototype board and know that the CPU end of your project will work straight away. If you need to build multiple copies of your design, Spark Fun can get small runs of blank circuit boards built for $5.00 per square inch. You can acquire the Eagle-Lite software from CadSoft for free to design the schematic and PCB masks.

So the hardware to experiment with 32-bit ARM microprocessors is available and affordable. What about the software required for editing, compiling, linking and downloading applications for the LPC2106 board?

Embedded microcomputer development software has always been considered “professional” and priced accordingly. It’s very common for an engineer in a technical company to spend $1000 to $5000 for a professional development package. I once ordered $18,000 of compilers and emulators for a single project. In the professional engineering world, time is money. The commercial software development packages for the ARM architecture install easily, are well supported and rarely have bugs. In fact, most of them can load your program into either RAM or FLASH and you can set breakpoints in either. The professional compiler packages are also quite efficient; they generate compact and speedy code.

The Rowley CrossWorks recommended by Olimex is $904.00, clearly out of the range for the student or hobby experimenter. I’ve seen other packages going up as high as $3000. A professional would not bat an eyelash about paying this – time is money.

There is a low cost alternative to the high priced professional software development packages, the GNU toolset. GNU is the cornerstone of the open-source software movement. It was used to build the LINUX operating system. The GNU Toolset includes compilers, linkers, utilities for all the major microprocessor platforms, including the ARM architecture. The GNU toolset is free.

The editor of choice these days is the Eclipse open-source Integrated Development Environment (IDE). By adding the CDT plugin (C/C++ Development Toolkit), you can edit and build C programs using the GNU compiler toolkit. Eclipse is also free.

Philips provides a Windows flash programming utility that allows you to transfer the hex file created by the GNU compiler/linker into the onboard flash EPROM on the LPC2106 microprocessor chip. The Philips tool is also free.

Macraigor has made available a free Windows utility called OCDremote that allows the Eclipse/GDB (GNU Debugger) to access the Philips LPC2106 microprocessor via the JTAG port using an expensive device called the "**wiggler**". The Norwegian company Zylin has created a custom version of CDT that enables the debugger to work better with cross-development applications.

At this point, you're probably saying "this is great – all these tools and they're FREE!" In the interest of honesty and openness, let's delineate the downside of the free open software GNU tools.

- The GNU tools do not currently generate as efficient code as the professional compilers.

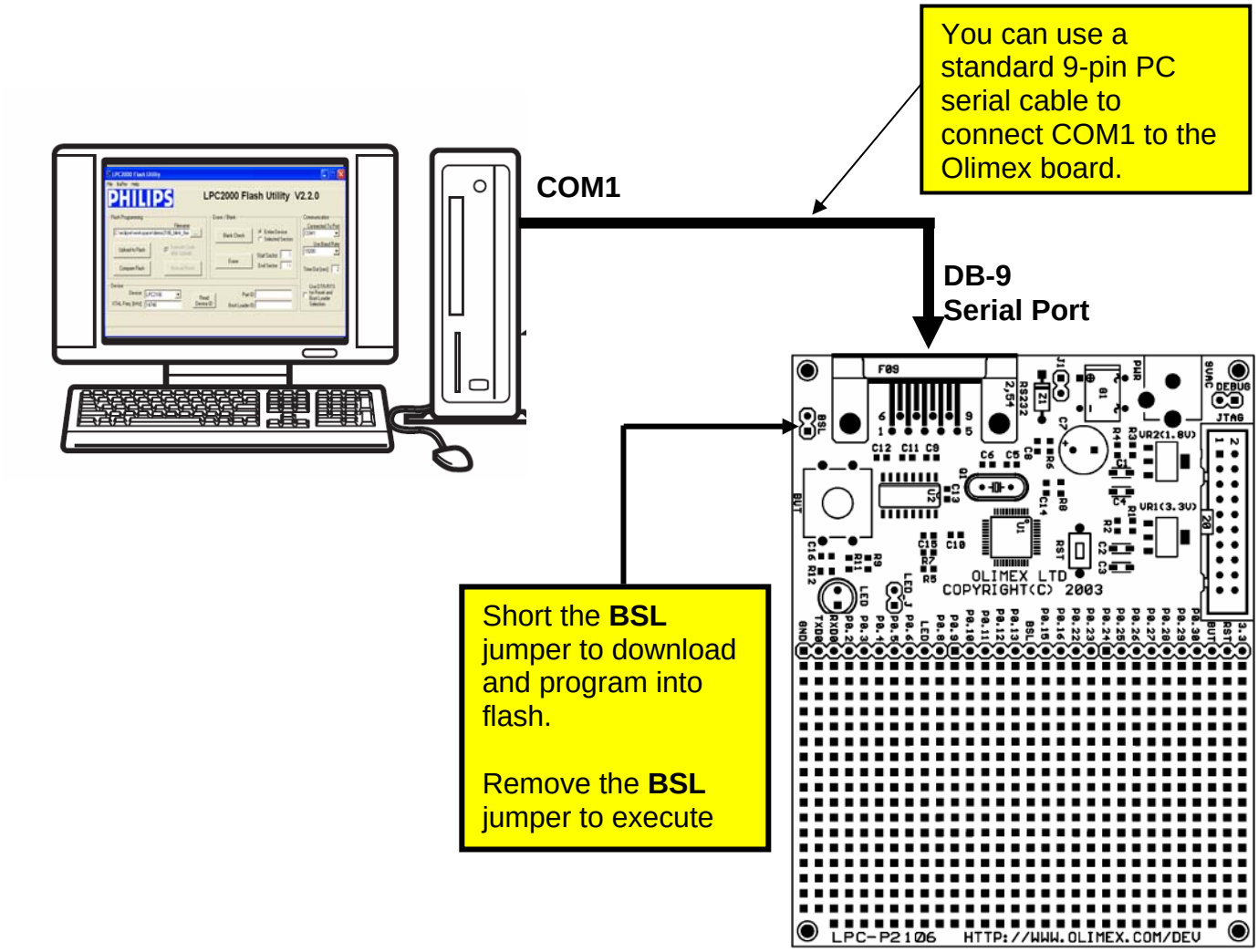
- The Eclipse CDT Debugger can only set two hardware breakpoints in FLASH.

- You need an internet broadband connection to download all these free software tools.

If you were a professional programmer, you might not accept these limitations. For the student or hobbyist, the Eclipse/GNU toolset still gives fantastic capabilities for zero cost.

The Eclipse/GNU Compiler toolset we will be creating in this tutorial operates in three modes.

A. Application programmed into FLASH (no debugging)

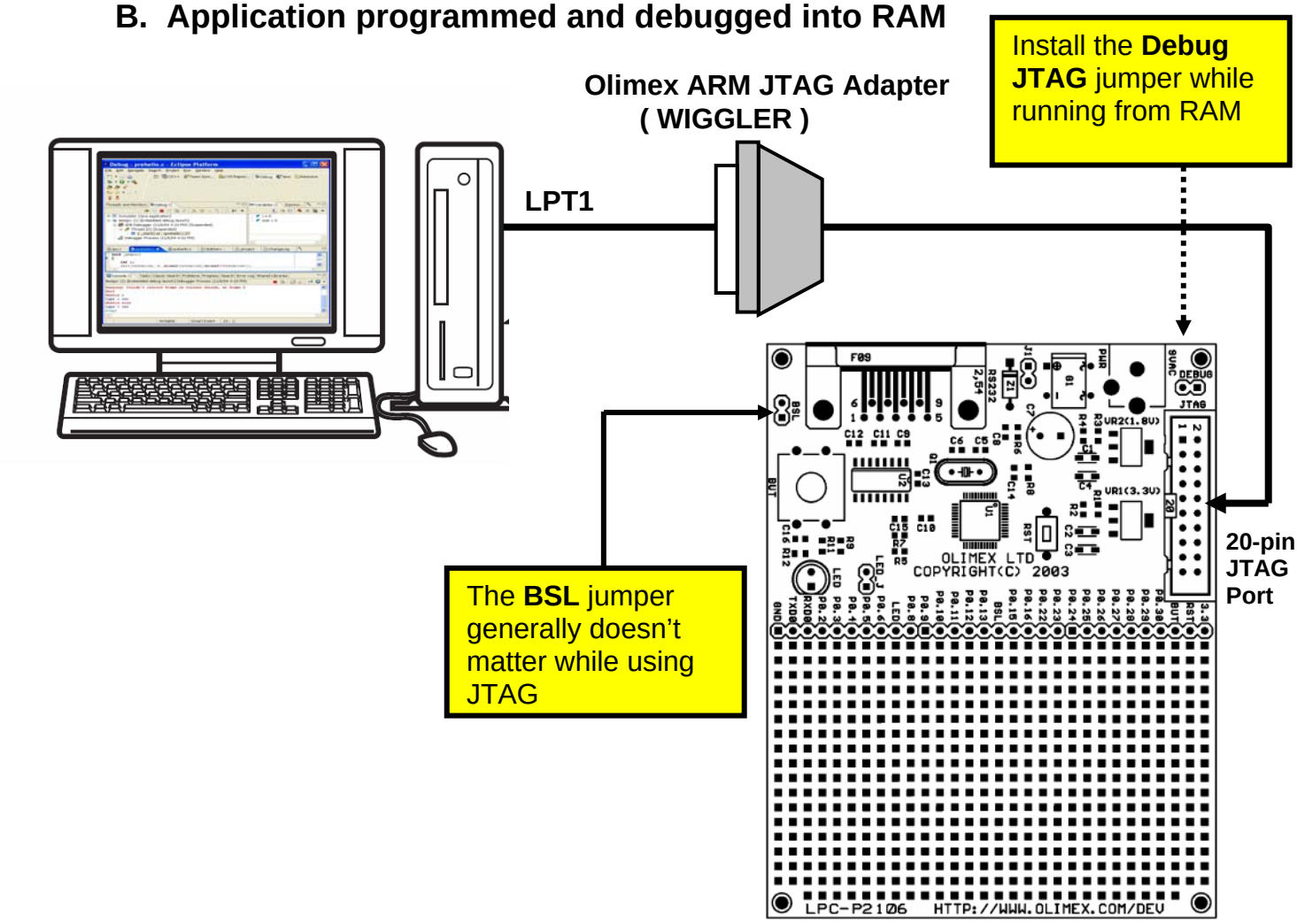


In this mode, the Eclipse/GNU development system assembles, compiles and links your application for loading into FLASH memory. The output of the compiler/linker suite is an Intel hex file, e.g. **main.hex**.

The Philips LPC2000 Flash Utility is started within Eclipse and will download your hex file and program the flash memory through the standard COM1 serial cable. The Boot Strap Loader (**BSL**) jumper must be shorted (installed) to run the Philips flash programming utility.

To execute the application, you remove the BSL jumper and push the RESET button to start the application.

B. Application programmed and debugged into RAM



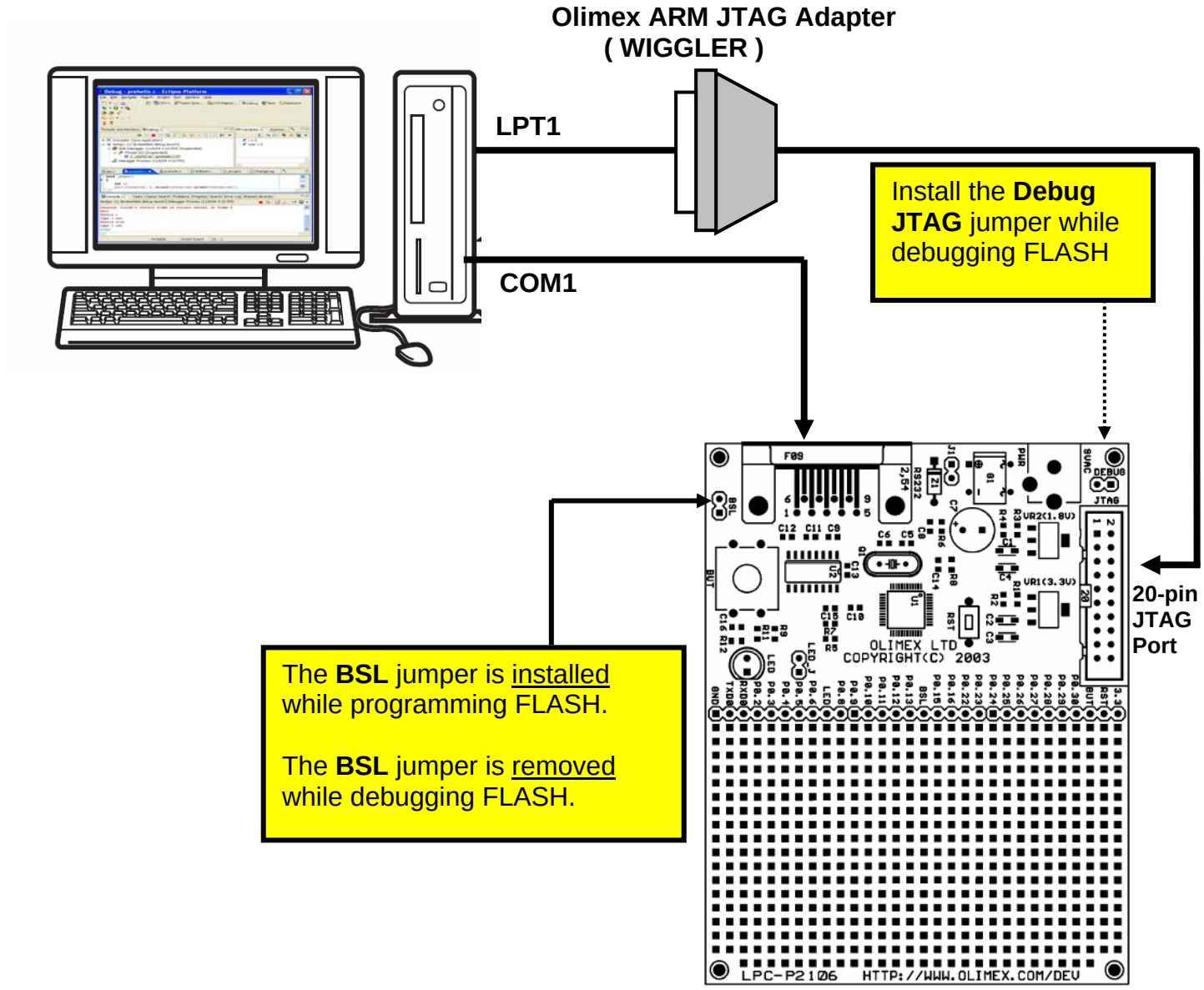
In this mode, the Eclipse/GNU development system assembles, compiles and links your application for loading into RAM memory. The output of the compiler/linker suite is a GNU **main.out** file.

The PC is connected from the PC's printer port LPT1 to the JTAG port through the **Olimex ARM JTAG** interface (costs about $19.95 from Spark Fun Electronics). The Olimex **ARM JTAG** is a clone of the Macraigor **Wiggler**.

You can run the **OCDRemote** program as an external tool from within Eclipse. The **CDT** debugger (started from within Eclipse) communicates with the Macraigor **OCDRemote** program that operates the JTAG port using the **Wiggler**. With the **CDT** debugger, you can connect to the **Wiggler** and load the GNU **main.out** file into RAM. From this point on, you can set software breakpoints, view variables and structures and, of course, run the application.

The drawback is that the application must fit within RAM memory on the LPC2106, which is 64 Kbytes. Still, it's better than nothing.

C. Application programmed and debugged into FLASH



In this mode, the Eclipse/GNU development system assembles, compiles and links your application for loading into FLASH memory. The output of the compiler/linker suite is an Intel hex file, e.g. **main.hex**.

The Philips LPC2000 Flash Utility is started within Eclipse and will download your hex file and program the flash memory through the standard COM1 serial cable. The Boot Strap Loader (**BSL**) jumper must be shorted (installed) to run the Philips flash programming utility.

Next you remove the Boot Strap Loader (**BSL**) jumper and attach the **JTAG** cable (or just leave it in). By starting the **OCDRemote** utility, the Eclipse debugger can operate in FLASH with two hardware breakpoints.

The Eclipse debugger will initialize the GDB debugger by loading the symbols from the output file "**main.out**". It will also instruct the OCDRemote utility to convert all Eclipse software breakpoints to hardware breakpoints. It will set a temporary

hardware breakpoint at main() and set the PC to 0x000000 (the reset vector). This will start execution and the Eclipse debugger will stop at main().

Now you can debug to your heart's content; as long as you don't specify more than two breakpoints.

If you are very new to ARM microcomputers, there's no better introductory book than "**The Insider's Guide to the Philips ARM7-Based Microcontrollers**" by Trevor Martin. Martin is an executive of Hitex, a UK vendor of embedded microcomputer development software and hardware and he obviously understands his material.

You can download this e-book for free from the Hitex web site.

http://www.hitex.co.uk/arm/lpc2000book/index.html

There is a controversial section in Chapter 2 with benchmarks showing that the GNU toolset is 4 times slower in execution performance and 3.5 times larger in code size than other professional compiler suites for the ARM microprocessors. Already Mr. Martin has been challenged about these benchmarks on the internet message boards; see "The Dhrystone benchmark, the LPC2106 and GNU GCC" at this web address:

http://www.compuphase.com/dhrystone.htm

Well, we can't fault Trevor Martin for tooting his own horn! In any case, Martin's book is a magnificent work and it would behoove you to download and spend a couple hours reading it. I've used Hitex tools professionally and can vouch for their quality and value. Read his book! Better yet, it's required reading.

My purpose in this tutorial is to guide the student or hobbyist through the myriad of documentation and web sites containing the necessary component parts of a working ARM software development environment. I've devised a simple sample program that blinks an LED that is compatible in every way with the GNU assembler, compiler and linker.

There are two variants of this program; a FLASH-based version and a RAM-based version. The RAM-based version is limited to the LPC2106 RAM space (64K) but you can set an unlimited number of software breakpoints. The FLASH-based version can be burned into onboard flash using the Philips ISP utility and then debugged using JTAG as long as you limit yourself to two breakpoints (hardware).

If you get this to work, you are well on your way to the fascinating world of embedded software development. Take a deep breath **and HERE WE GO!**

2 Installing the Necessary Components

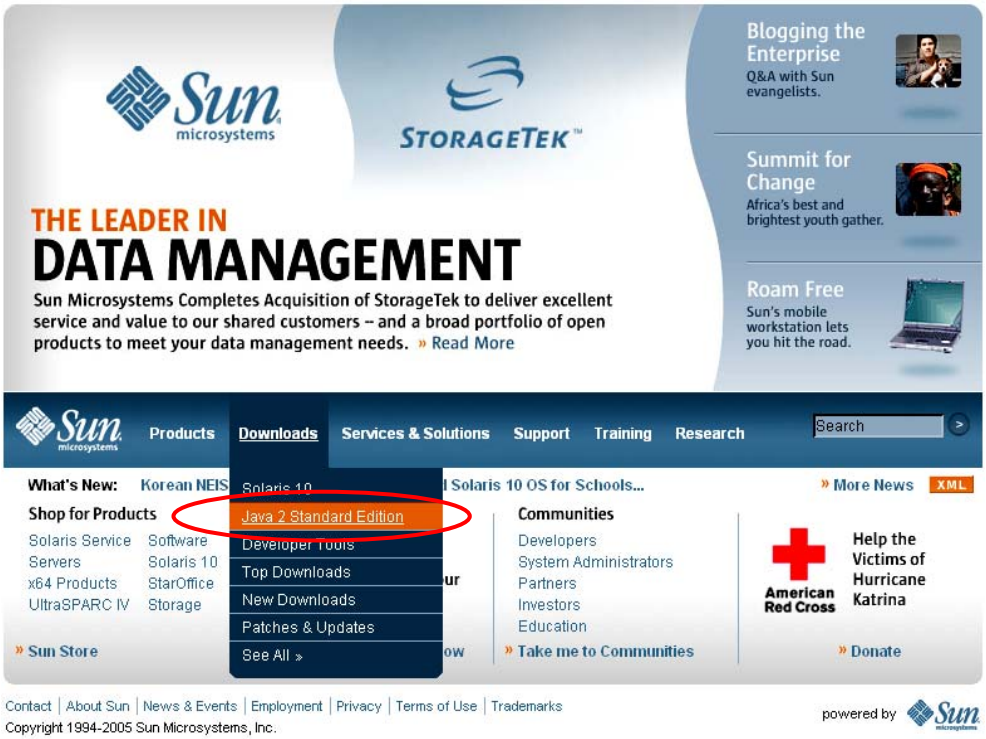
To set up an ARM cross-development environment using Eclipse, you need to download and install several components. The required parts of the Eclipse/ARM cross development system are:

1. **SUN Java Runtime**
2. **Eclipse IDE**
3. **Eclipse CDT Plug-in for C++/C Development (Zylin custom version)**
4. **CYGWIN GNU C++/C Compiler and Toolset for Windows**
5. **GNUARM GNU C++/C Compiler for ARM Targets**
6. **Philips Flash Programmer for LPC2100 Family CPUs**
7. **Macraigor OCDremote for JTAG debugging**

3 JAVA Runtime

The Eclipse IDE was written entirely in JAVA. Therefore, you must have the JAVA runtime installed on your Windows computer to run Eclipse. Most people already have JAVA set up in their Windows system, but just in case you don't have JAVA installed, here's how to do it.

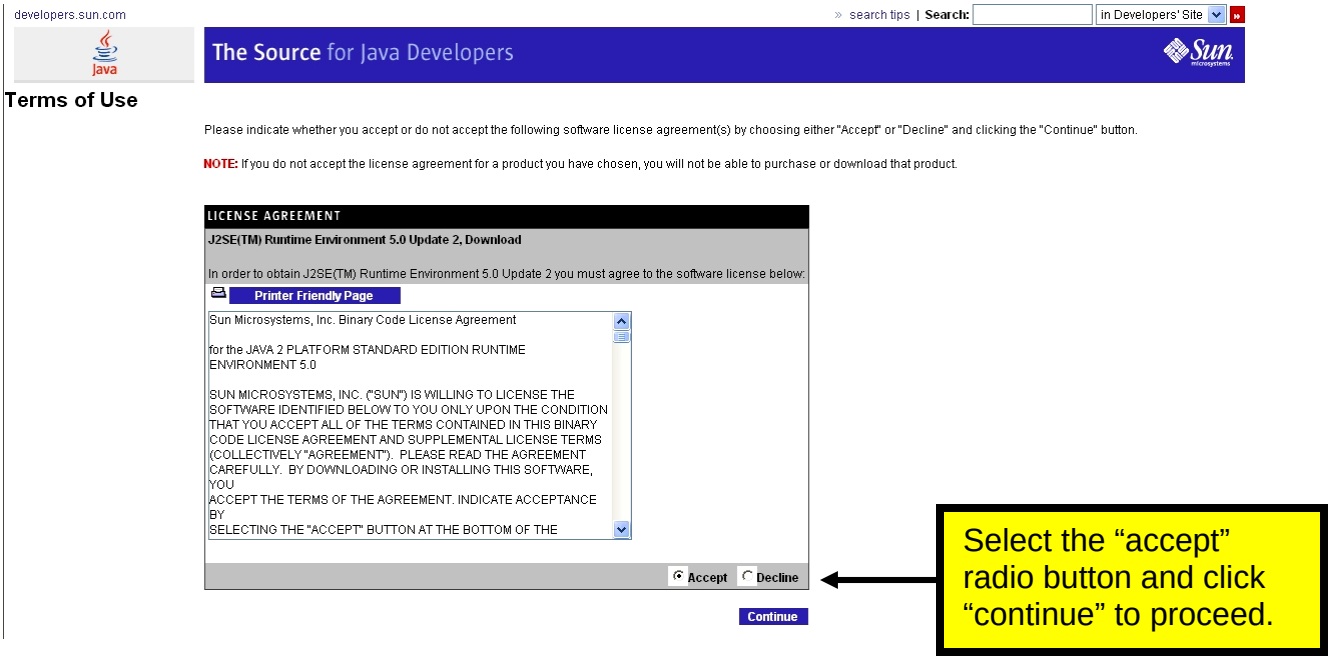
The JAVA runtime is available free at www.sun.com. The following screen will appear. Click on "**Downloads – Java 2 Standard Edition**" to continue.



Select the “latest and greatest” Java runtime system by clicking on **J2SE 5.0**.

Specifically, we need only the Java Runtime Environment (JRE). Click on “**Download JRE 5.0 Update 3.**”

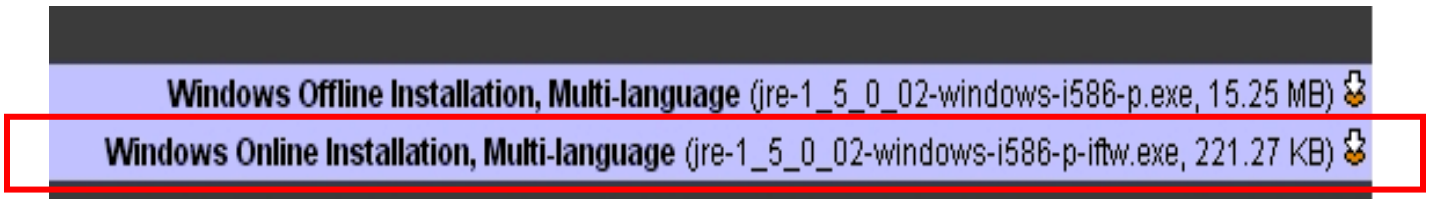
The Sun “Terms of Use” screen appears first. You have to accept the Sun binary code license to proceed. If you develop a commercial product using the Sun JAVA tools, you will have to pay royalties to them.



Select the “accept” radio button and click “continue” to proceed.

One more choice to decide on – we want the “**online**” installation for Windows.

Here’s a blow-up of the line we must click on. We select “**online**” so we can install immediately.



Finally the “file download” window appears. Click on “**Run**” to download and run the installation.

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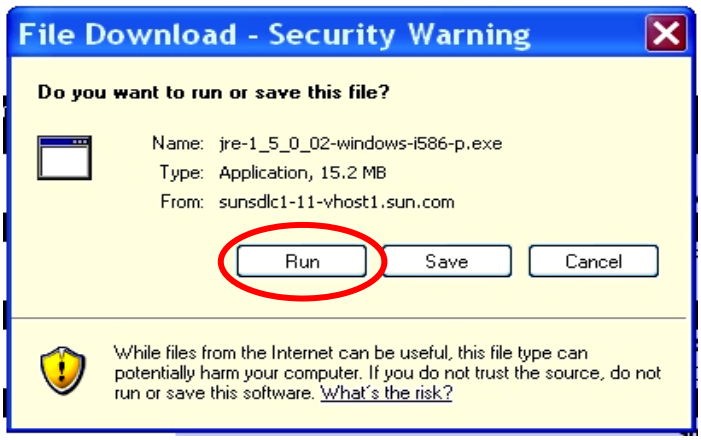
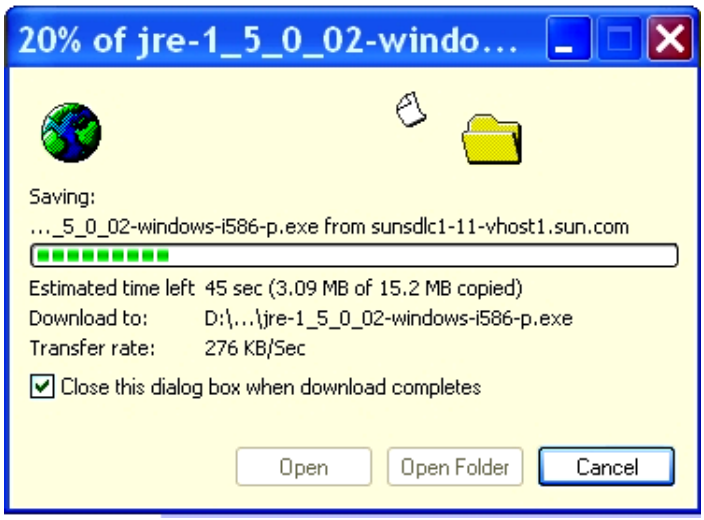
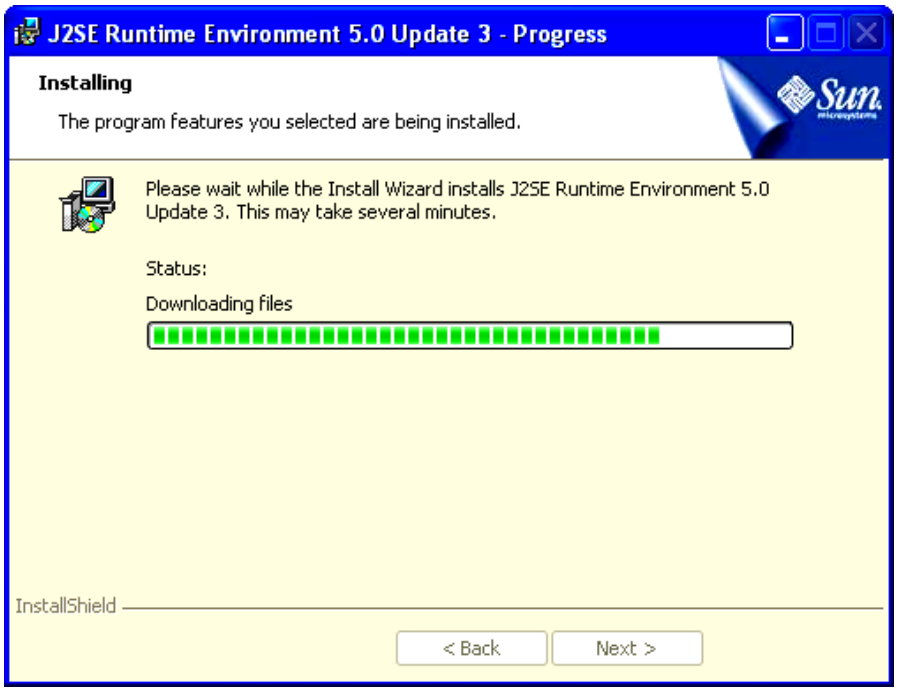


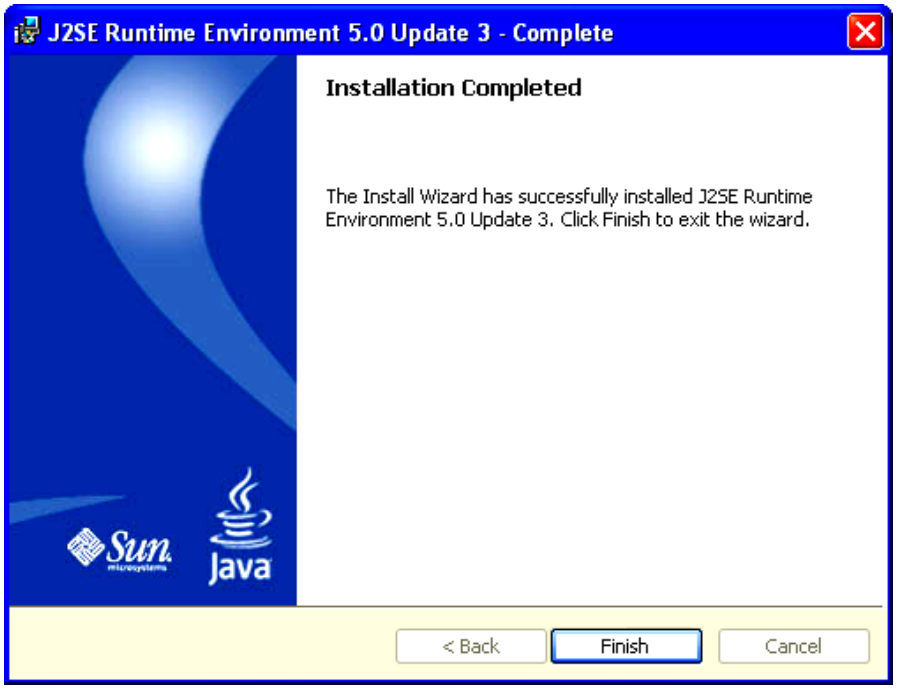
Now the downloading will start.



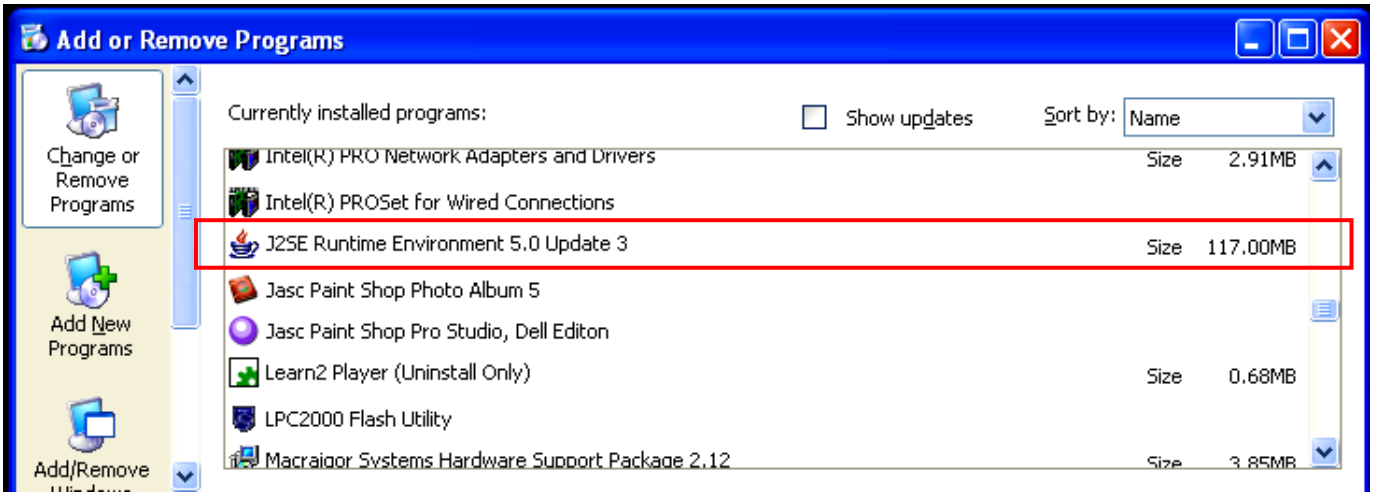
After downloading, the installation will proceed automatically.



When the Java Runtime Environment installation completes, you will see this display. Click on "**Finish**."



As a quick check, go to the Windows **Start** menu and select "**Start – Control Panel – Add or Remove Programs**." Scroll down the list of installed programs and see if the Java J2SE Runtime Environment was indeed installed!



The Sun Microsystems web site is very dynamic, changing all the time. Don't be surprised if some of the example displays shown here are a bit different.

4 Eclipse IDE

The Eclipse IDE is a complete integrated development platform similar to Microsoft's Visual Studio. Originally developed by IBM, it has been donated to the Open-Source community and is now a massive world-wide Open-Source development project.

Eclipse, by itself, is configured to edit and debug JAVA programs. By installing the CDT plug-ins, you can use Eclipse to edit and debug C/C++ programs (more on that later).

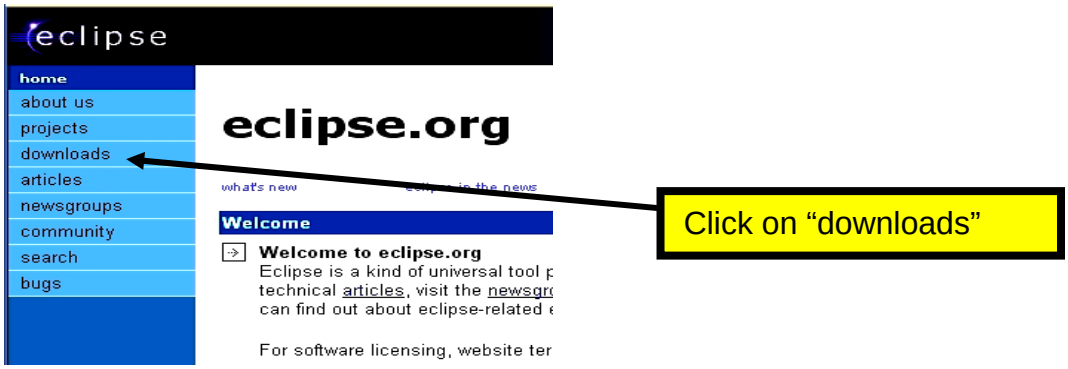
When properly setup, you will have a sophisticated programmer's editor, compilers and debugger sufficient to design, build and debug ARM applications.

You can download Eclipse for free at the following web site.

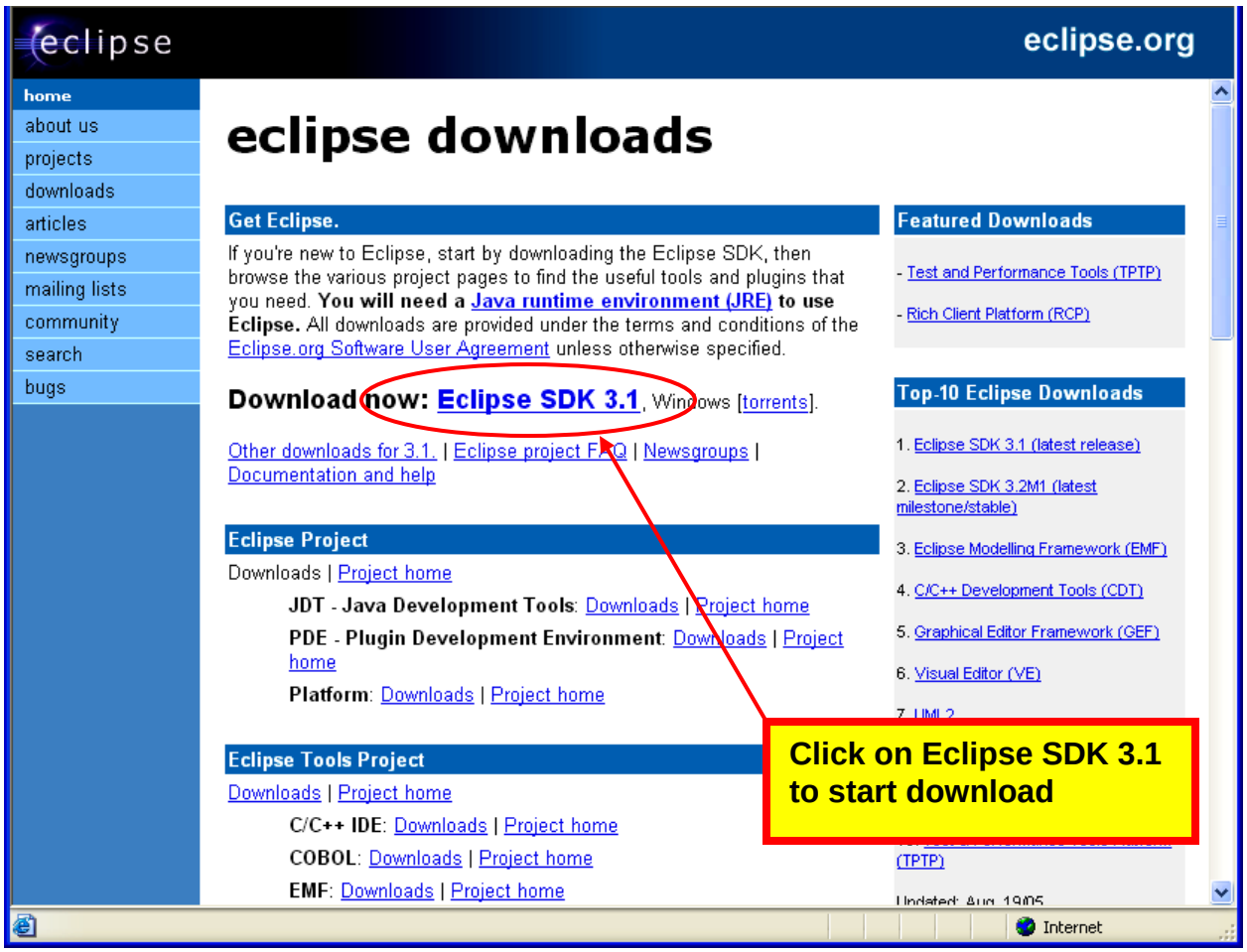
www.eclipse.org

The following Eclipse welcome page will display. Expect some differences from my example below since the Eclipse web site is very dynamic.

Click on “**Downloads**” to get things started.



The Eclipse download window will appear. Eclipse is constantly being improved and new releases come several times a year. Usually the safest thing to download is the “official” latest release. When this tutorial was created, the latest release was **Eclipse SDK 3.1**



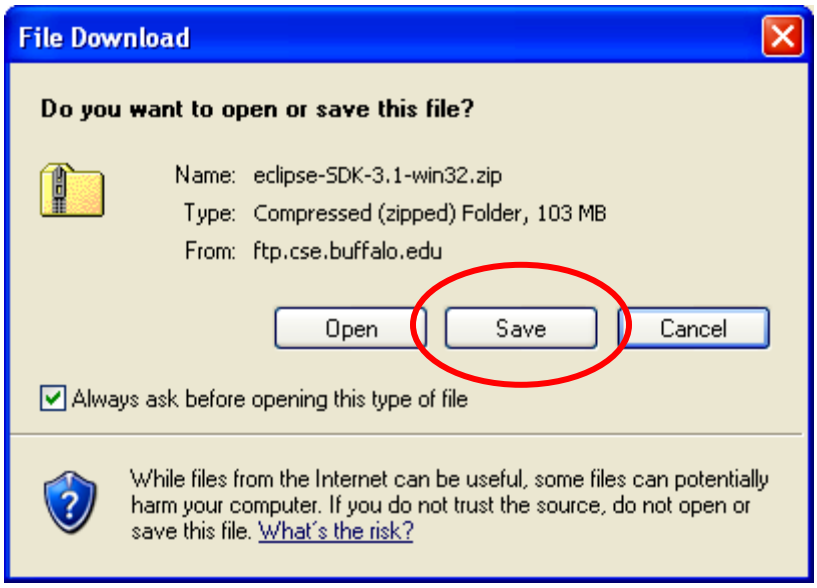
When working with the Eclipse and CDT, it’s important to be sure that the CDT plugin you’ve selected is compatible with the Eclipse revision you also selected. Be sure to study the Eclipse web sites to be sure that you have compatible revisions selected.

If you click on **Eclipse SDK 3.1** where it says "**Download Now:**" shown above, this is the **Windows** version of the download.

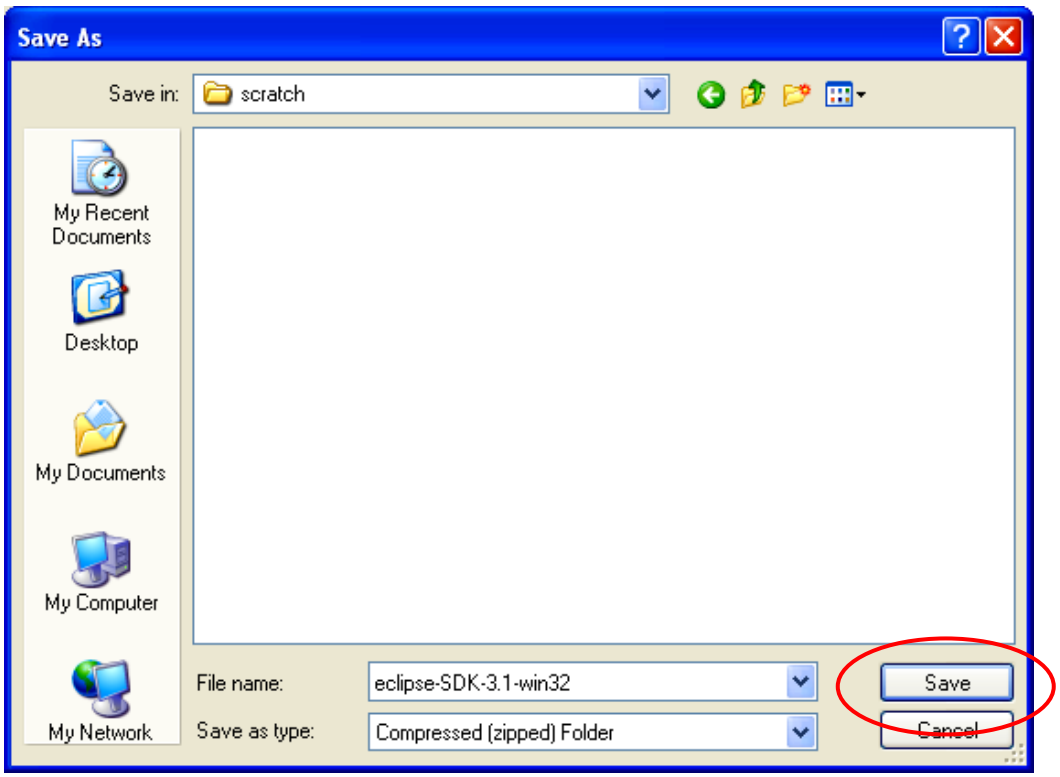
What appears next is a list of download mirror sites that host the Eclipse components. I selected the **University of Buffalo** in my home town (and where I got my Master's degree).

When the mirror site starts the download process, you have to select a destination directory to place the Eclipse zip file. In my case, I created an empty **C:/scratch** directory on one of my hard drives (you could use any other drive as well).

First click on **Save** below.

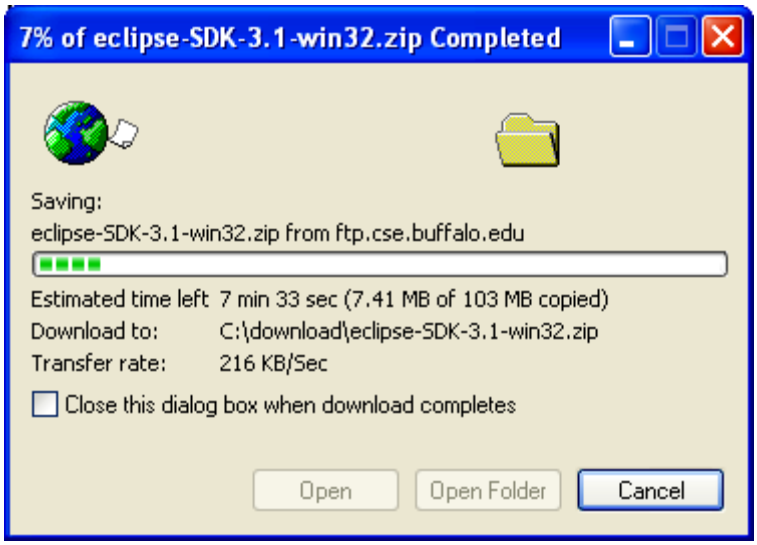


Now browse to the **c:/scratch** directory that you created previously.

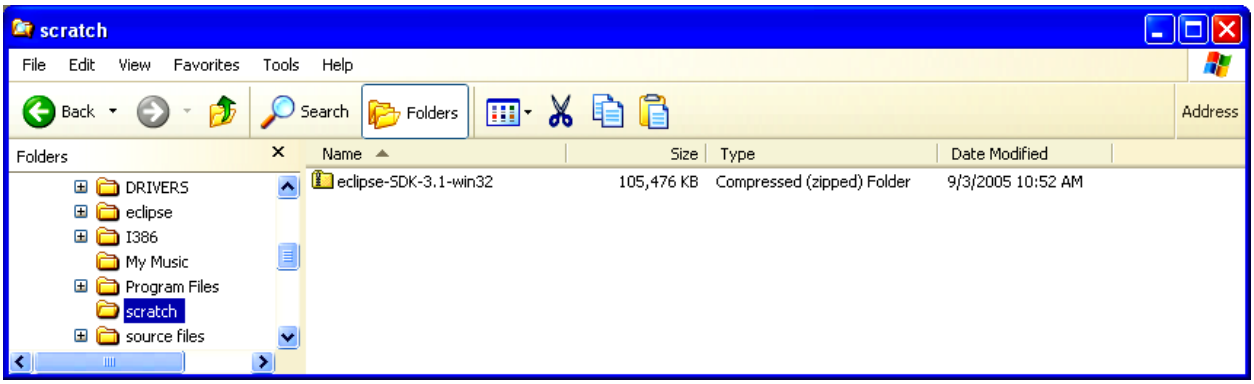


Click on **Save** to start the download.

Now the download will start. Eclipse is delivered as a ZIP file. It's 103 **megabytes** in length and takes 9 minutes to download with my broadband cable modem. If you have a dialup internet connection, this will be excruciating. If you don't have a cable modem high-speed internet connection, I suggest you find somebody who does and go over there with a blank CDROM and a gift.



When the Eclipse download completes, you should see the following zip file in your scratch directory.

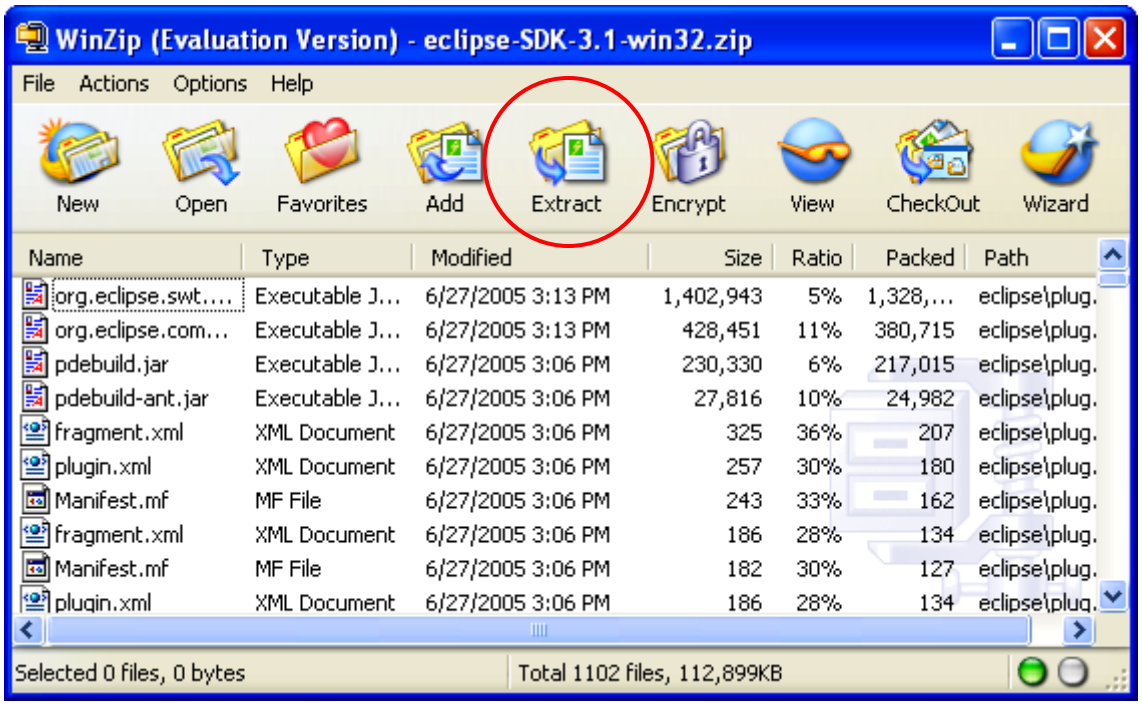


Eclipse is delivered as a ZIP file (**eclipse-SDK-3.1-win32.zip**). You can use WinZip to decompress this file and load its constituent parts on your hard drive.
If you don't have WinZip, you can get a free evaluation version from this address:

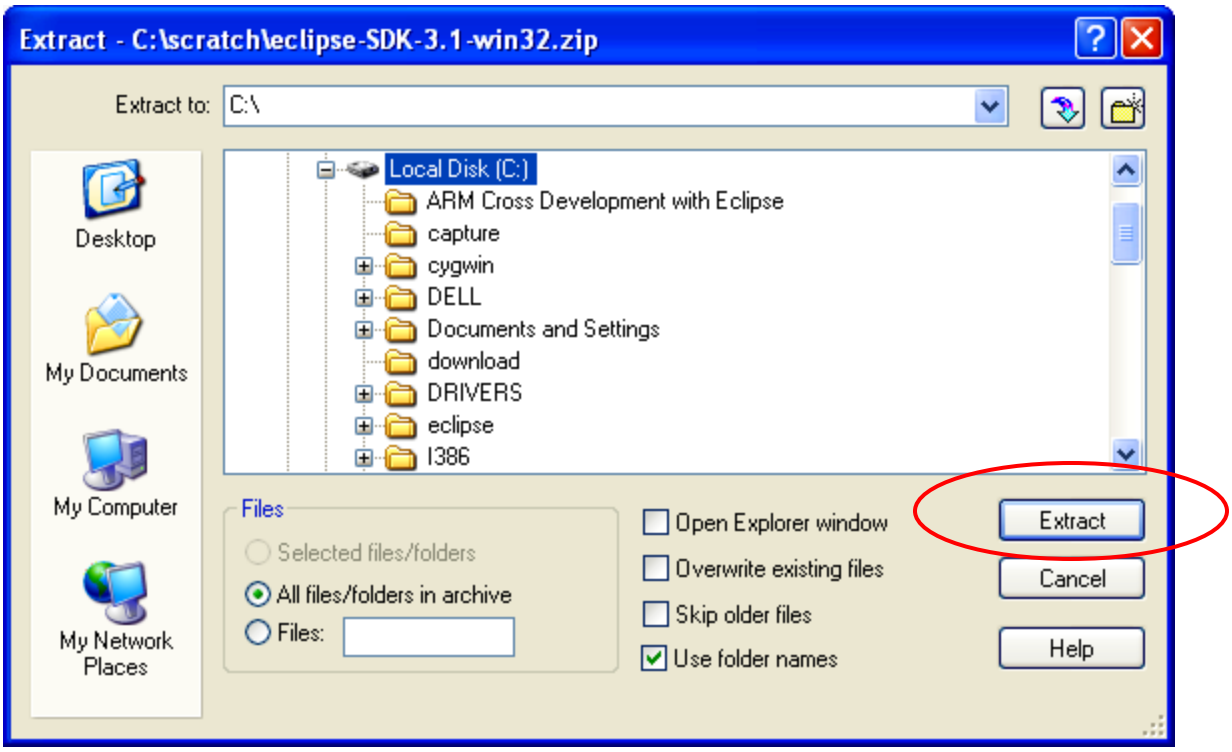
http://www.winzip.com/

There's a decent Help file supplied by WinZip. Therefore, we're going to assume that the reader is able to use a tool such as WinZip to extract from zip files.

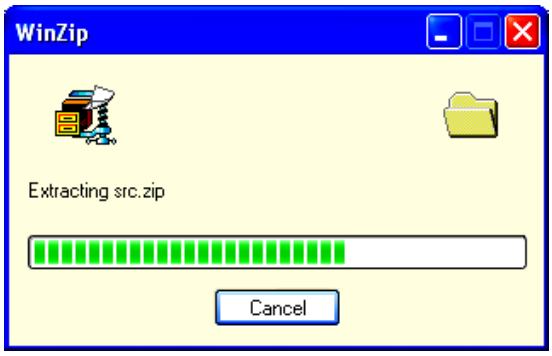
In my computer, with WinZip installed, double-clicking on the zip file name (**eclipse-SDK-3.1-win32.zip**) in the Windows Explorer display above will automatically start up WinZip. Click on "**Extract**" to start the Eclipse file decompression.



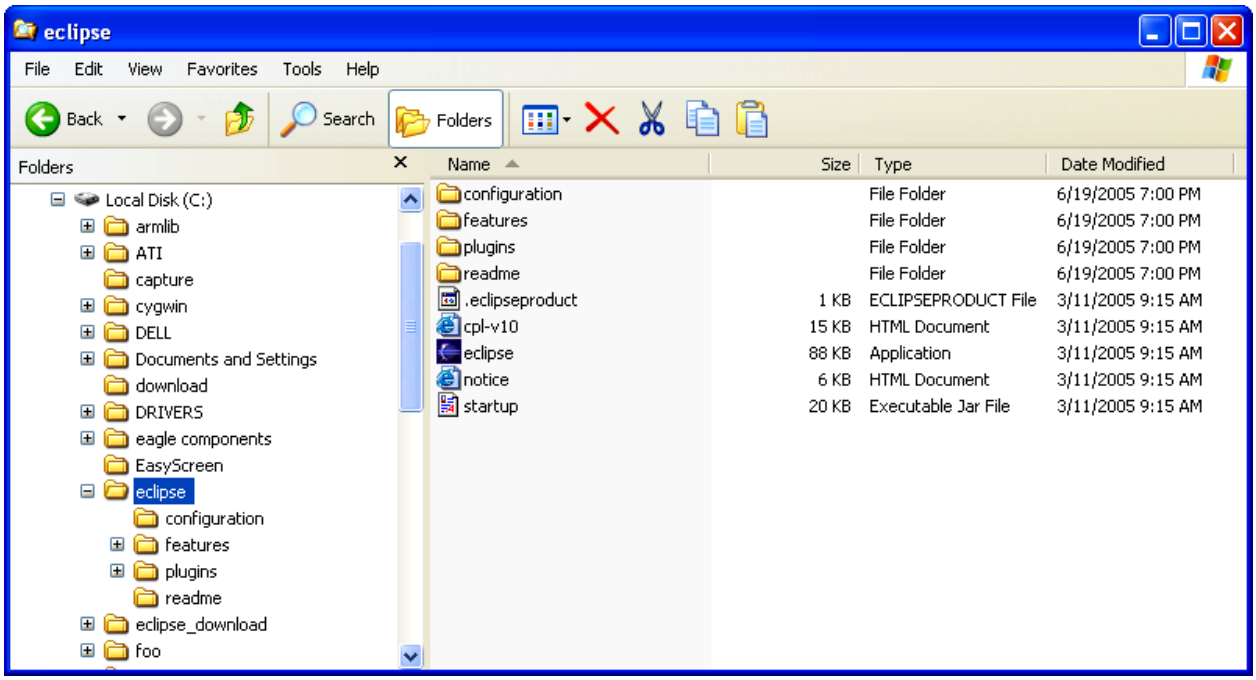
WinZip will ask you into what directory you wish to extract the contents of the zip file. In this case, you must specify the root drive **C:**



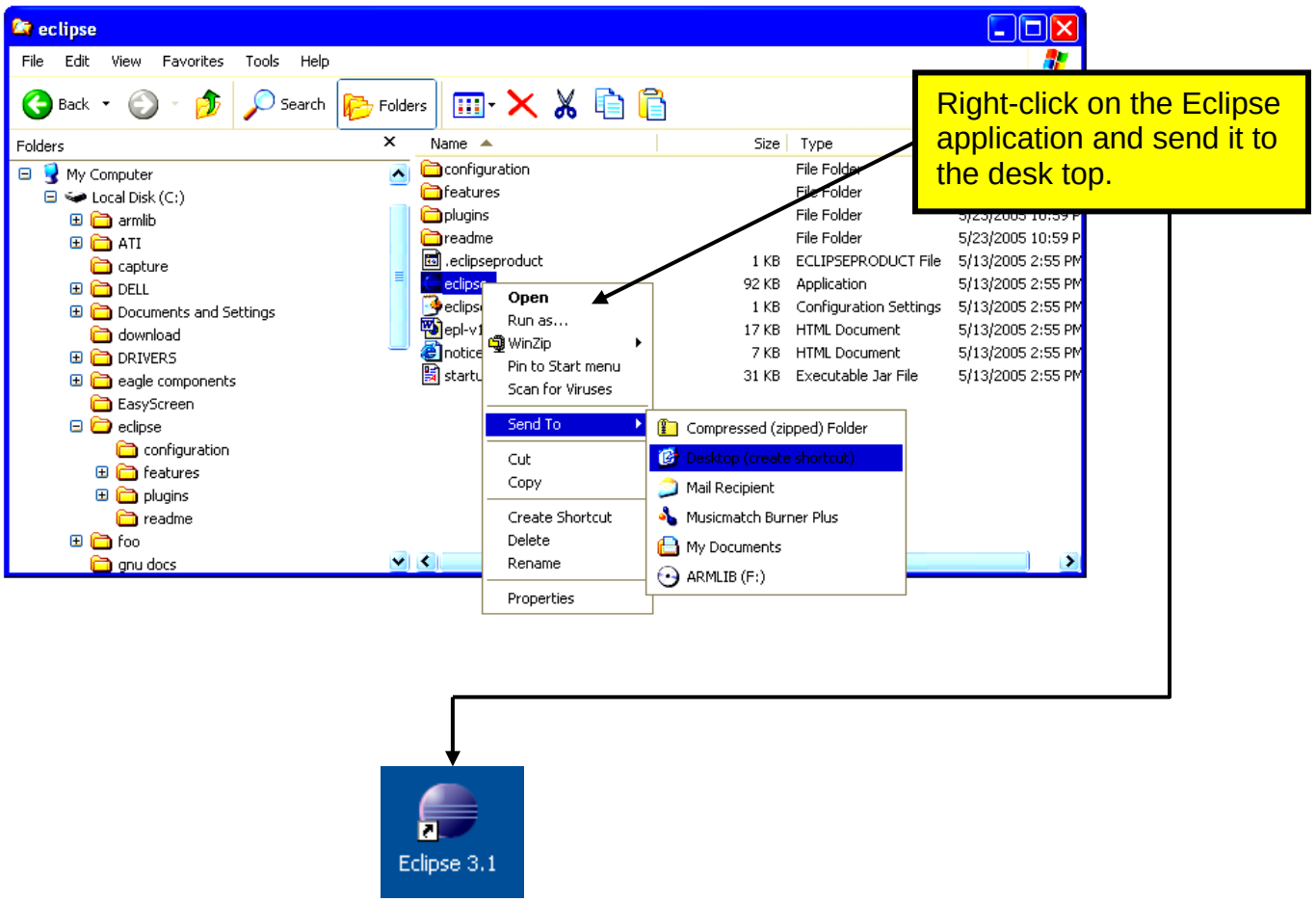
The WinZip Utility will start extracting all the Eclipse files and directories into a c:/eclipse directory on your root drive **C:**



At this point, Eclipse is already installed (some things are done when you run it for the first time). The beauty of Eclipse is that there are no entries made into the Windows registry, Eclipse is just an ordinary executable file. Here's what the Eclipse directory looks like at this point.



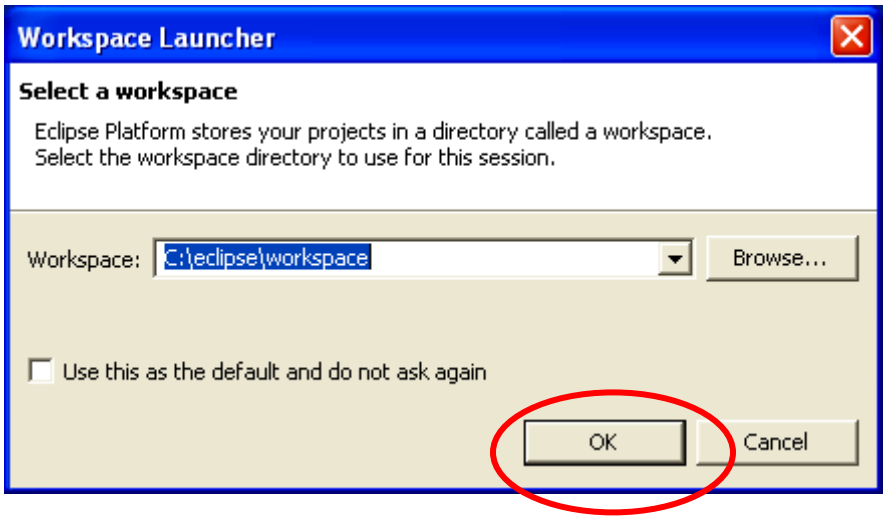
You can create a desktop icon for conveniently starting Eclipse by right-clicking on the Eclipse application above and sending it to the desk top.



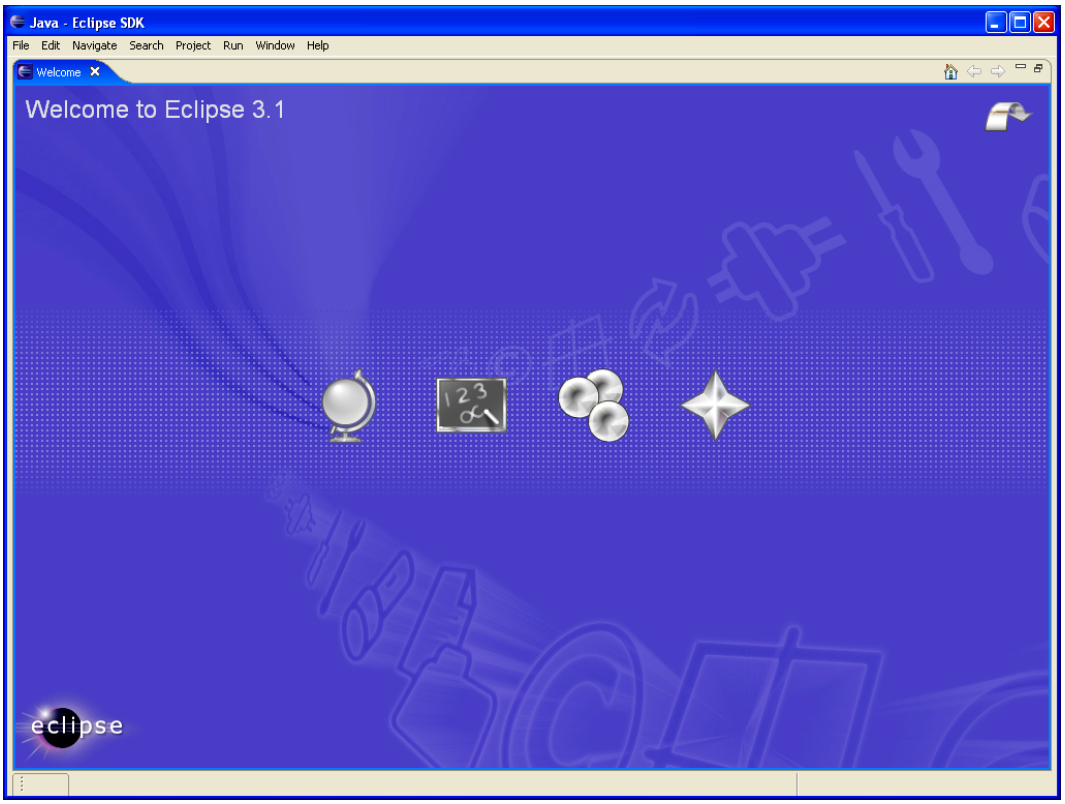
Now is a good time to test that Eclipse will actually run. Click on the desktop icon to start the Eclipse IDE.

If the Eclipse Splash Screen appears, we have succeeded. If not, chances are that the Java Run Time Environment is not in place. Review and repeat the instructions on installing Java on your computer.

The first order of business is to specify the location of the Workspace. I choose to place the workspace within the Eclipse directory. You are free to place this anywhere; you can have multiple workspaces; here is where you make that choice.



When you click OK, the Eclipse main screen will start up.



If you made it this far, you now have a complete Eclipse system capable of developing JAVA programs for the PC. There are a large number of JAVA books and some really good ones showing how to develop Windows applications with JAVA using the Eclipse toolkit.

Eclipse itself was written entirely in JAVA and this shows you just how sophisticated a program can be developed with the Eclipse JAVA IDE.

However, the point of this tutorial is to show how the Eclipse platform with the CDT plug-ins can be used to develop embedded software in C language for the ARM microcomputers.

5 Eclipse CDT

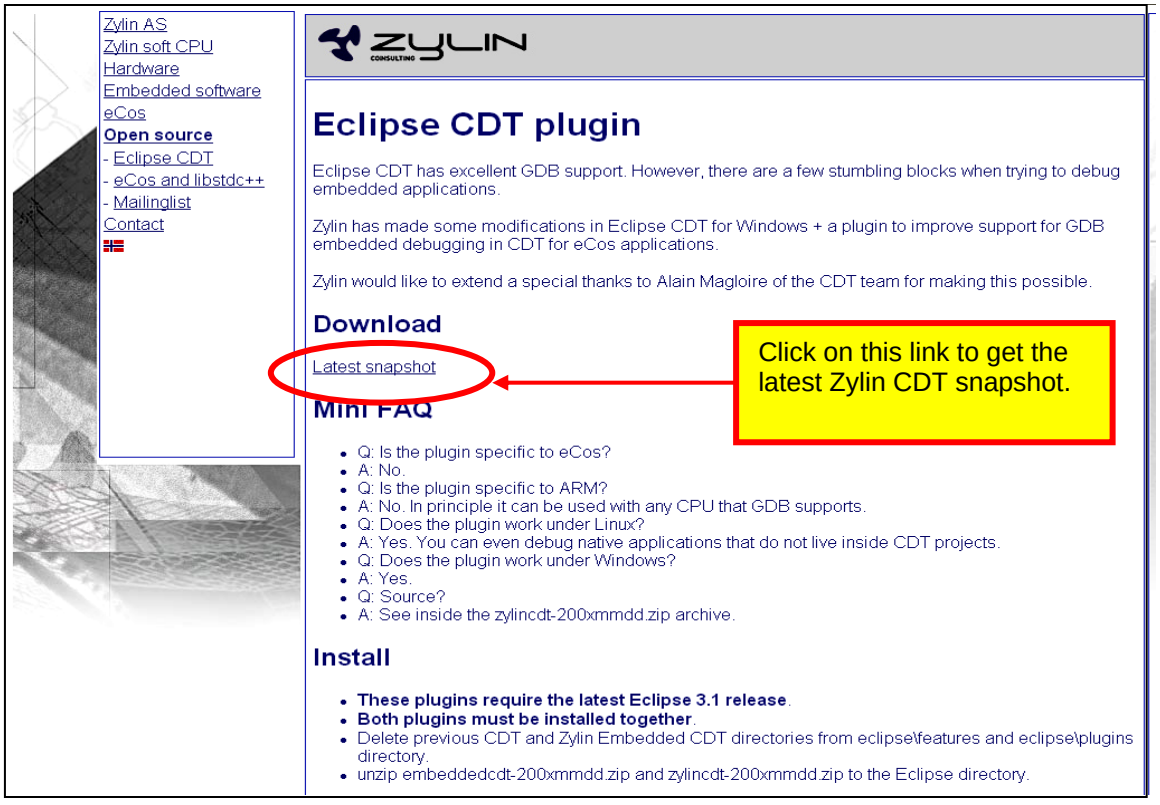
Eclipse, just by itself, is designed to edit and debug JAVA programs. To equip it to handle C and C++ programs, you need to download the **CDT** (C Development Toolkit) plug-in. The **CDT** plug-in is simply zip files that are unzipped into the Eclipse directory.

Unfortunately, the **CDT** plug-in from the Eclipse web site has some problems debugging applications in a cross-development environment (e.g. where the target is a circuit board with an ARM microprocessor and a JTAG interface). To the rescue is the Norwegian engineering company Zylin who have developed a special custom version of **CDT** that properly interfaces the **GDB** debugger to a remote target. The Zylin version of **CDT** was developed with the cooperation of the **CDT** Development Team and is essentially a copy of the latest version of **CDT** with the special debug modifications. The open source community owes a debt of thanks to Øyvind Harboe and his associates at Zylin.

To download the Zylin version of the CDT plug-in, click on the following link:

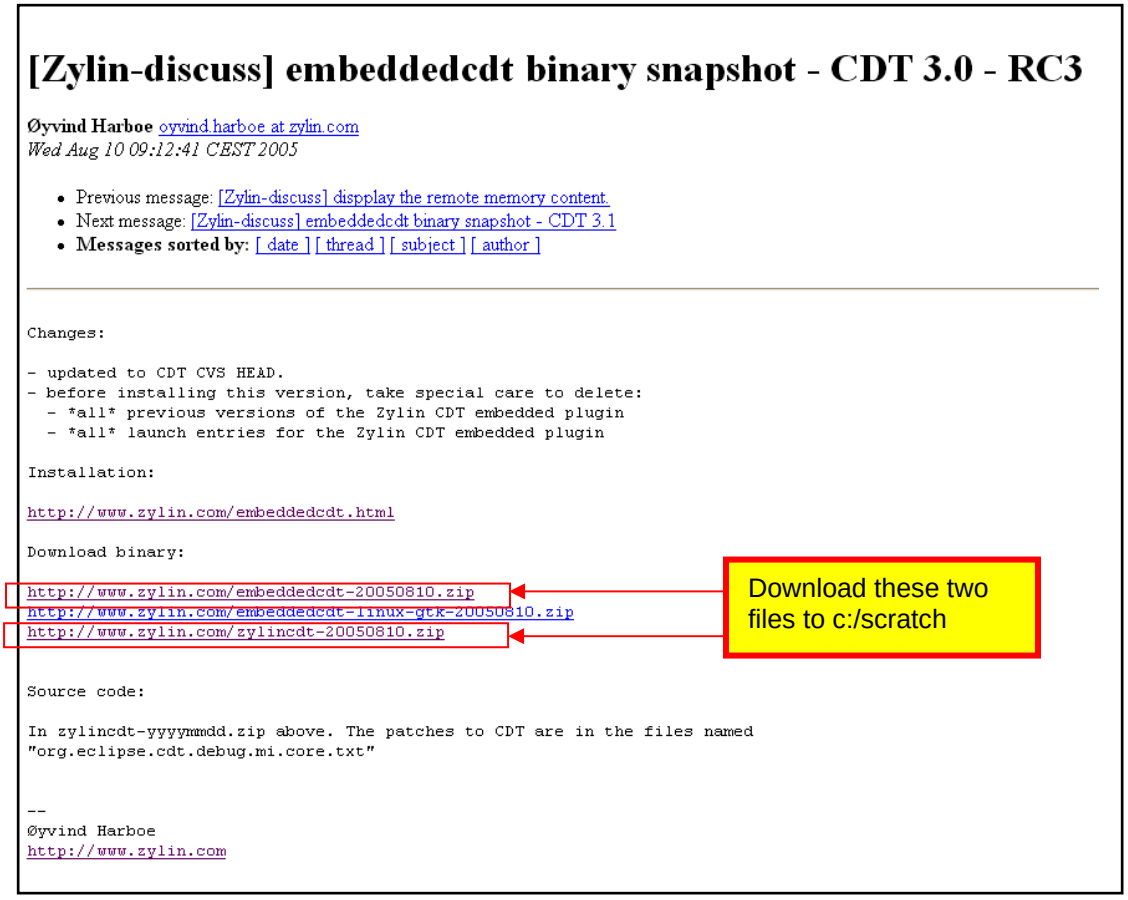
http://www.zylin.com/embeddedcdt.html

The Zylin website page devoted to the CDT plug-in will have a link to the latest “snapshot”. This snapshot is two zip files that you will extract to the c:\eclipse folder.



Download the following two files from the Zylin web site.

http://www.zylin.com/embeddedcdt-20050810.zip
http://www.zylin.com/zylincdt-20050810.zip



[Zylin-discuss] embeddedcdt binary snapshot - CDT 3.0 - RC3

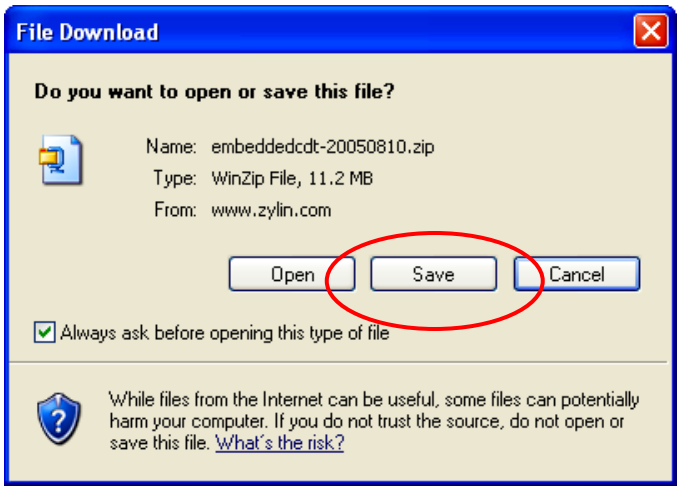
Øyvind Harboe oyvind.harboe at zylin.com
Wed Aug 10 09:12:41 CEST 2005

- Previous message: [Zylin-discuss] dispplay the remote memory content.
- Next message: [Zylin-discuss] embeddedcdt binary snapshot - CDT 3.1
- **Messages sorted by:** [date] [thread] [subject] [author]

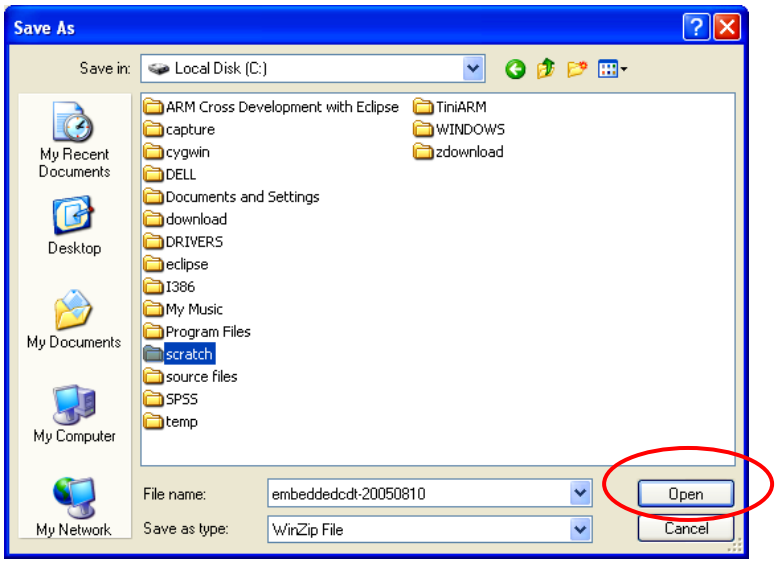
```
Changes:

- updated to CDT CVS HEAD.
- before installing this version, take special care to delete:
  - *all* previous versions of the Zylin CDT embedded plugin
  - *all* launch entries for the Zylin CDT embedded plugin

Installation:

http://www.zylin.com/embeddedcdt.html

Download binary:

http://www.zylin.com/embeddedcdt-20050810.zip
http://www.zylin.com/embeddedcdt-linux-gtk-20050810.zip
http://www.zylin.com/zylincdt-20050810.zip


Source code:

In zylincdt-yyyymmdd.zip above. The patches to CDT are in the files named
"org.eclipse.cdt.debug.mi.core.txt"


--
Øyvind Harboe
http://www.zylin.com
```

Download these two files to c:/scratch

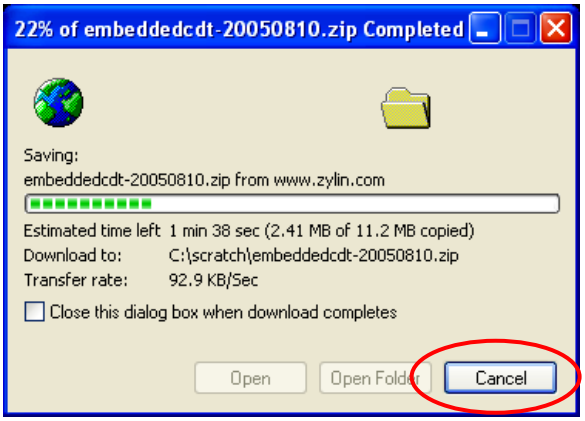
First, click on **http://www.zylin.com/embeddedcdt-20050810.zip** to download. Then click on "**Save**" in the File Download window.



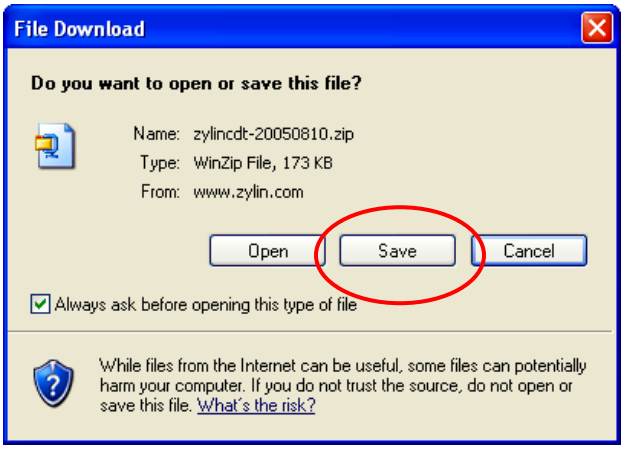
Select the temporary **c:\scratch** directory as the target of the download and click "**Open**."



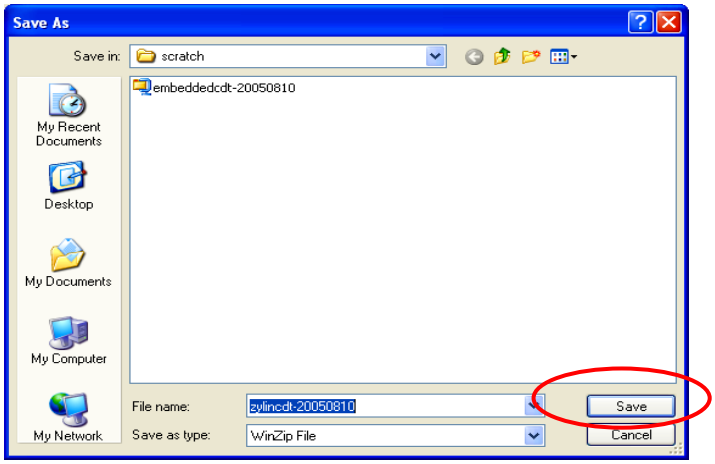
The first Zylin CDT zip file will download into the **c:\scratch** folder. This file is an 11 Mb download.



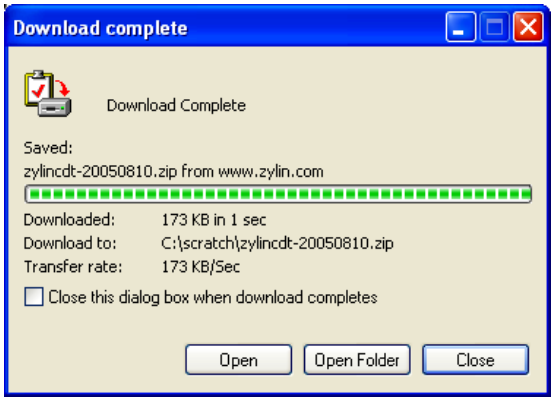
Next, click on **http://www.zylin.com/zylincdt-20050810.zip** to download. Then click on "**Save**" in the File Download window.



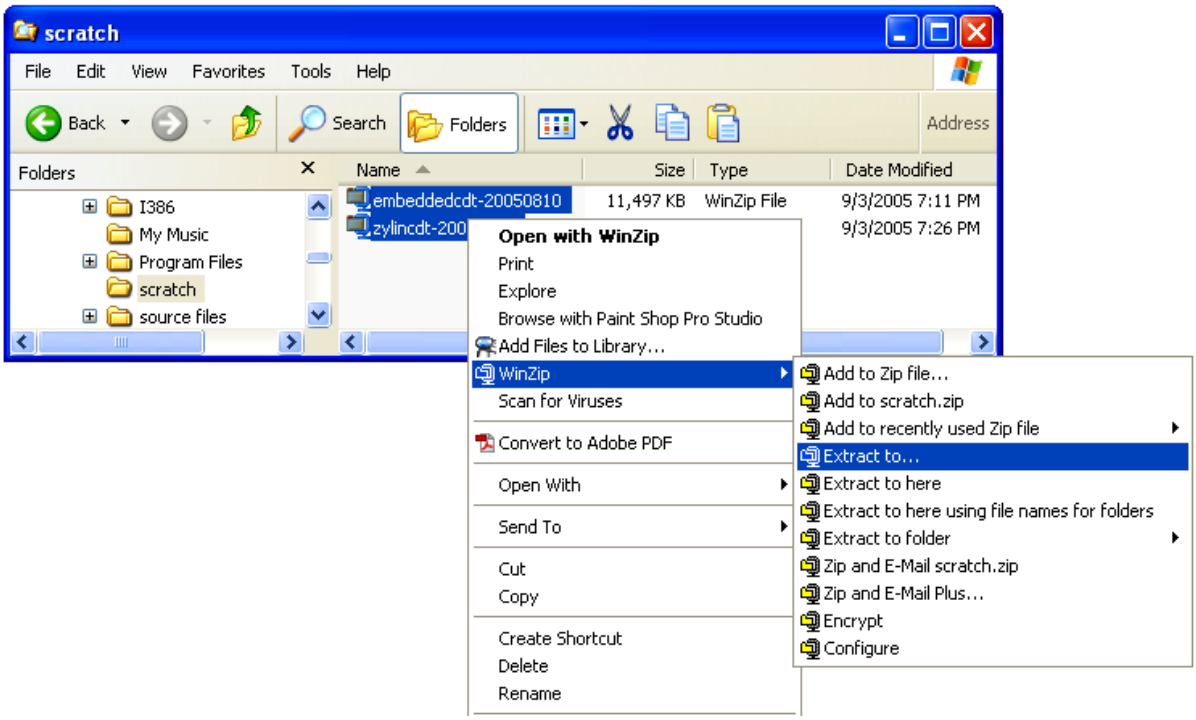
Select the temporary **c:\scratch** directory as the target of the download.

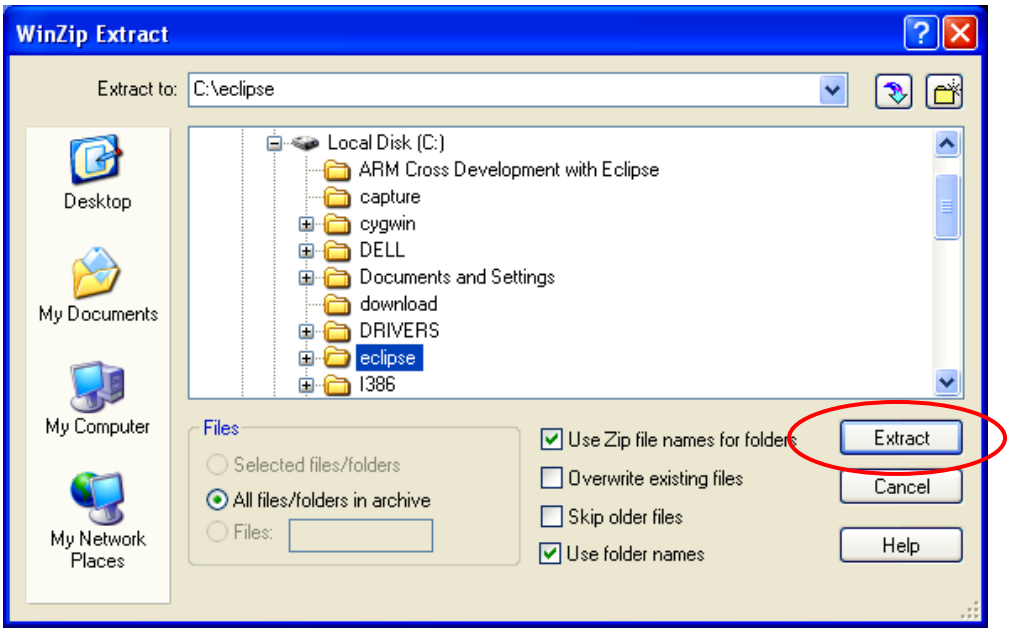


The second Zylin CDT zip file will download into the **c:\scratch** folder. This file is a shorter file, only 173 Kb.



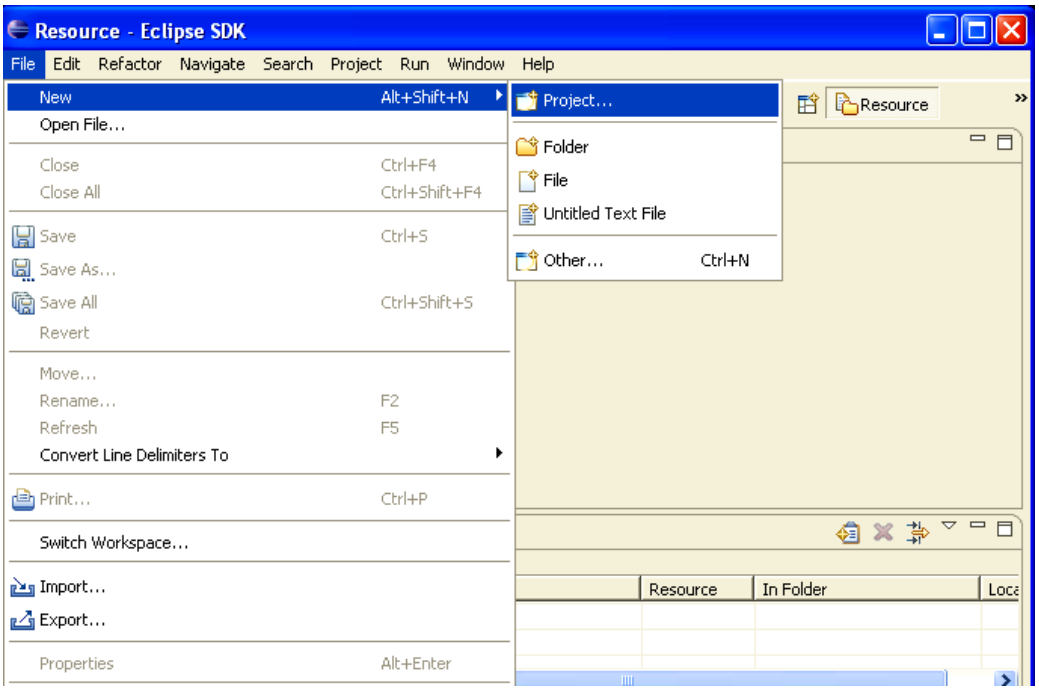
Select both Zylin **CDT** files in the **c:\scratch** folder using Windows Explorer and use WinZip to extract them to the **c:\eclipse** folder.



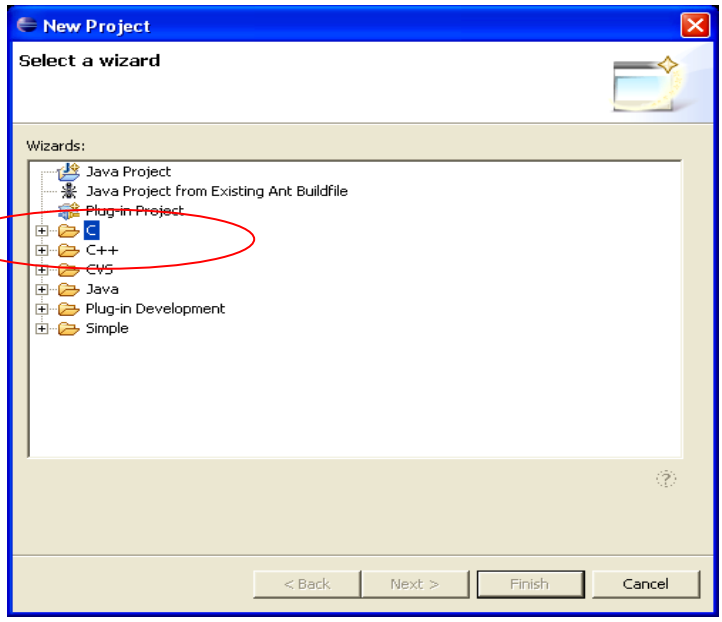


To verify that Eclipse had the **CDT** installed properly, start Eclipse by clicking on the desktop icon.

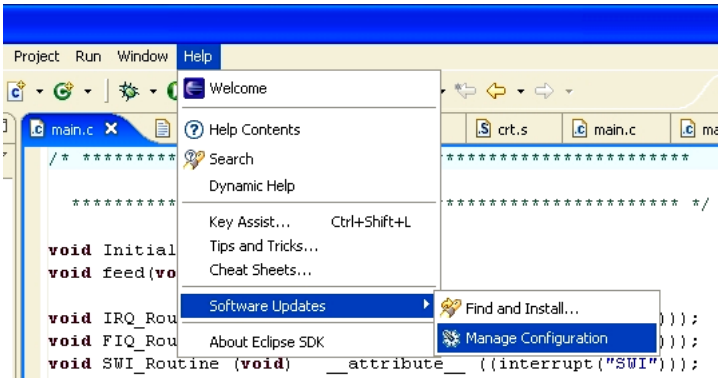
When Eclipse starts, click on "**File – New - Project…**"



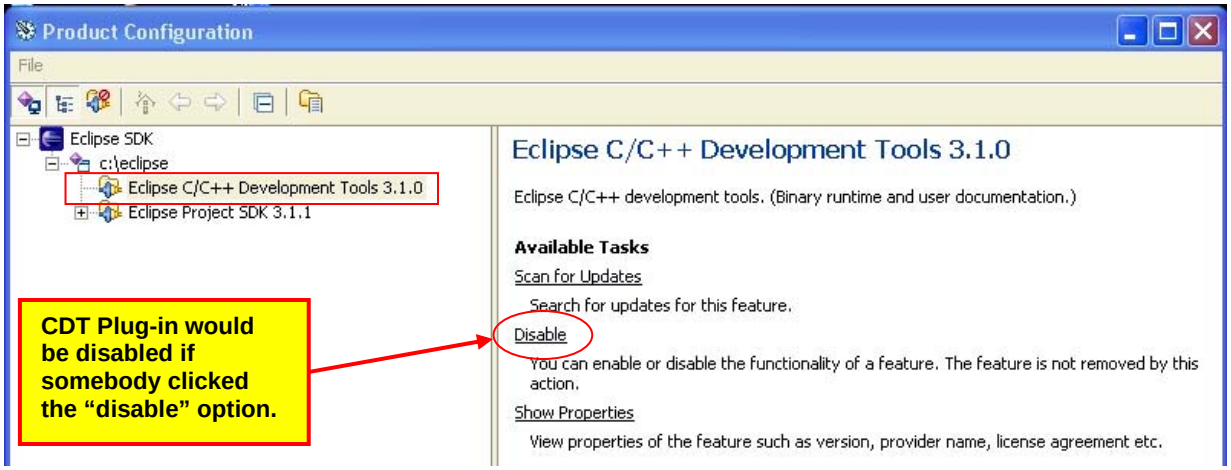
When the New Project window appears, check if C and C++ appear as potential projects. If this is true, Eclipse CDT has been installed properly.



If you don't see the C and C++ listed, here's what might have happened. It's possible to disable the CDT plug-in. To see where this may be done, click "**Help – Software Updates – Manage Configuration**".



If you click on **Eclipse C/C++ Development Tools 3.1.0**, you will see an option to **disable** the CDT plug-in. If this has been disabled, use these menus to reverse this situation.



6 CYGWIN GNU Toolset for Windows

The GNU toolset is an open-source implementation of a universal compiler suite; it provides C, C++, ADA, FORTRAN, JAVA, and Objective C. All these language compilers can be targeted to most of the modern microcomputer platforms (such as the ARM 32-bit RISC microcontrollers) as well as the ubiquitous Intel/Microsoft PC platforms. By the way, GNU stands for “GNU, not Unix”, really – I’m serious!

Unfortunately for all of us that have desktop Intel/Microsoft PC platforms, the GNU toolset was originally developed and implemented with the Linux operating system. To the rescue came Cygwin, a company that created a set of Windows dynamic link libraries that trick the GNU compiler toolset into thinking that it’s running on a Linux platform. If you install the GNU compiler toolset using the Cygwin system, you can literally open up a DOS command window on your screen and type in a DOS command like this:

```
>arm-elf-gcc   –g  –c     main.c
```

The above will compile the source file **main.c** into an object file **main.o** for the ARM microcontroller architecture. In other words, if you install the Cygwin GNU toolset properly, you can forget that the GNU compiler system is Linux-based.

Normally, the Cygwin installation gives you a compiler toolset whose target architecture is the Windows/Intel PC platform. It does not include a compiler toolset for the ARM microprocessors, the MIPS microprocessors, and so forth.

It is possible to build a compiler toolset for the ARM processors using the generic Cygwin GNU toolkit. In his book “**Embedded System Design on a Shoestring**”, Lewin A.R.W. Edwards gives detailed instructions on just how to do that. Fortunately, there are quite a few pre-built tool chains on the internet that simplify the process. One such tool chain is GNUARM which gives you a complete set of ARM compilers, assemblers and linkers. This will be done in the next section of this tutorial.

It’s worth mentioning that the GNUARM tool chain doesn’t include the crucial MAKE utility, it’s in the Cygwin tool kit we’re about to install. This is why you have to add two path specifications to your Windows environment; one for the **c:/cygwin/bin** folder and one for the **c:/programfiles/gnuarm/bin**.

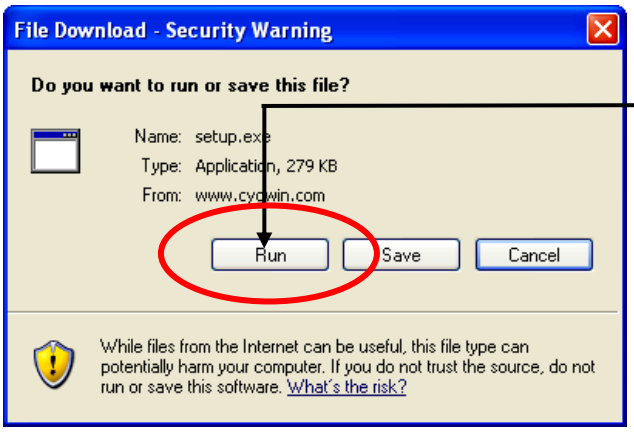
The Cygwin site that has the GNU toolset for Windows is:

www.cygwin.com

The Cygwin web site opens as follows:

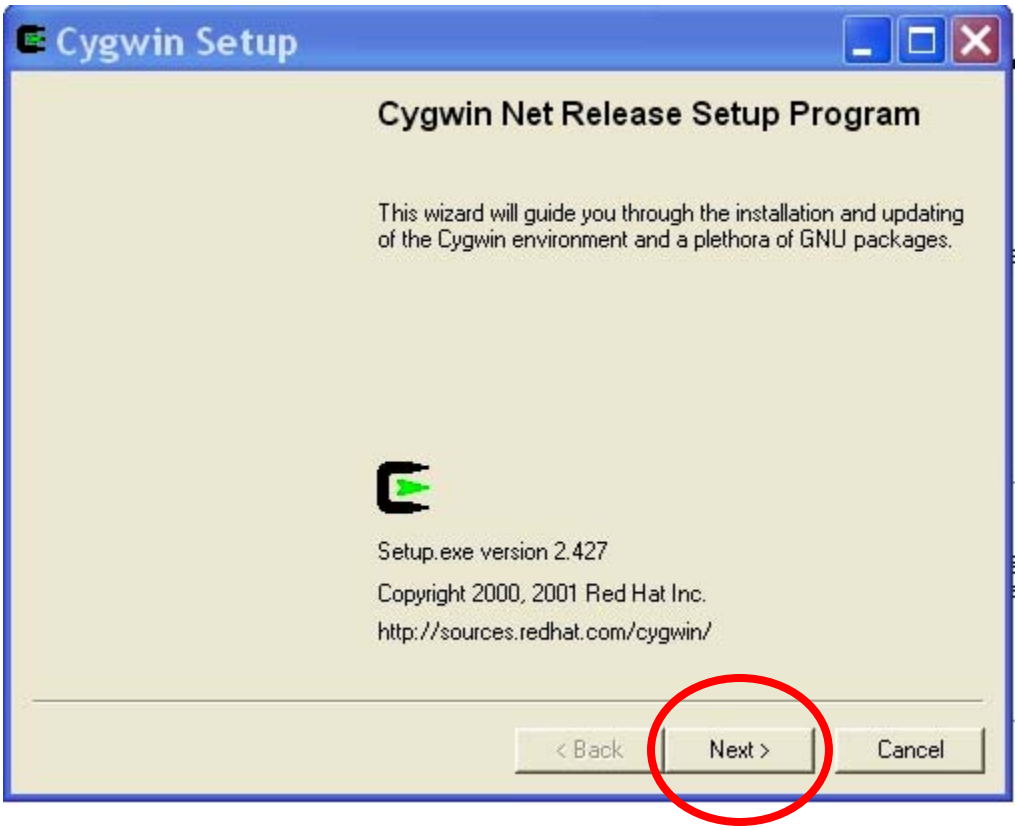
The first thing to do is to click on the install icon:

We need to download the setup executable and automatically run it.

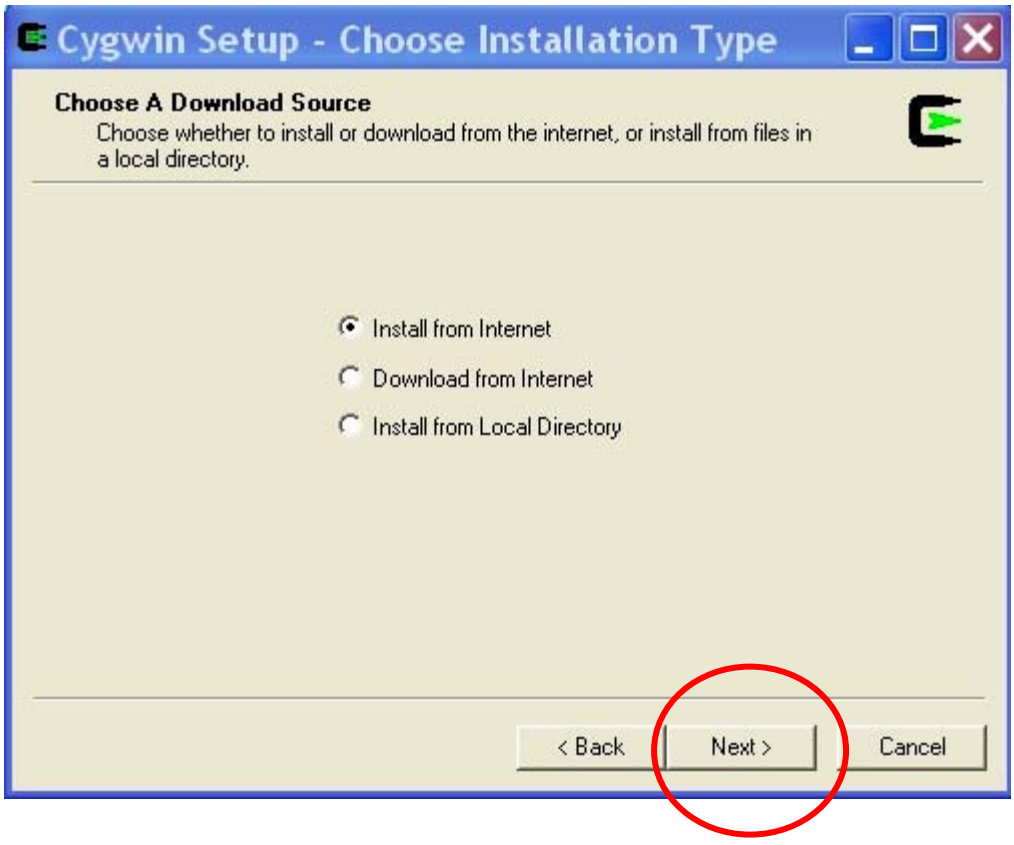


Click on "**Run**" to download and run the Cygwin setup program.

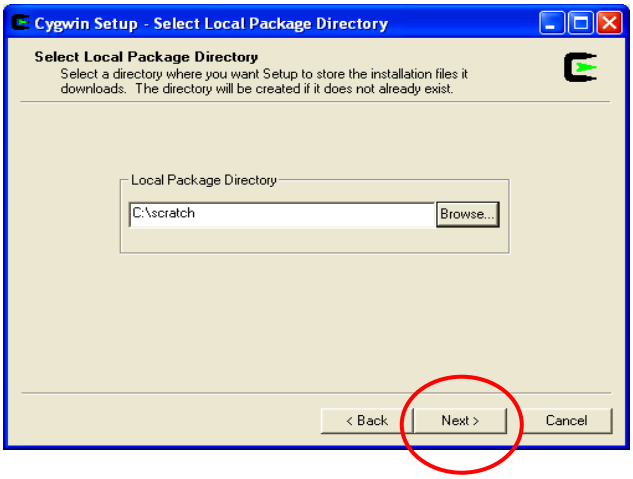
Now the Cygwin wizard will start up. Select "**Next**" to continue.



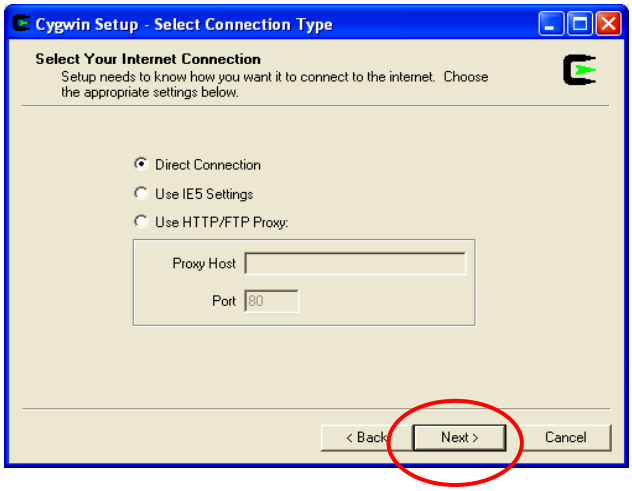
Choose "**Install from Internet**" and then click "**Next**."



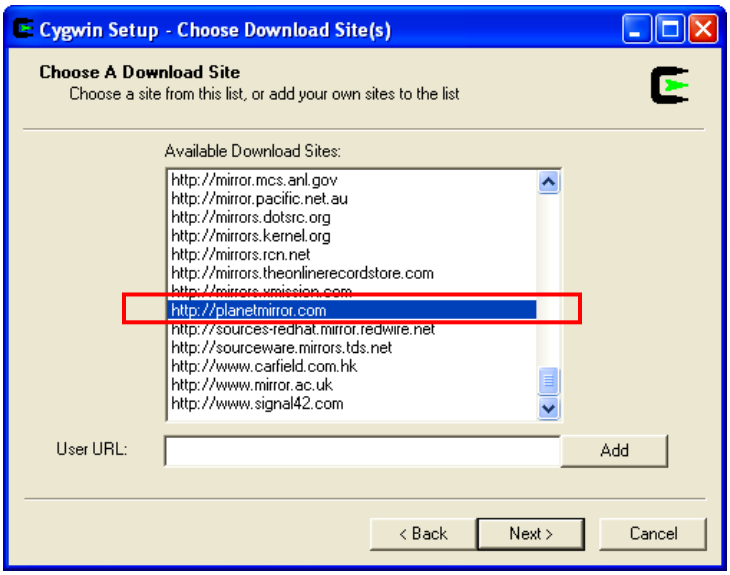
Now we specify a directory where all the downloaded components go, our **c:/scratch** folder will do just fine.



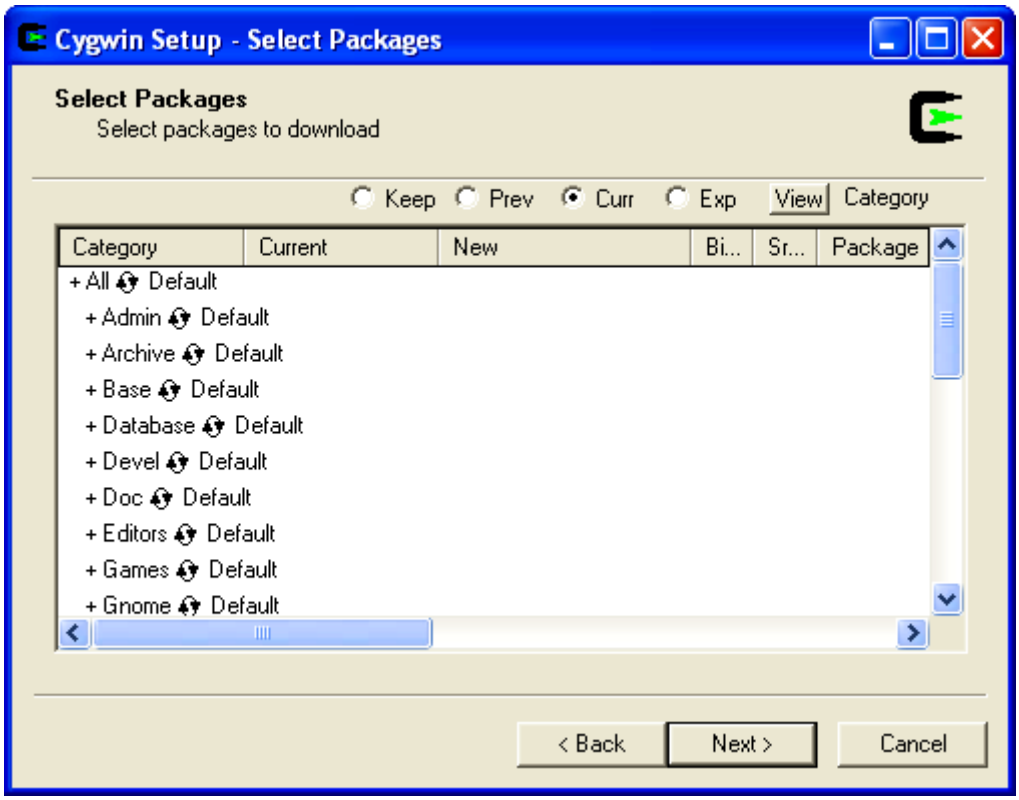
Since I have a high speed internet connection, I always select "**Direct Connection**." Click "**Next**" to continue.



Now the Cygwin Installer presents you with a list of mirror sites that can deliver the Cygwin GNU Toolkit. It's a bit of a mystery which one to choose; I picked http://planetmirror.com because it sounds cool. You may have to experiment to find one that downloads the fastest. Click "**Next**" to continue.



Cygwin will download a few bits for a couple of seconds and then display this "**Select Packages**" list allowing you to tailor exactly what is included in the down load.



The screen above allows you to specify what GNU packages you wish to install.

Basically, we want an installation that will allow us to compile for the Windows XP / Intel platform. This will allow us to use Eclipse to build Windows applications (not covered in this document). Remember that we'll be installing the GNUARM suite of compilers, linkers etc. for the ARM processor family shortly.

If you look at the Cygwin "Select Packages" screen below, you'll see the following line.

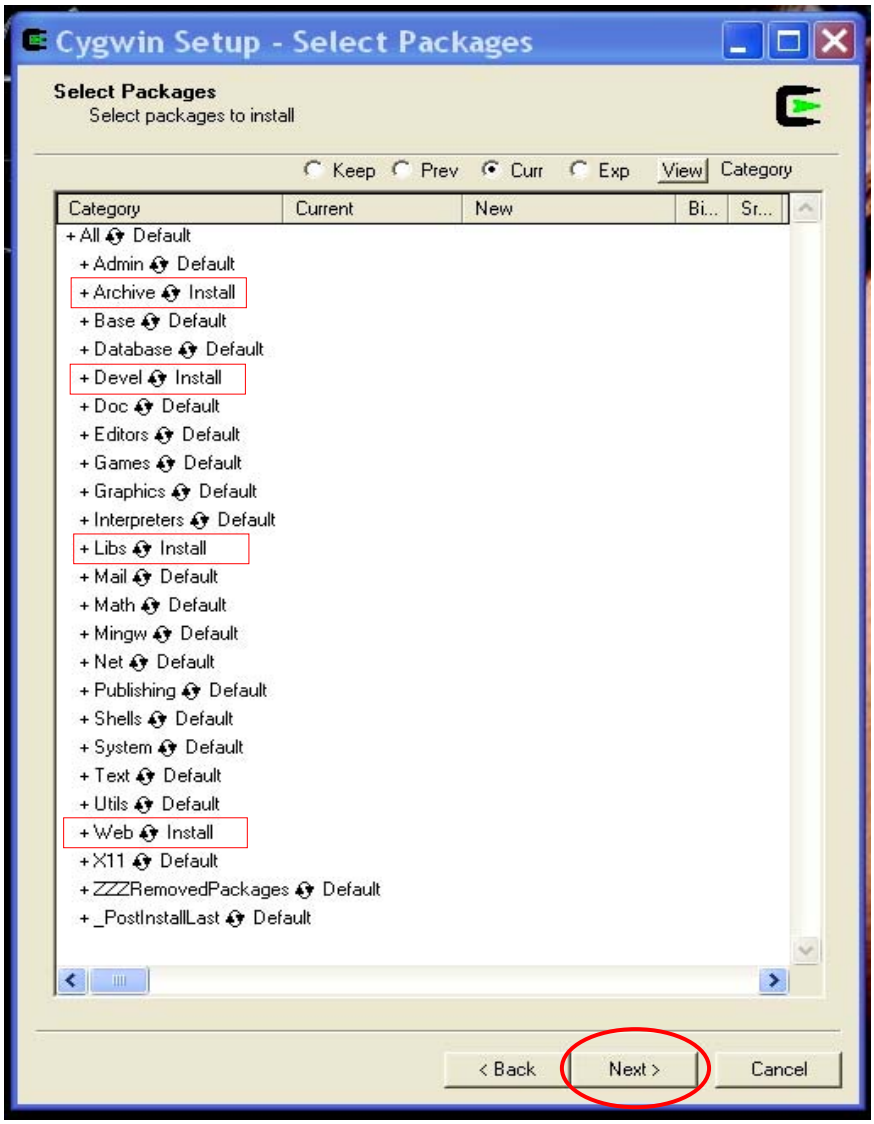
You must click on the little circle with the two arrowheads until the line changes to this:

This will force installation of the default GNU compiler suite for Windows/Intel targets. Here's the "**Select Packages**" screen before clicking on the circle with arrowheads.

The following four packages must be selected and changed from “**default**” to “**install**.”

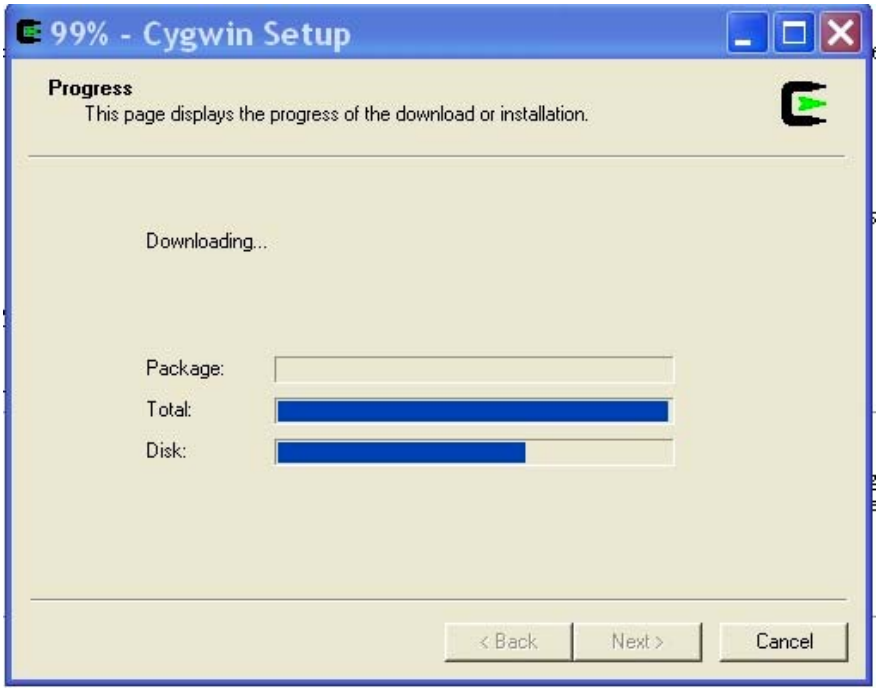
Archive	↻	**Default**		**Archive**	↻ **Install**
Devel	↻	**Default**		**Devel**	↻ **Install**
Libs	↻	**Default**	→	**Libs**	↻ **Install**
Web	↻	**Default**		**Web**	↻ **Install**

Click on the little circle with the arrowheads until you change the four packages listed above from “**default**” to “**install**.” You should see the screen displayed directly below. Note that the Archive, Devel, Libs and Web components are selected for “Install”. Everything else is left as “default.”



Click “**Next’** to start the download.

Now the Cygwin will start downloading. This creates a huge 700 Megabyte directory on your hard drive and takes 30 minutes to download and install using a cable modem.



When the installation completes, Cygwin will ask you if you want any desktop icons and start menu entries set up. Say "**No**" to both. These icons allow you to bring up the BASH shell emulator (like the command prompt window in Windows XP). This would allow you do some Linux operations, but this capability is not necessary for our purposes here. Click on "**Finish**" to complete the installation.

Now the Cygwin installation manager completes and shows the following result.

The directory **c:\cygwin\bin** must be added to the **Windows XP** path environment variable. This allows Eclipse to easily find the Make utility, etc.

Using the **Start Menu**, go to the **Control Panel** and click on the "**System**" icon.

Then click on the "**Advanced**" tab and select the "**Environment Variables**" icon. Highlight the "**Path**" line and hit the "**Edit**" button. Add the addition to the path as shown in the dialog box shown below (don't forget the semicolon separator). The Cygwin FAQ advises putting this path specification before all the others.

We are now finished with the CYGWIN installation. It runs silently in the background and you should never have to think about it again.

7 Downloading the GNUARM Compiler Suite

At this point, we have all the GNU tools needed to compile and link software for Windows/Intel computers. It is possible to use all this to build a custom GNU compiler suite for the ARM processor family. The very informative book "**Embedded System Design on a Shoestring**" by Lewin A.R.W. Edwards ©2003 describes how to do this and it is rather involved.

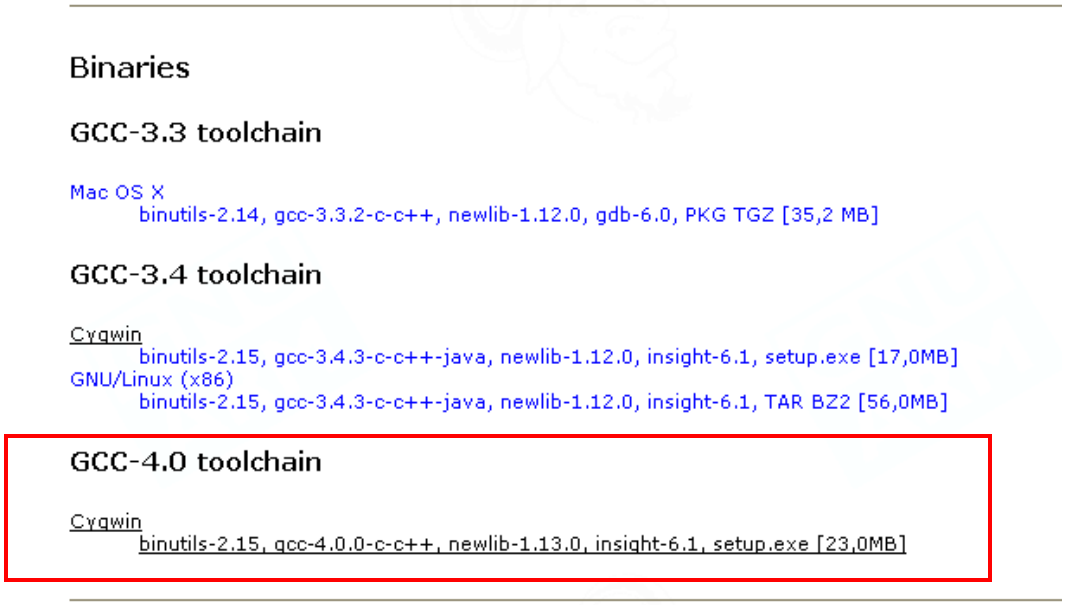
Fortunately, Rick Collins, Pablo Bleyer Kocik and the people at **gnuarm.com** have come to the rescue with pre-built GNU compiler suite for the ARM processors. Just download it with the included installer and you're ready to go.

Click on the following link to download the GNUARM package.

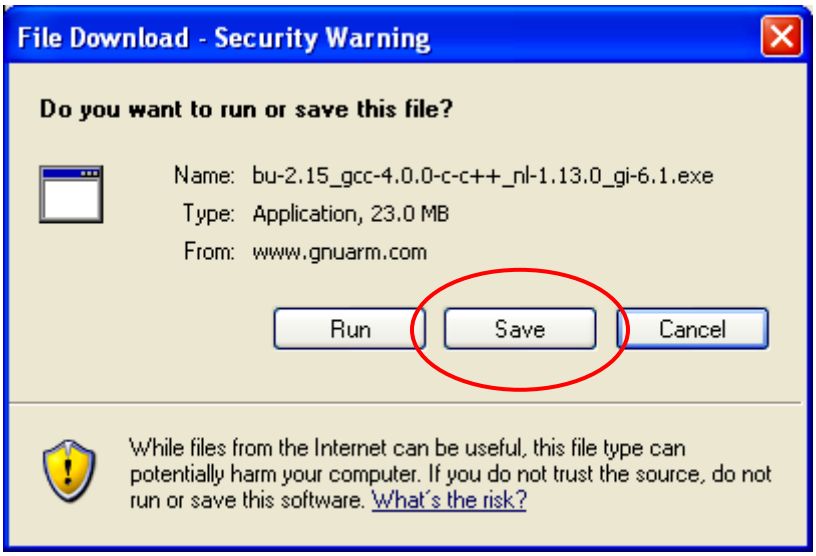
www.gnuarm.com

The GNUARM web site will display and you should click on the "**Files**" tab.

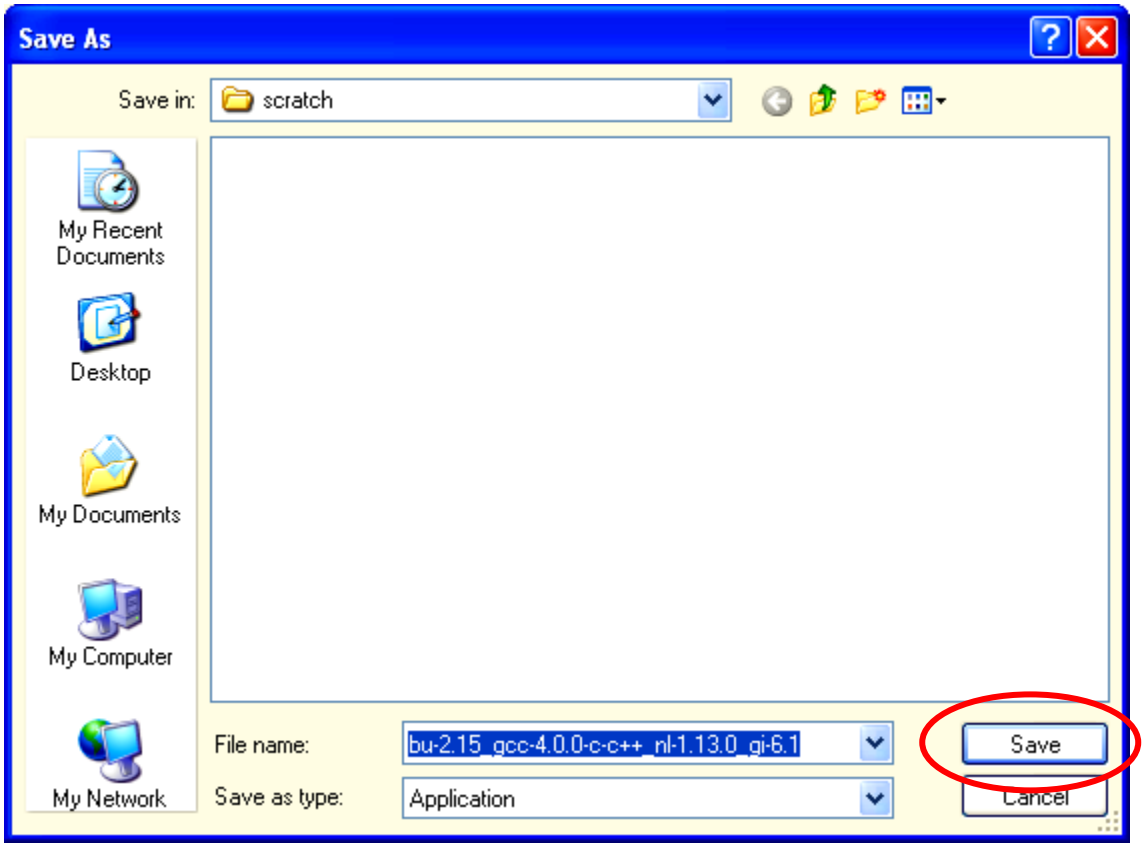
The correct package to download is **Binaries Cygwin – GCC- 4.0 toolchain**



Just like all the other downloads we've done, we direct this one to our empty download directory on the hard drive. Here we click "**Save**" and then specify the download destination.

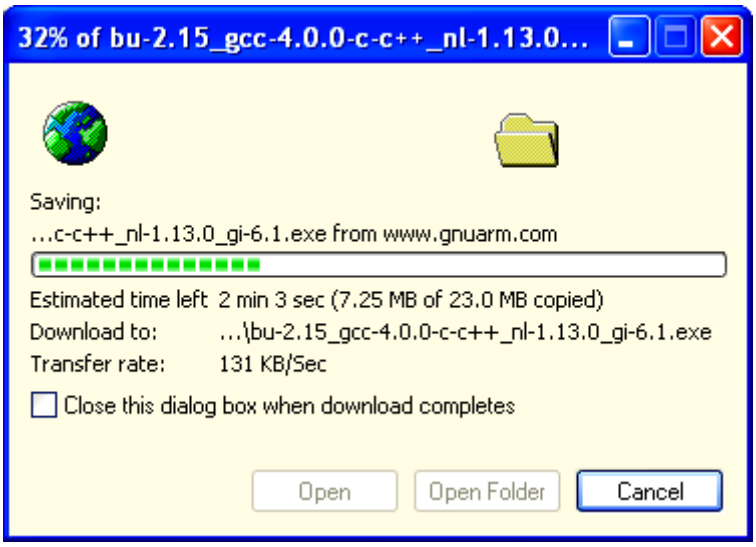


Once again, our **c:/scratch** directory will suffice.



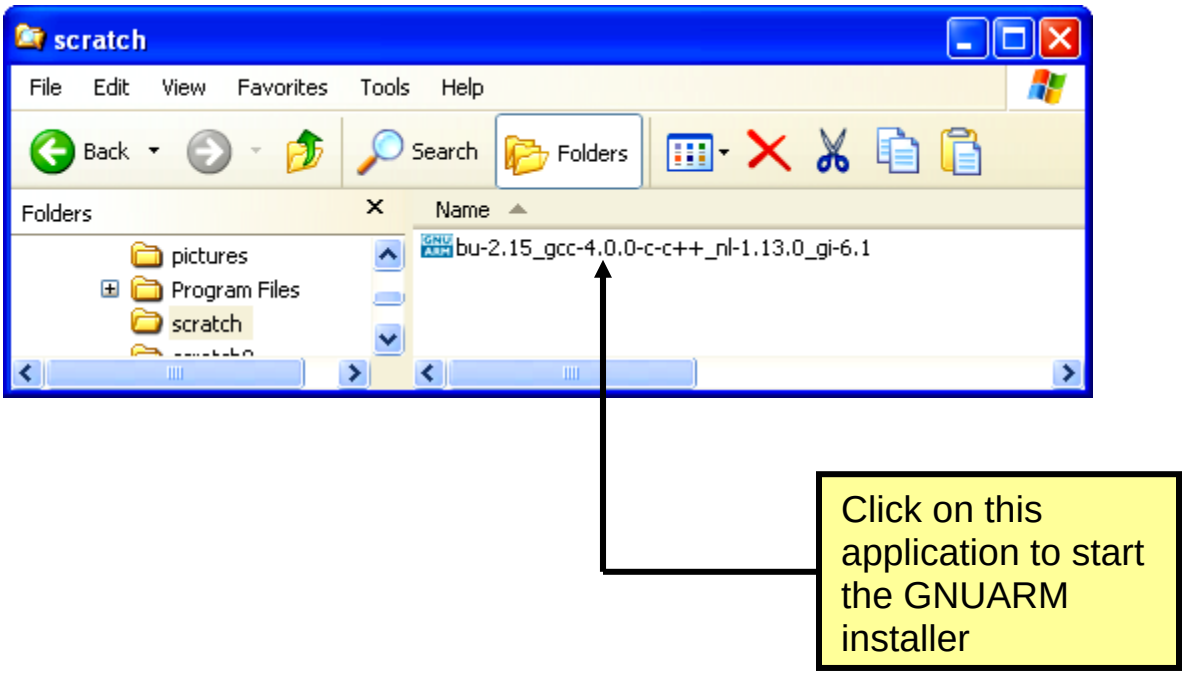
As you can see, this download has a very long name!

This download is a 18 megabyte file and takes 30 seconds on a cable modem.

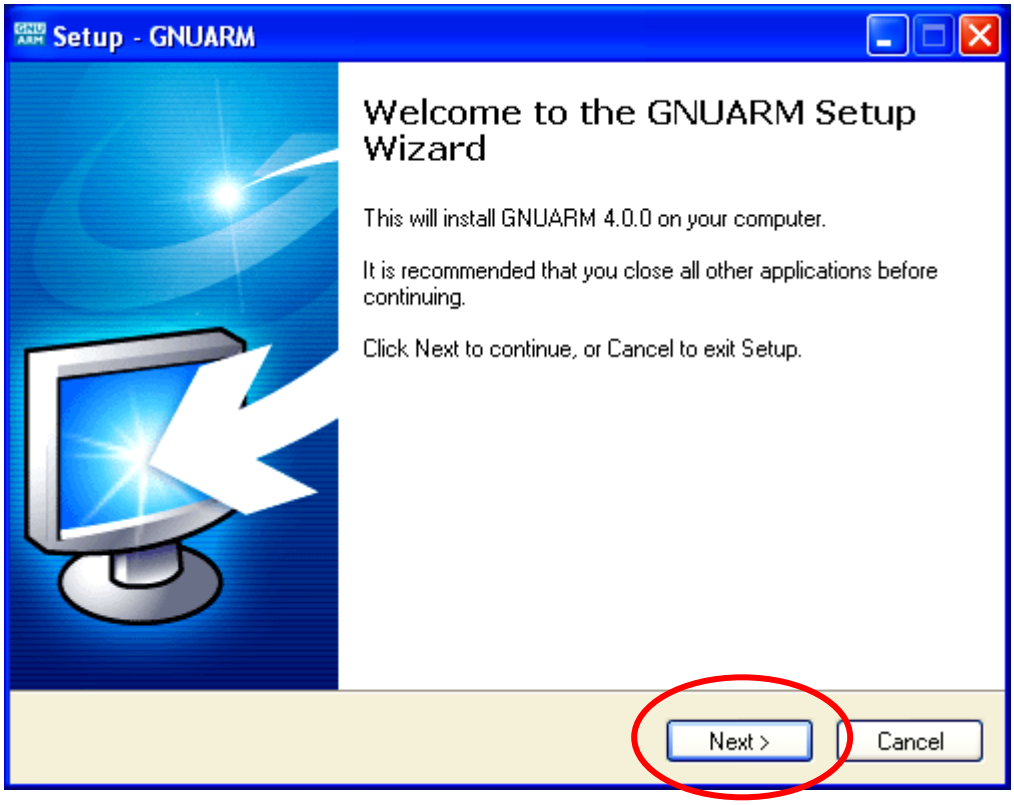


The download directory now has the following setup application with the following unintelligible filename: **bu-2.15_gcc-3.4.1-c-c++-java_nl-1.12.0_gi-6.0.exe**

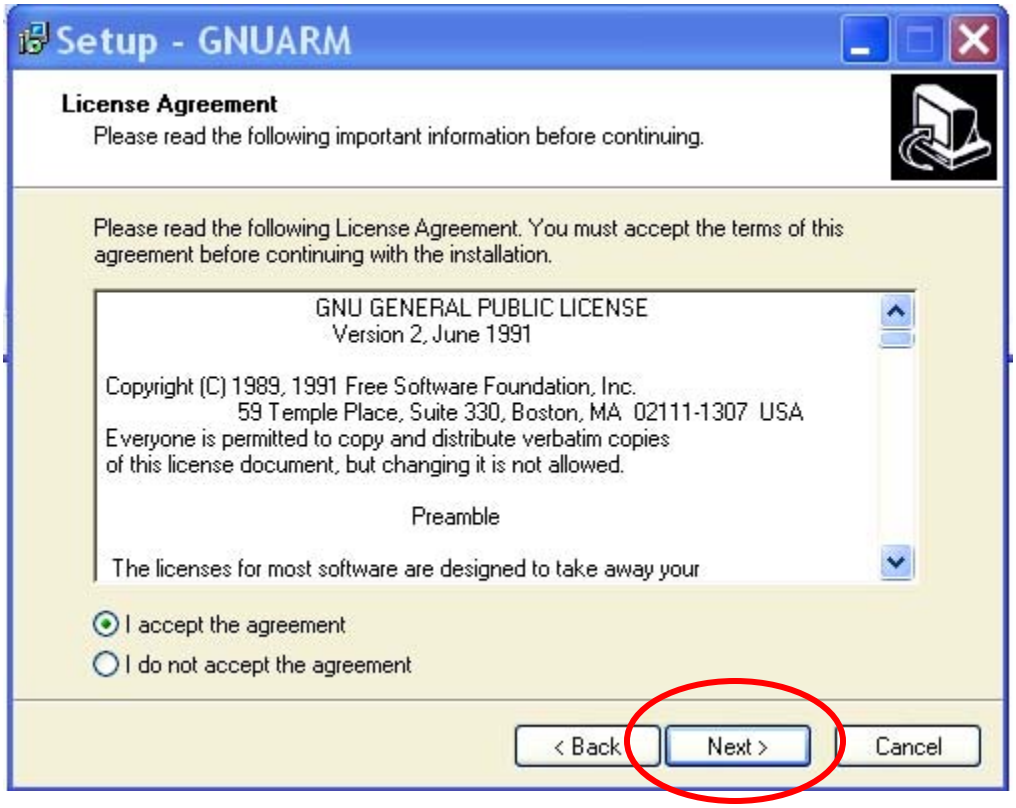
Click on that filename to start the installer.



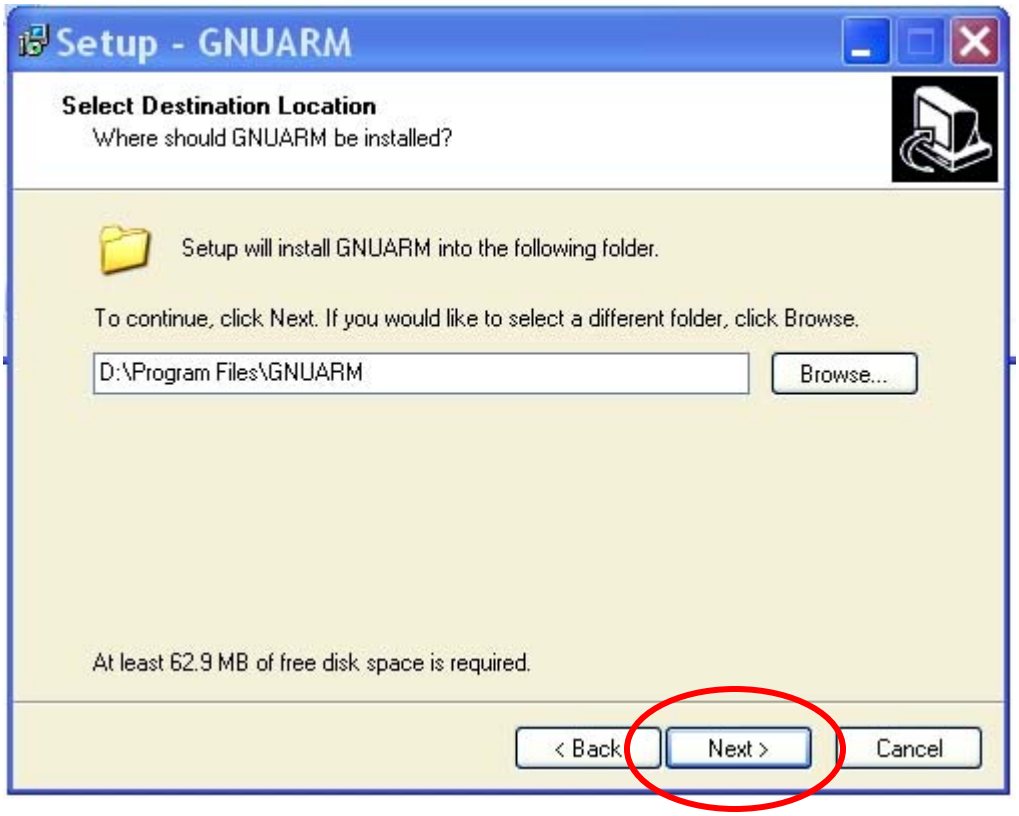
The GNUARM installer will now start. Click **“Next”** to continue.



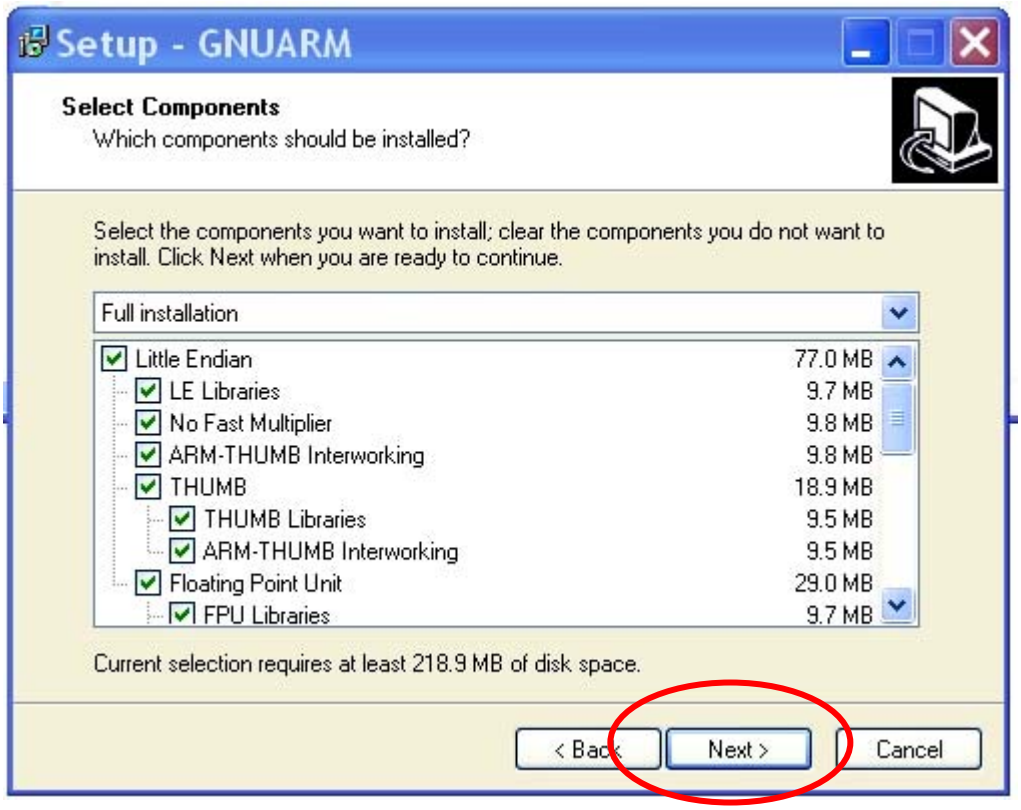
Accept the GNU license agreement – don’t worry, it’s still free. Click **“Next”** to continue.



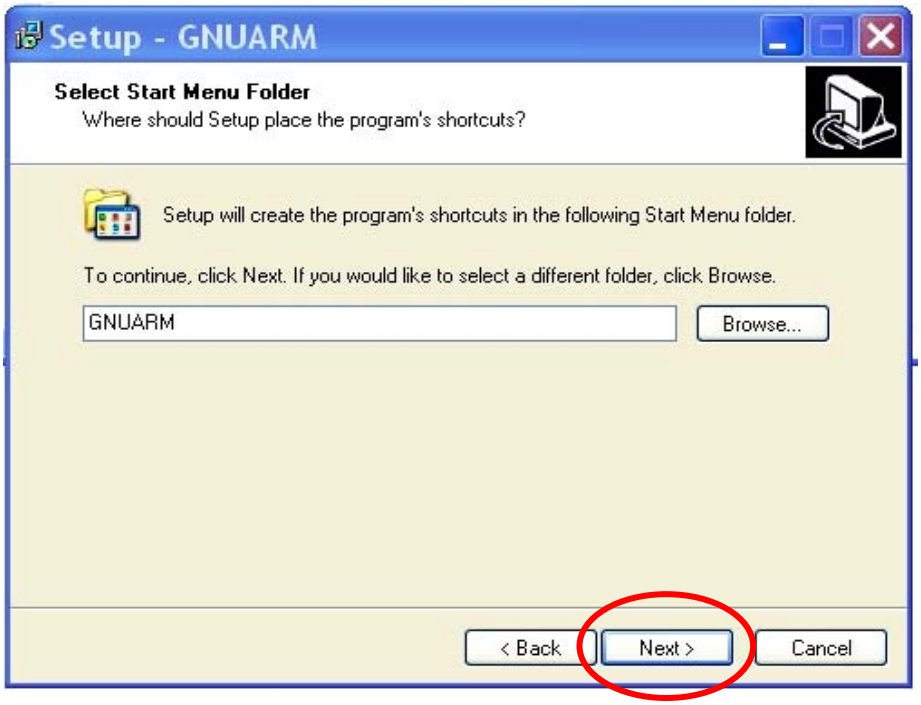
We'll take the default and let it install into the "**Program Files**" directory. Click **"Next"** to continue.



We'll also take the defaults on the "Select Components" window. Click **"Next"** to continue.

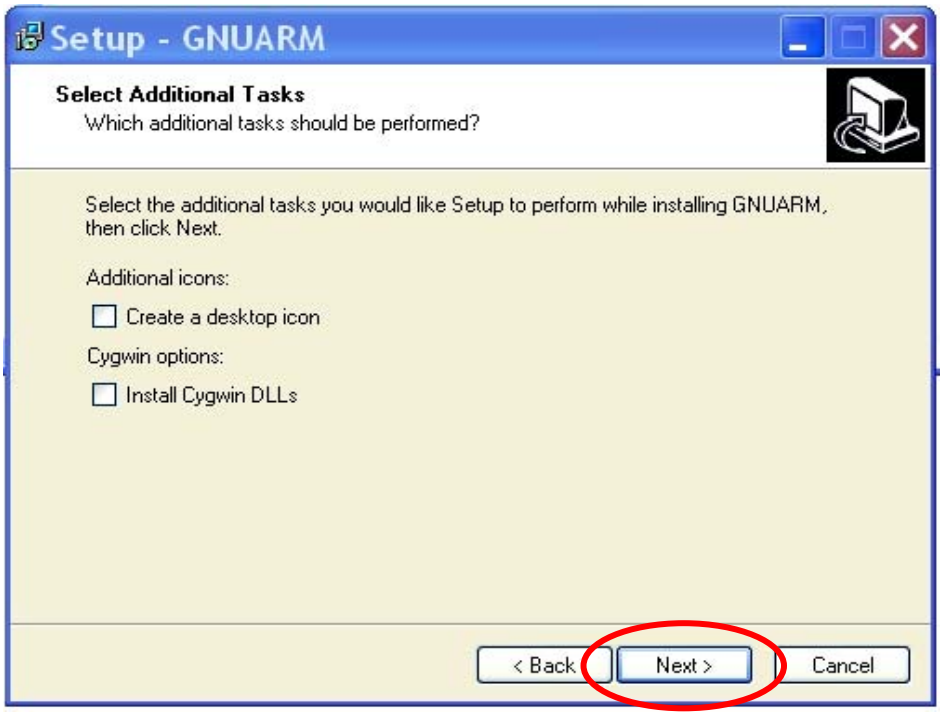


Take the default on this screen. Click **"Next"** to continue.

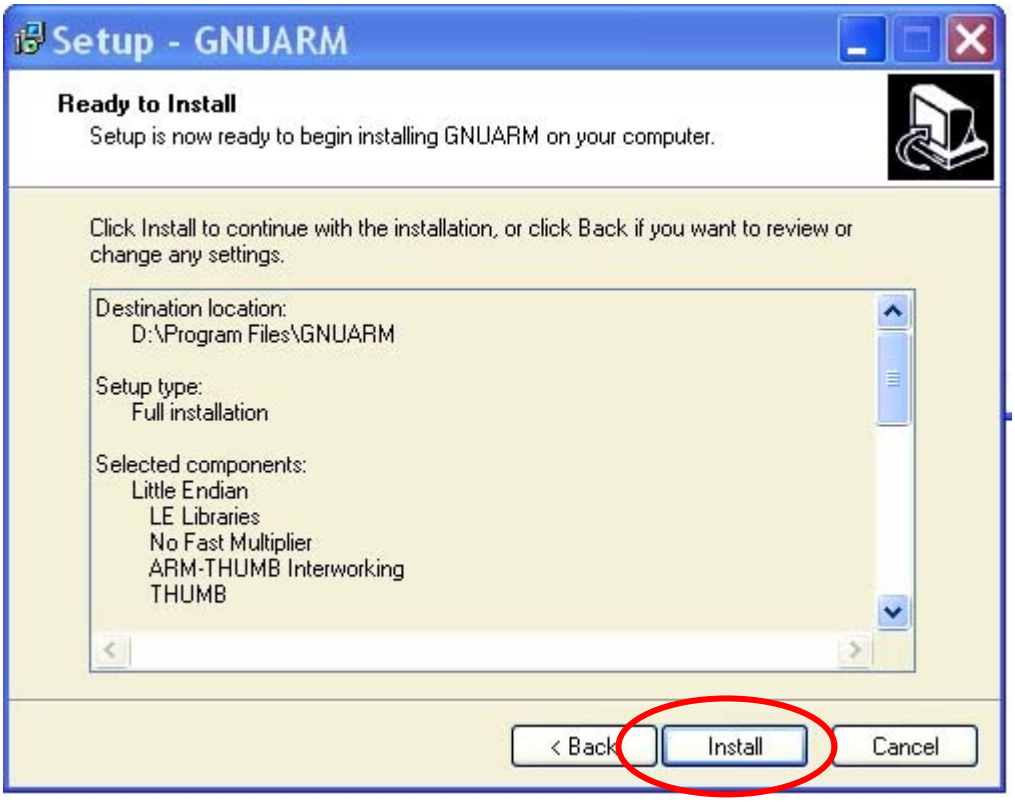


It's very important that you <u>don't check</u> **"Install Cygwin DLLs**" below. We already have the Cygwin DLLs installed from our Cygwin environment installation. In fact, the ARM message boards have had recent comments suggesting that the Cygwin DLL installation from within GNUARM has some problems.

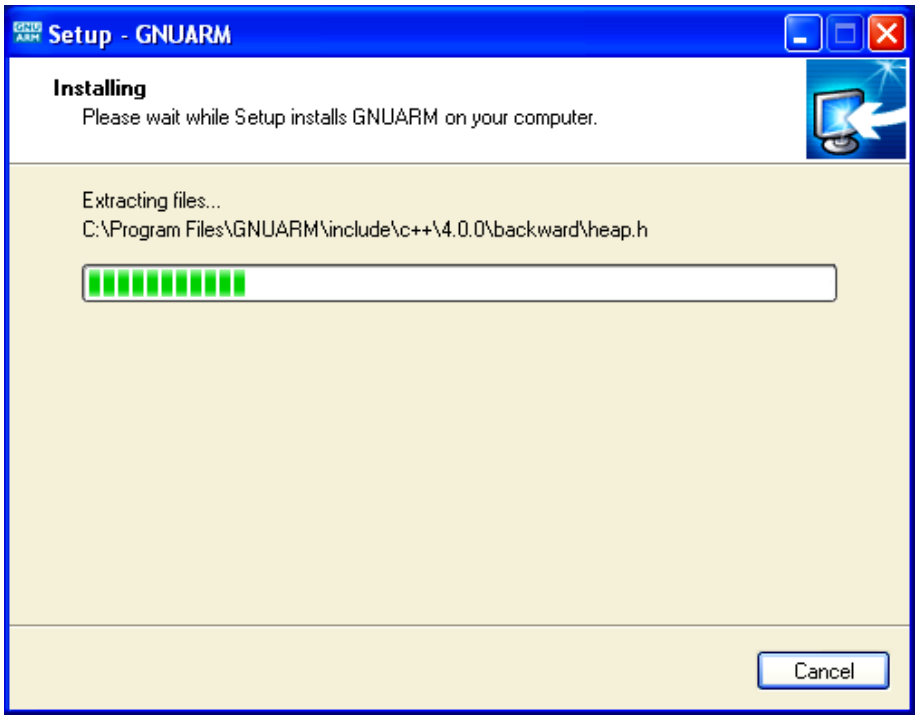
Since all operations are called from within Eclipse, we don't need a "**desktop icon**" either. Click **"Next"** to continue.



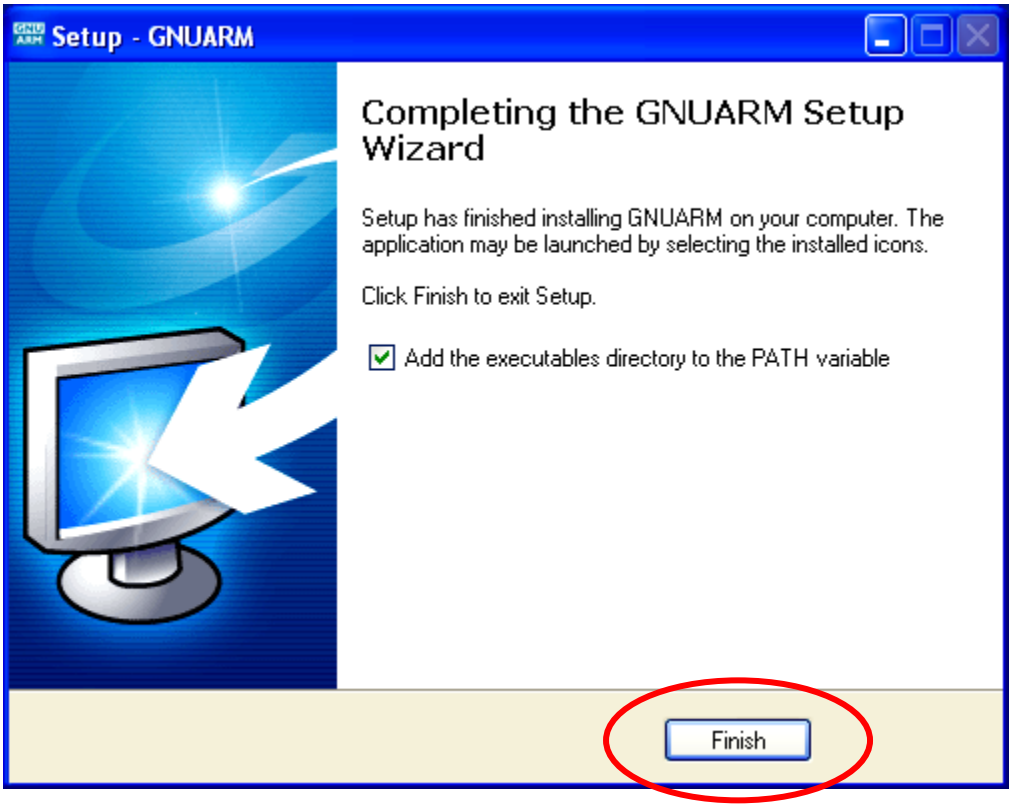
Click on “**Install**” to start the GNUARM installation.



Sit back and watch the GNUARM compiler suite install itself.



When it completes, the following screen is presented. Make sure that "**Add the executables directory to the PATH variable**" is checked. This is crucial.



This completes the installation of the compiler suites. Since Eclipse will call these components via the make file, you won't have to think about it again.

It's worth mentioning that the GNUARM web site has a nice Yahoo user group with other users posing and answering questions about GNUARM. Pay them a visit. The GNUARM web site also has links to all the ARM documentation you'll ever need.

8 Installing the Philips LPC2000 Flash Utility into Eclipse

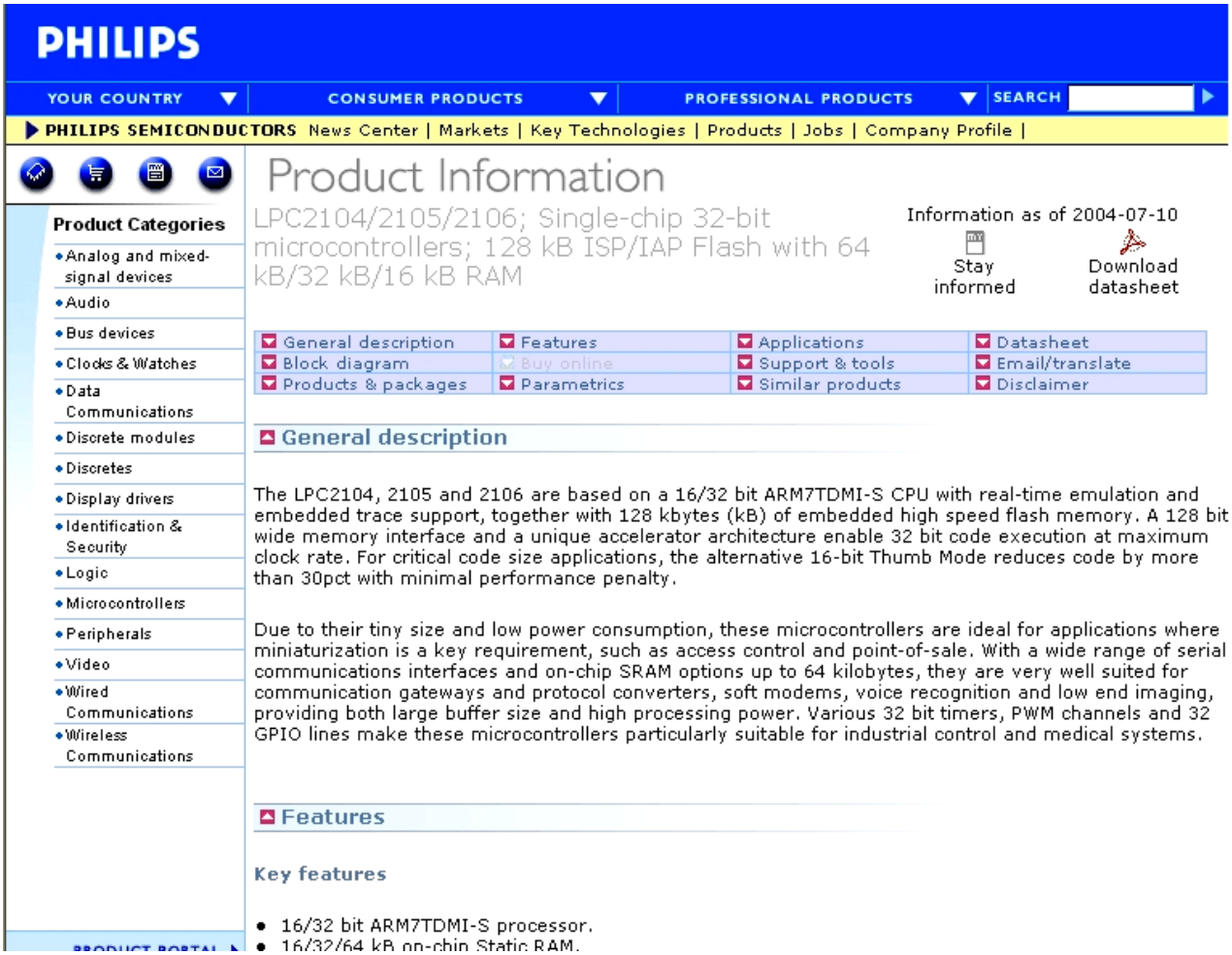
The Philips LPC2000 Flash Utility allows downloading of hex files from the COM1 port of the desktop computer to the **Olimex LPC-P2106** board's flash (or RAM) memory.

We need to download the latest version of this program from the Philips web site and unzip and install it into the **program files** directory. Then we will start Eclipse and add the LPC2000 Flash Utility as an external tool to be invoked.

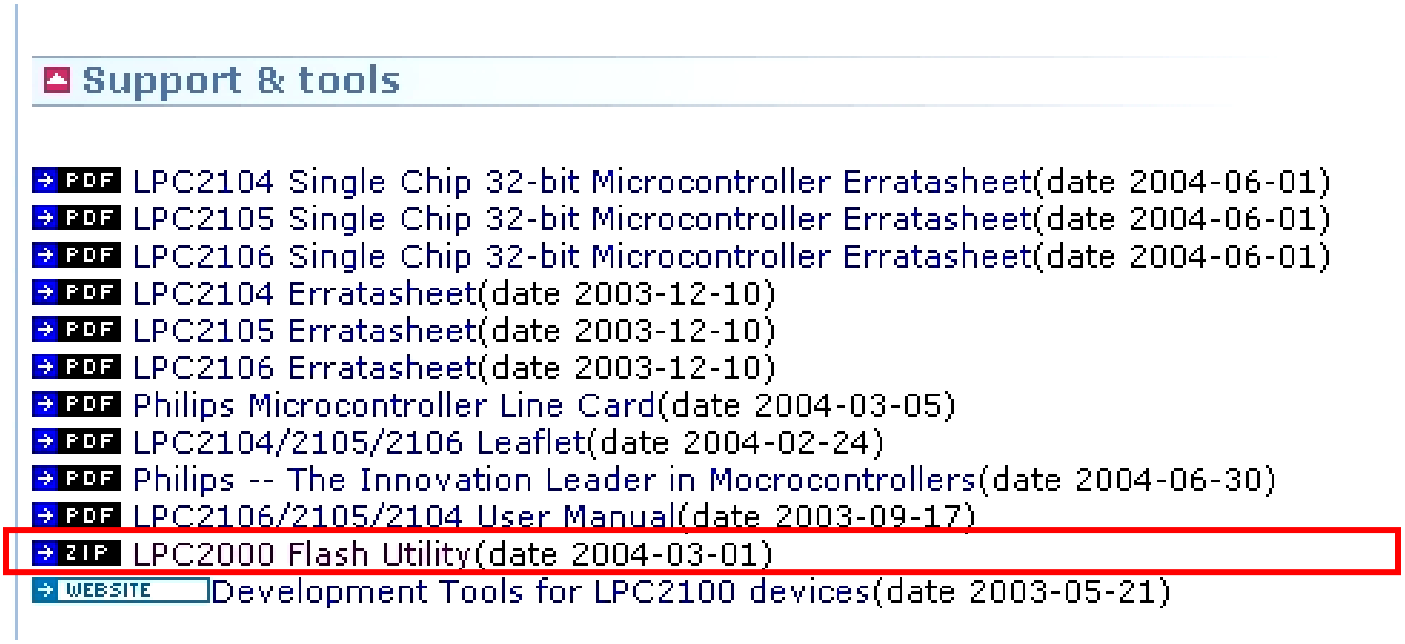
Click on the following link to access the Philips LPC2106 web page.

www.semiconductors.philips.com/pip/LPC2106.html

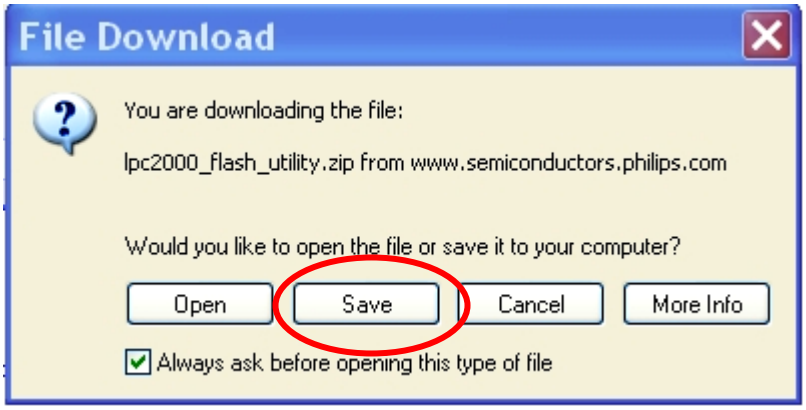
The following web page for the LPC2106 should open.

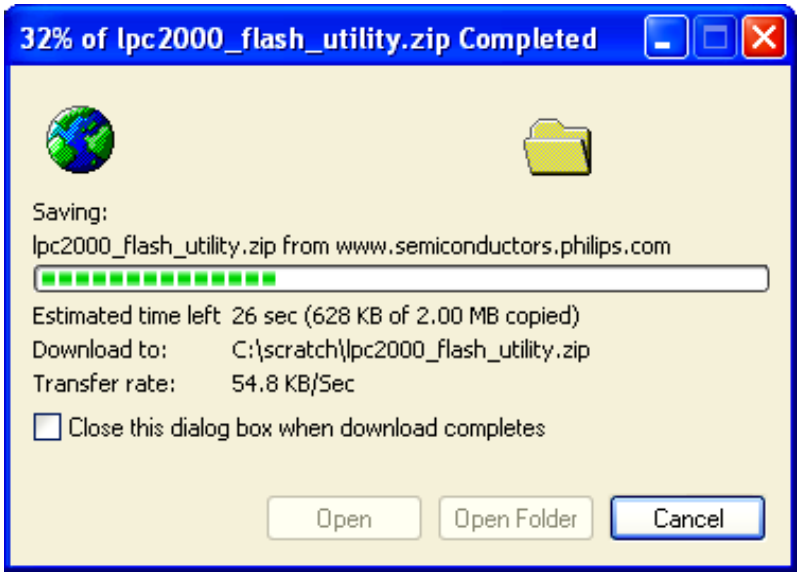


If you scroll down this page, you will see a link to the LPC2000 Flash Utility download. Click on the ZIP file LPC2000 Flash Utility (date 2004-03-01)

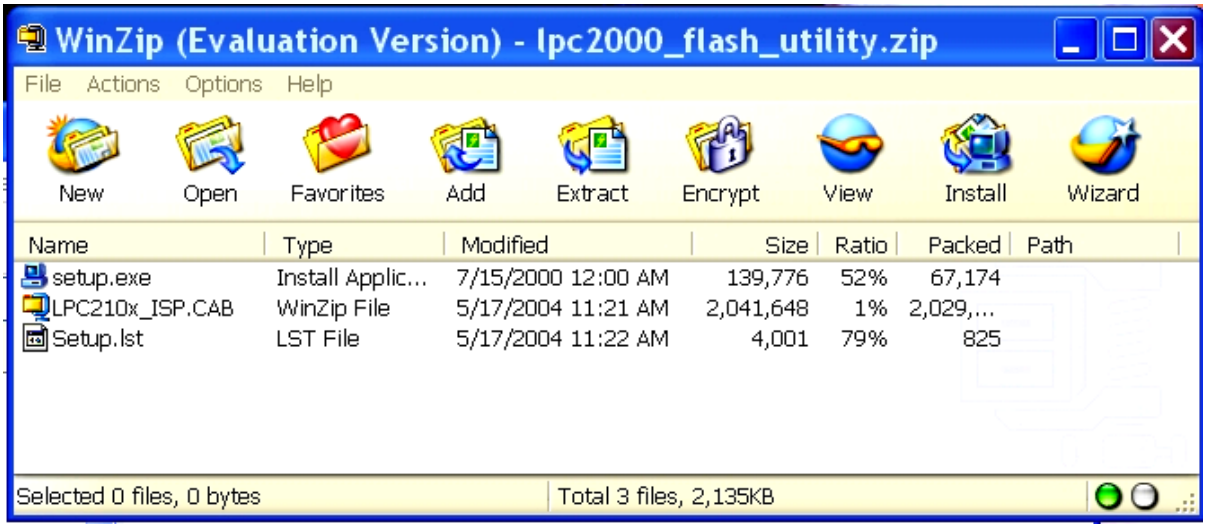


As before, we'll save the downloaded zip file in our empty **c:/scratch** directory. This is a fairly short download, only about 2 megabytes.

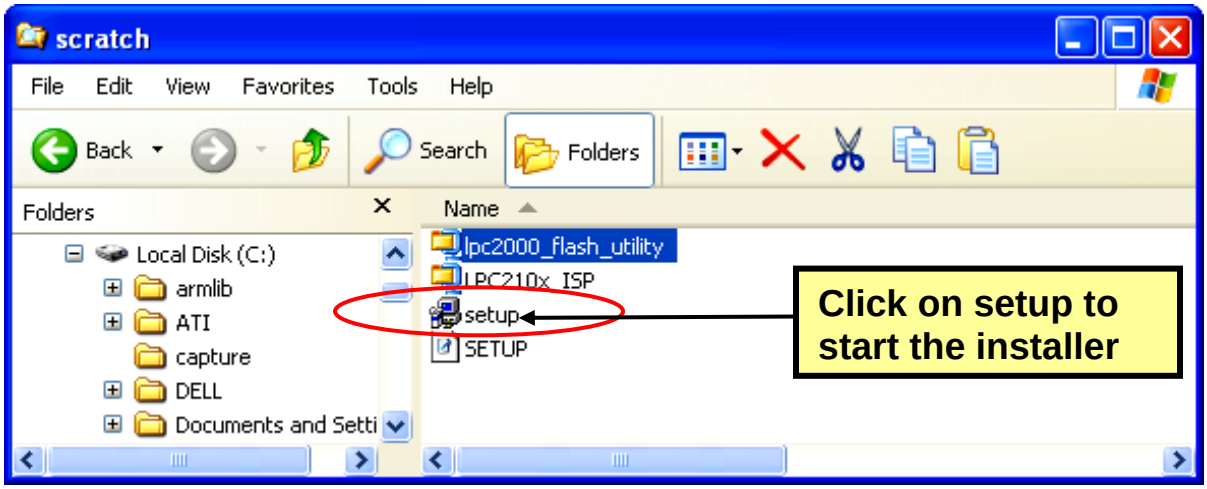




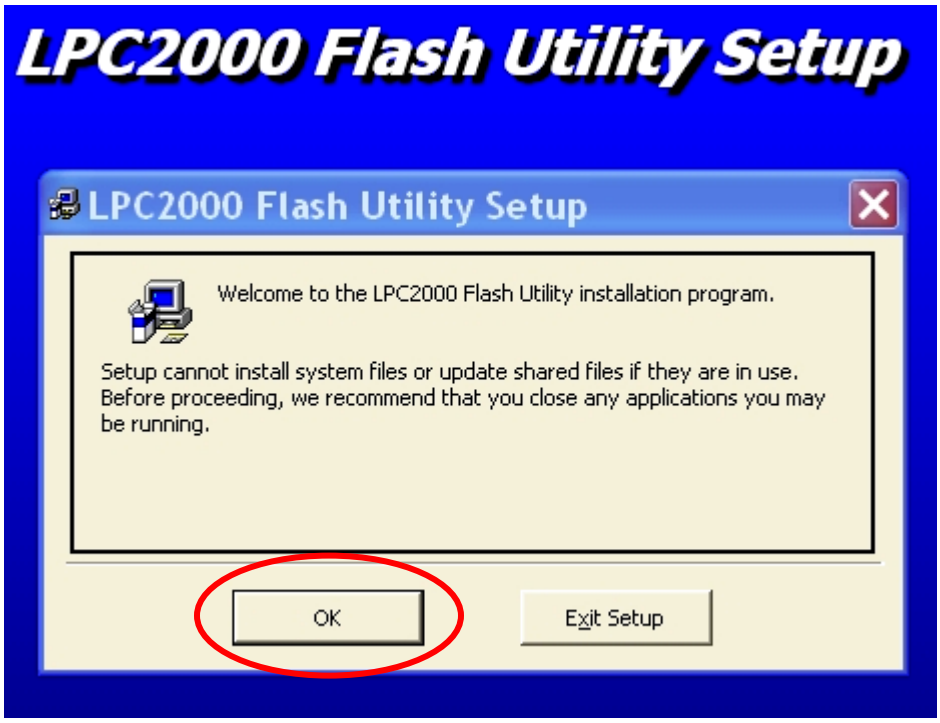
We'll use WinZip to unzip this into the **c:/scratch** directory.



Now you can see that the download directory has a setup utility and another zip file containing the LPC2000 Hex Utility. Click on the **setup.exe** application to start the installer.



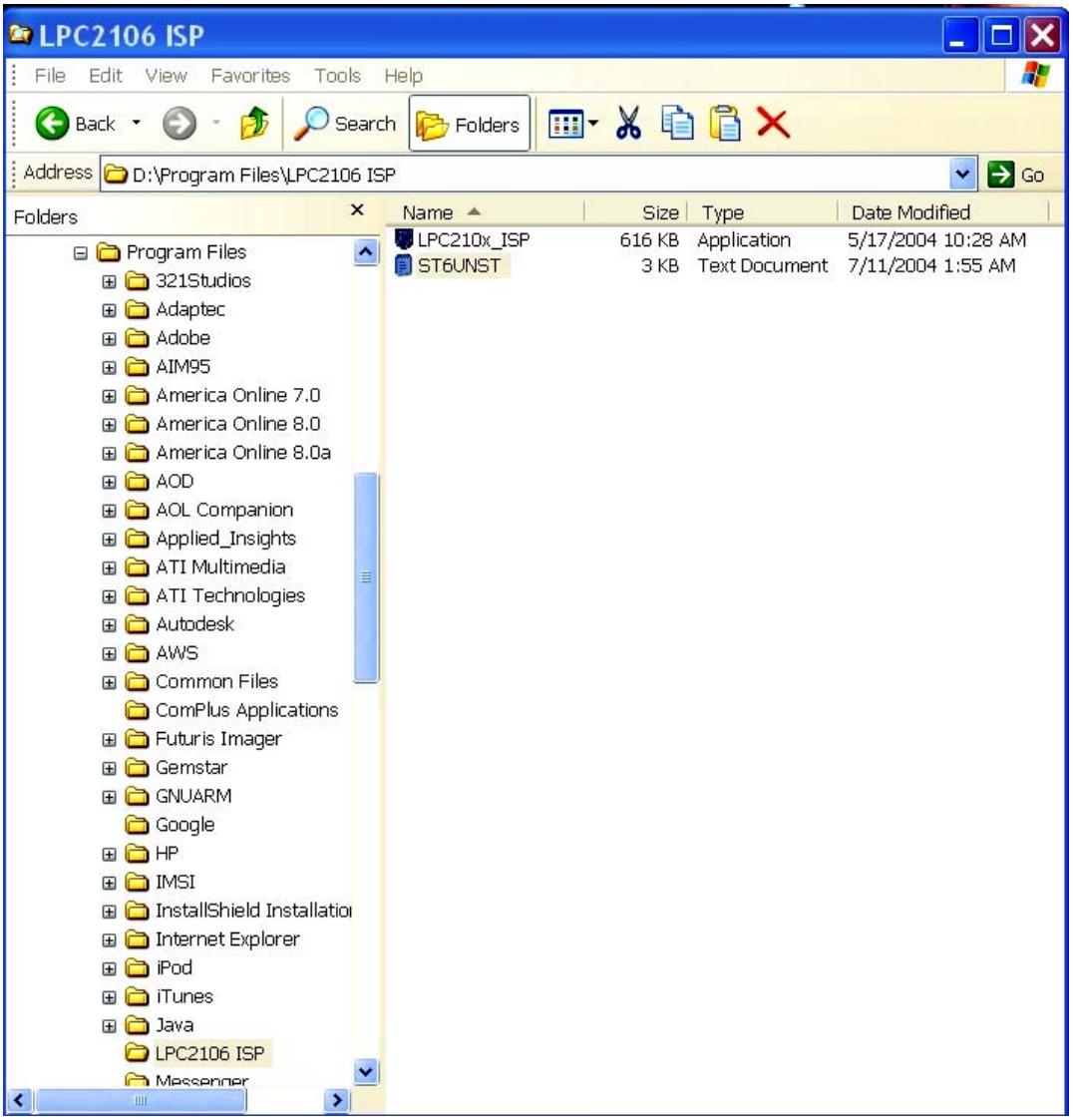
The LPC2000 Flash Utility setup now starts. Click on **OK** to proceed.



Take the default on this screen below and let it install the LPC2000 Flash Utility into the Program Files directory.

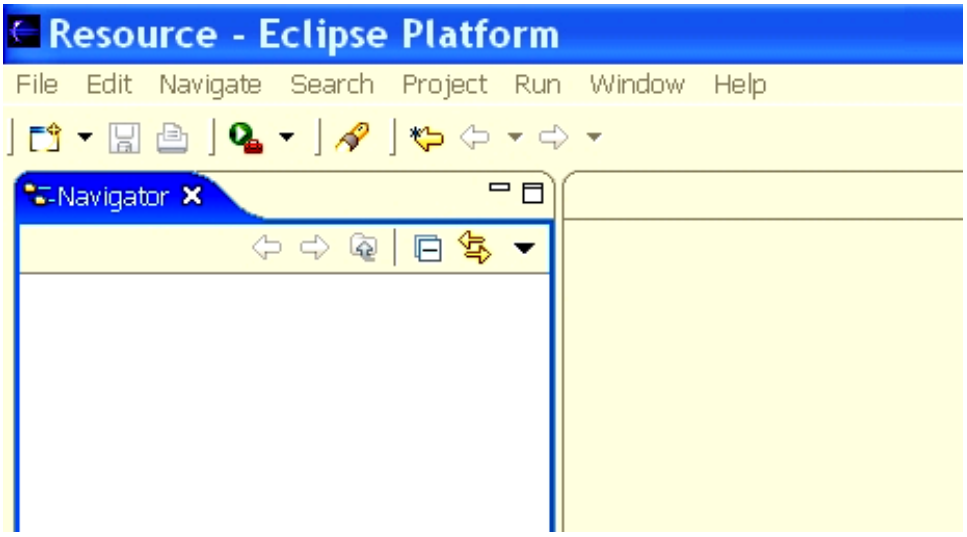
In a very few seconds, the installer will complete and you should see this screen.

Here we see the utility residing in the Program Files directory, just as promised.

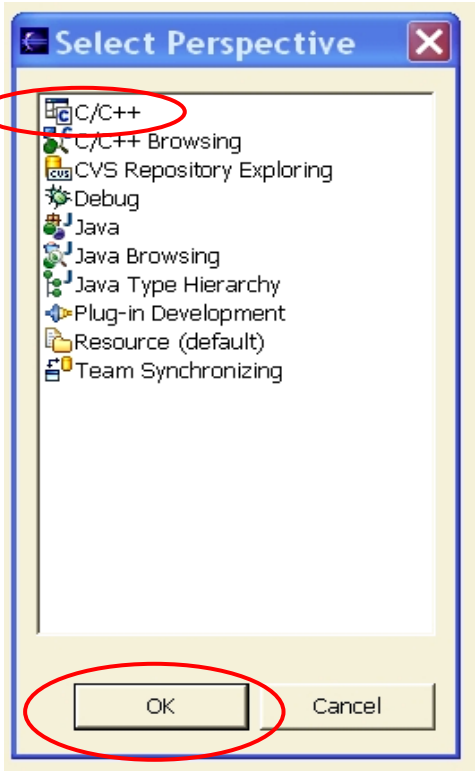


Now that the Philips LPC2000 Flash Utility is properly installed on our computer, we'd like to install it into Eclipse so that it can be invoked from the RUN pull-down menu under the "**external tools**" option. Start Eclipse by clicking on the desktop icon.

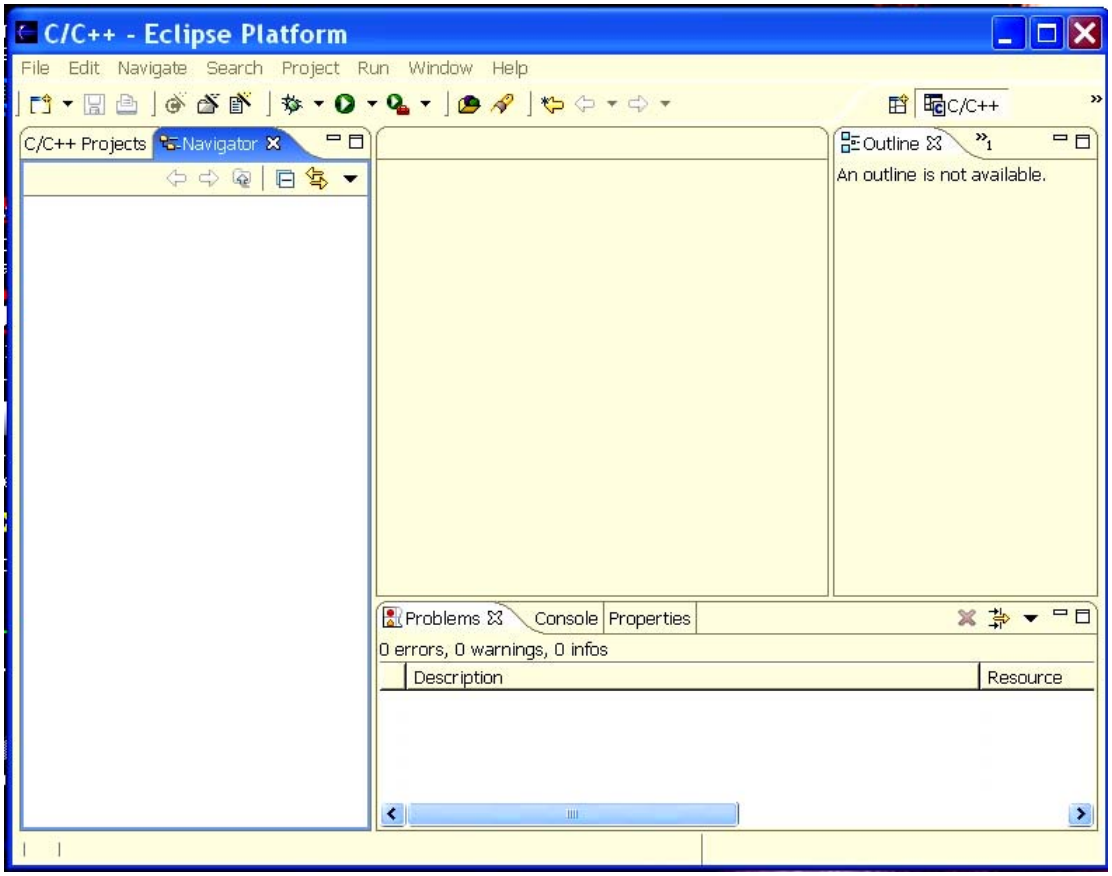
The layout of the Eclipse screen is called a "perspective." The default perspective is the "resource" perspective, as shown below.



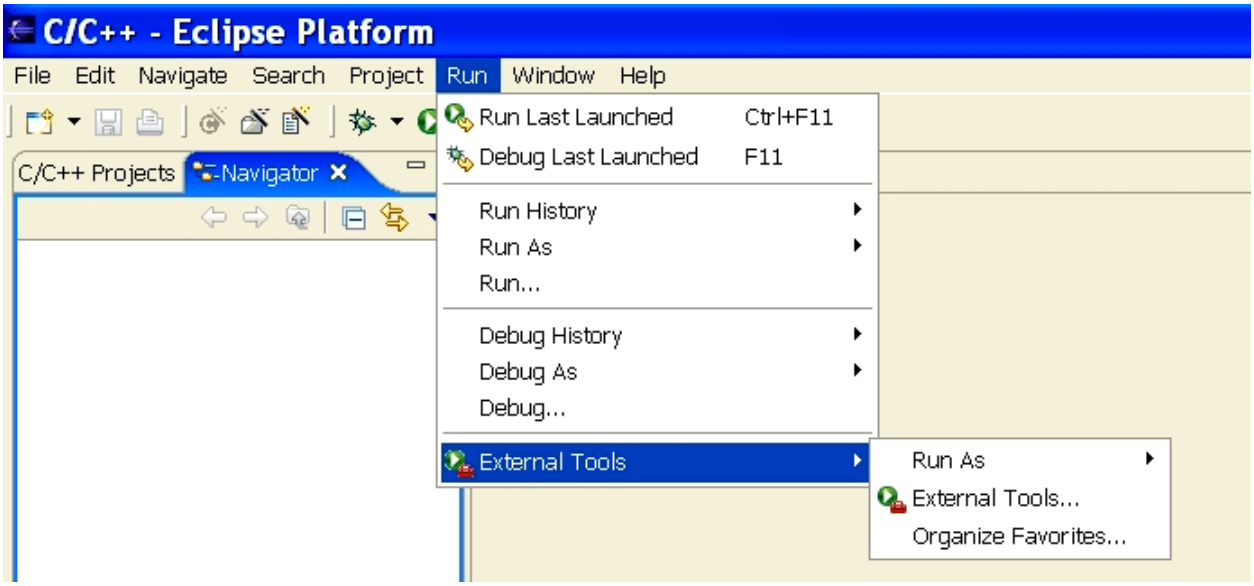
We need to change it into the C/C++ perspective. In the **Window** pull-down menu, select **Window – Open Perspective – Other – C/C++** and then click **OK**.



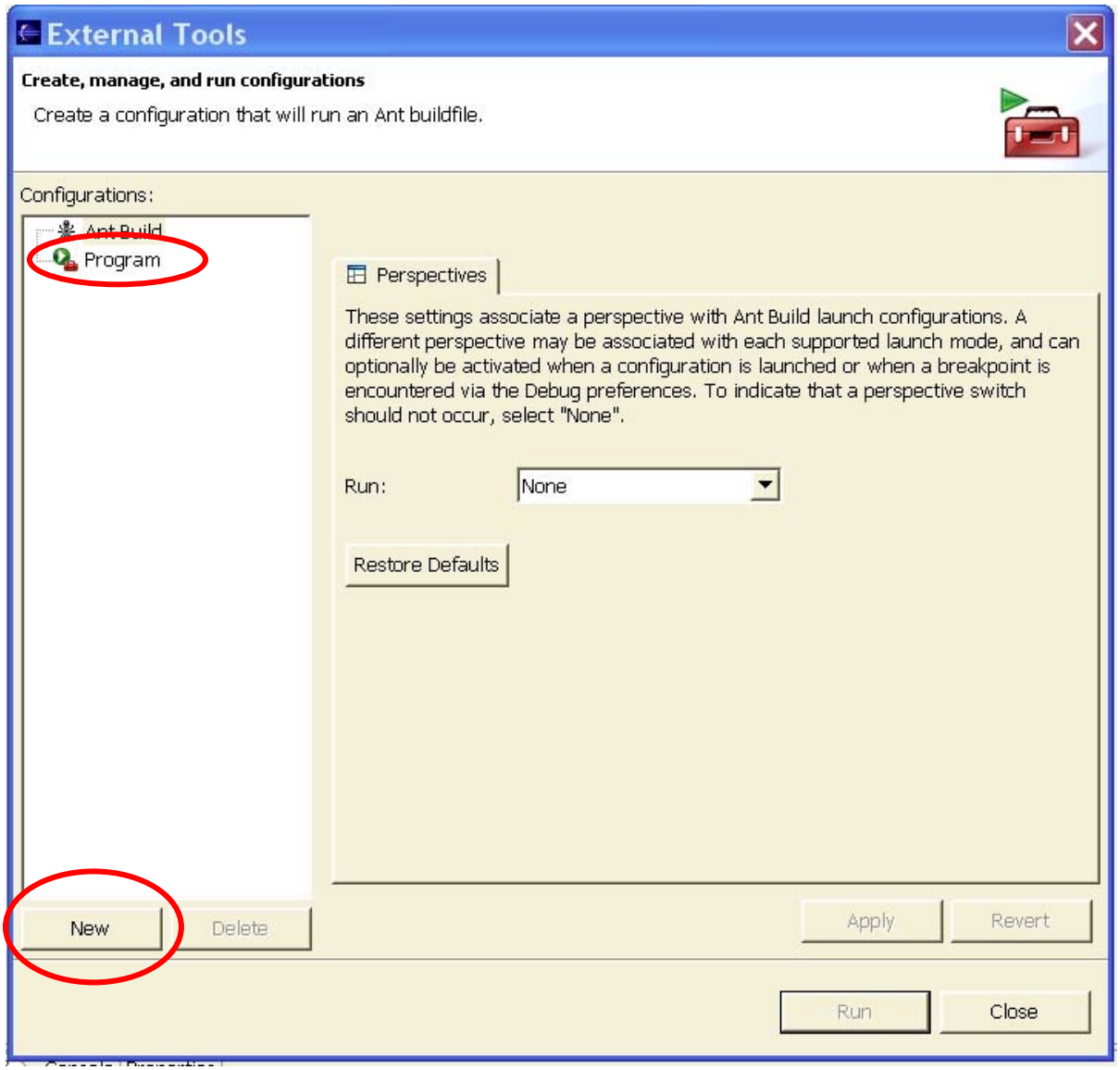
Eclipse will now switch to the **C/C++** perspective shown below and will remember it when you exit.



Now we want to add the Philips LPC2000 Flash Utility to the "**External Tools**" part of the **Run** pull-down menu. Select **RUN – External Tools – External Tools**.



We want to add a new program to the External Tools list, so click on **Program** and then **New**.

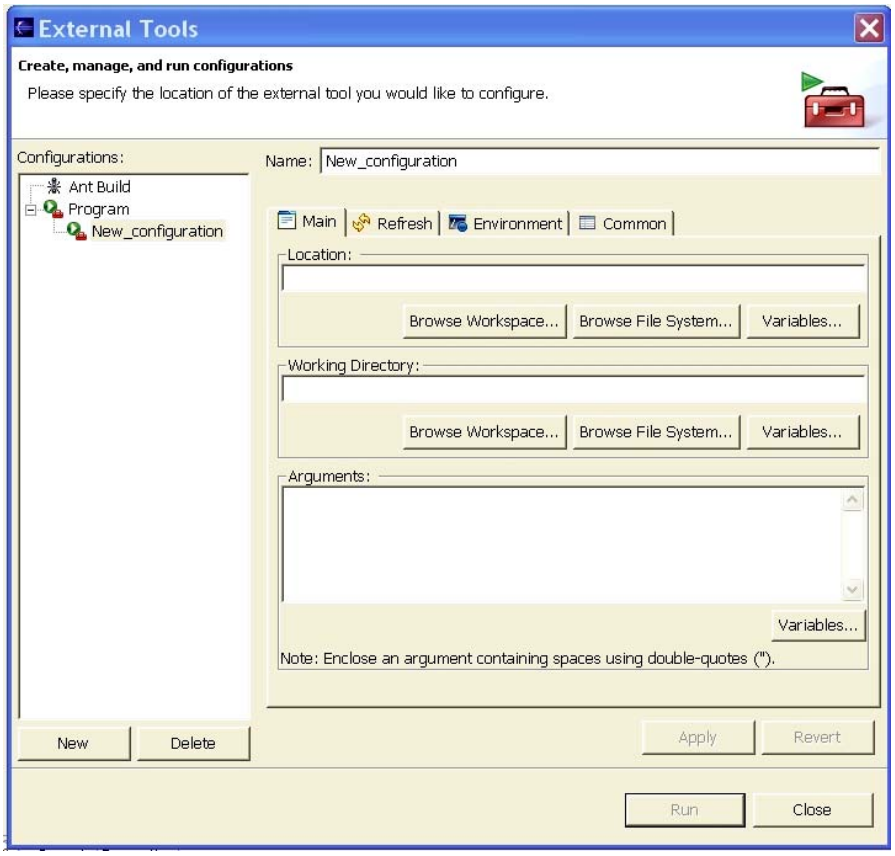


Note below that there's a new program under the "program" tree with the name **New_configuration** and there's no specifications as to what it is.

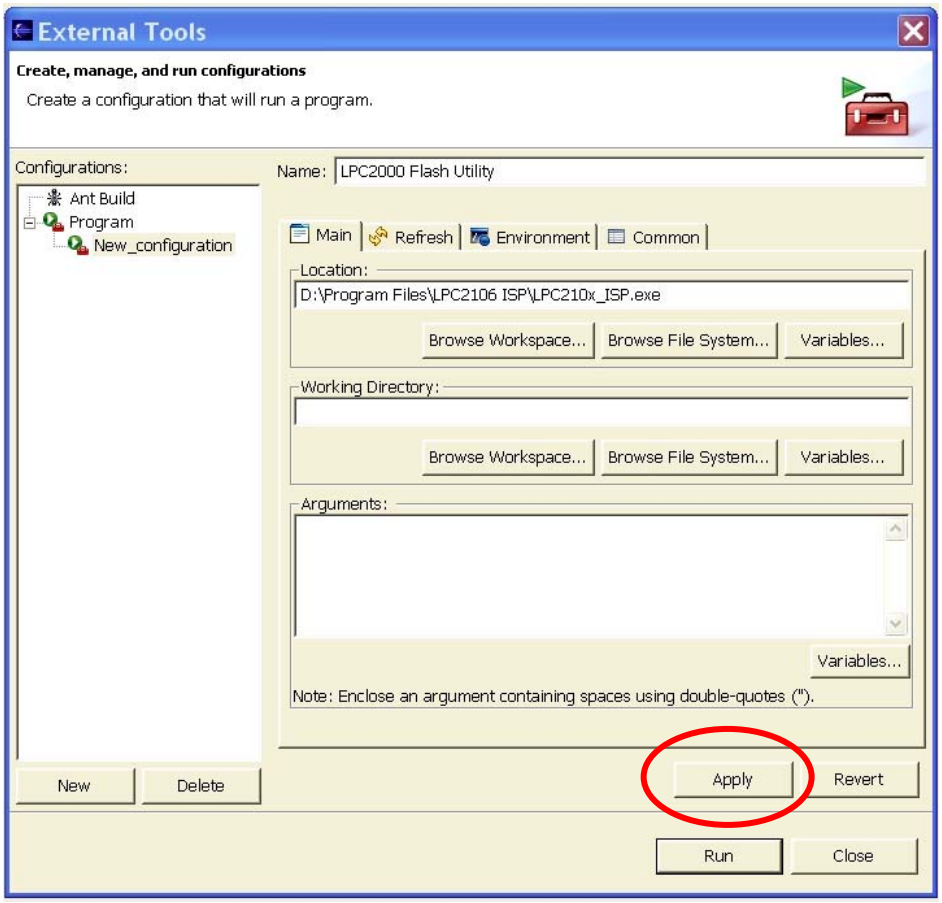
In the **Name** text box, replace **New-configuration** with **LPC2000 Flash Utility**.

In the **Location** text box, use the "**Browse File System**" tool to find the Philips LPC2000 Flash Utility in the Program Files directory. Its name is **LPC210x_IPC.exe**.

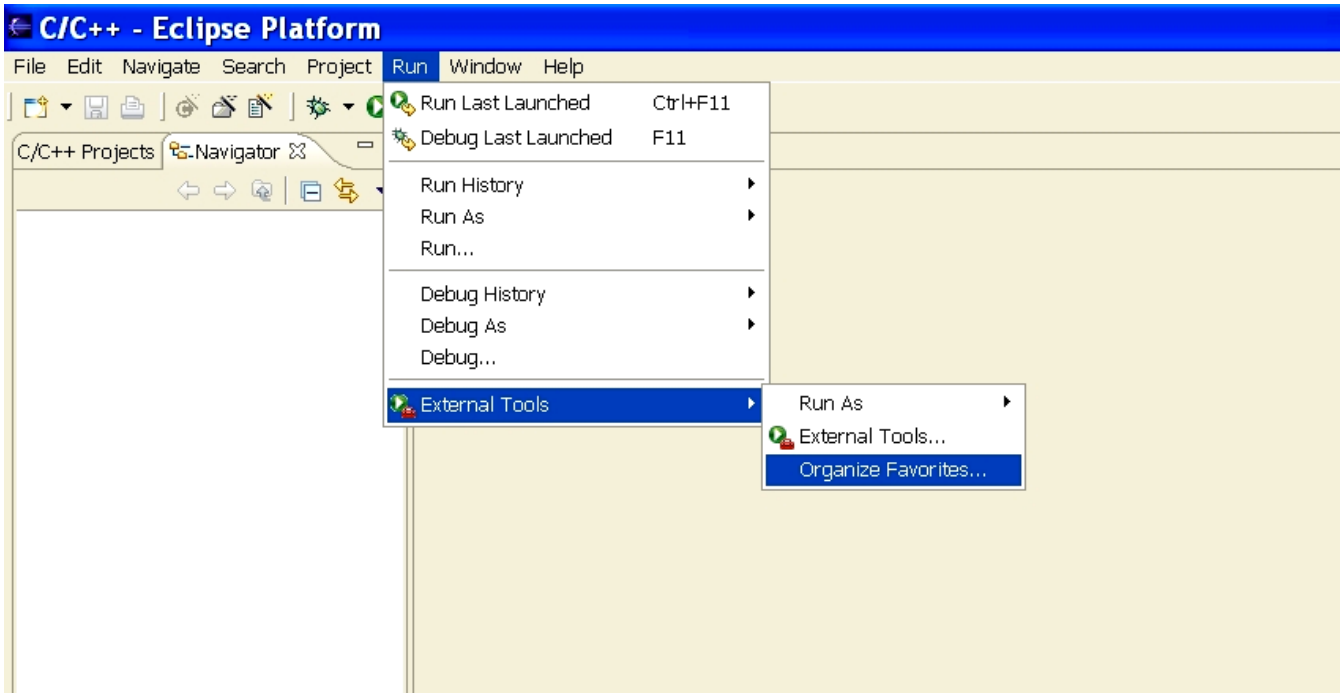
Here's the External Tools window before editing.



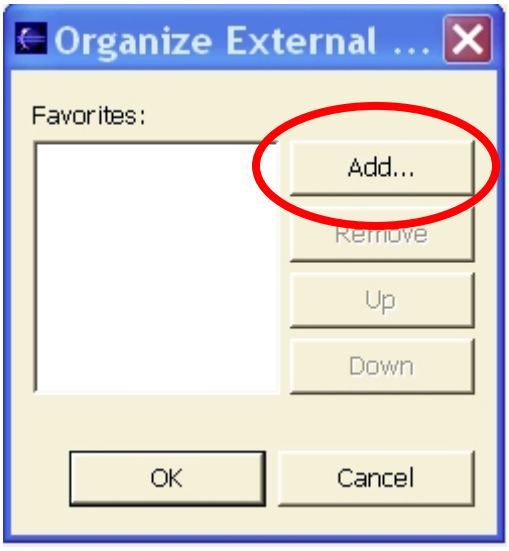
Here's the External Tools window after our modifications. Click on **Apply** to accept.



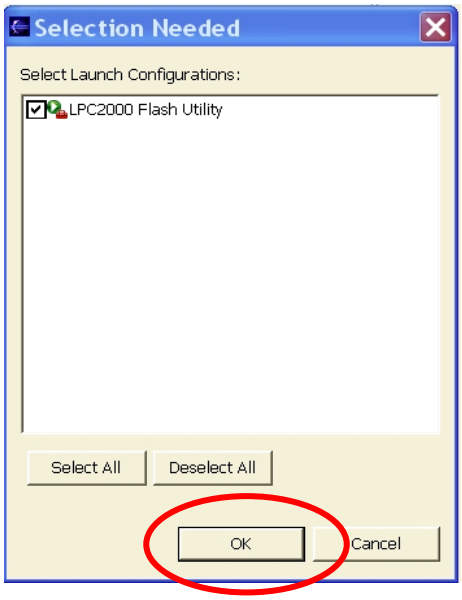
Close everything out and return to the **Run** pull-down menu. Select **Run – External Tools – Organize Favorites**.



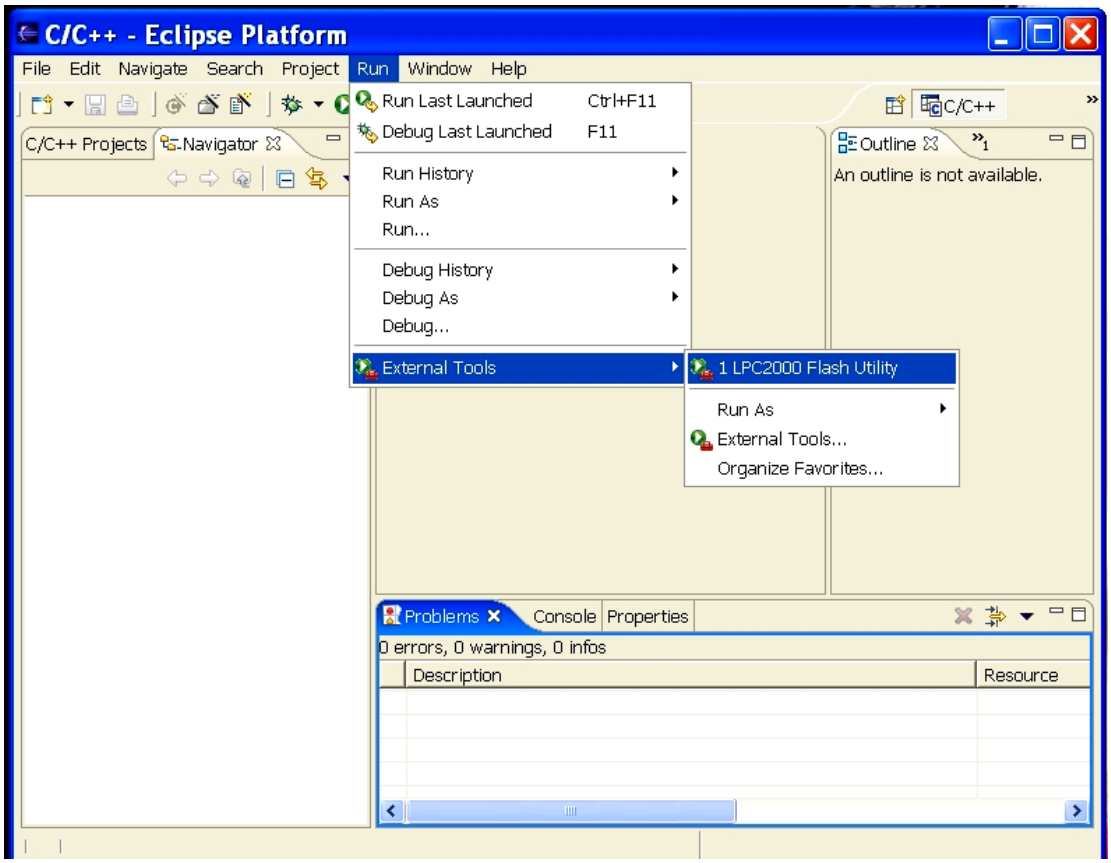
We're now going to put the Philips PLC2000 Flash Utility into the "favorites" list. Click on "**Add**" in the window below.



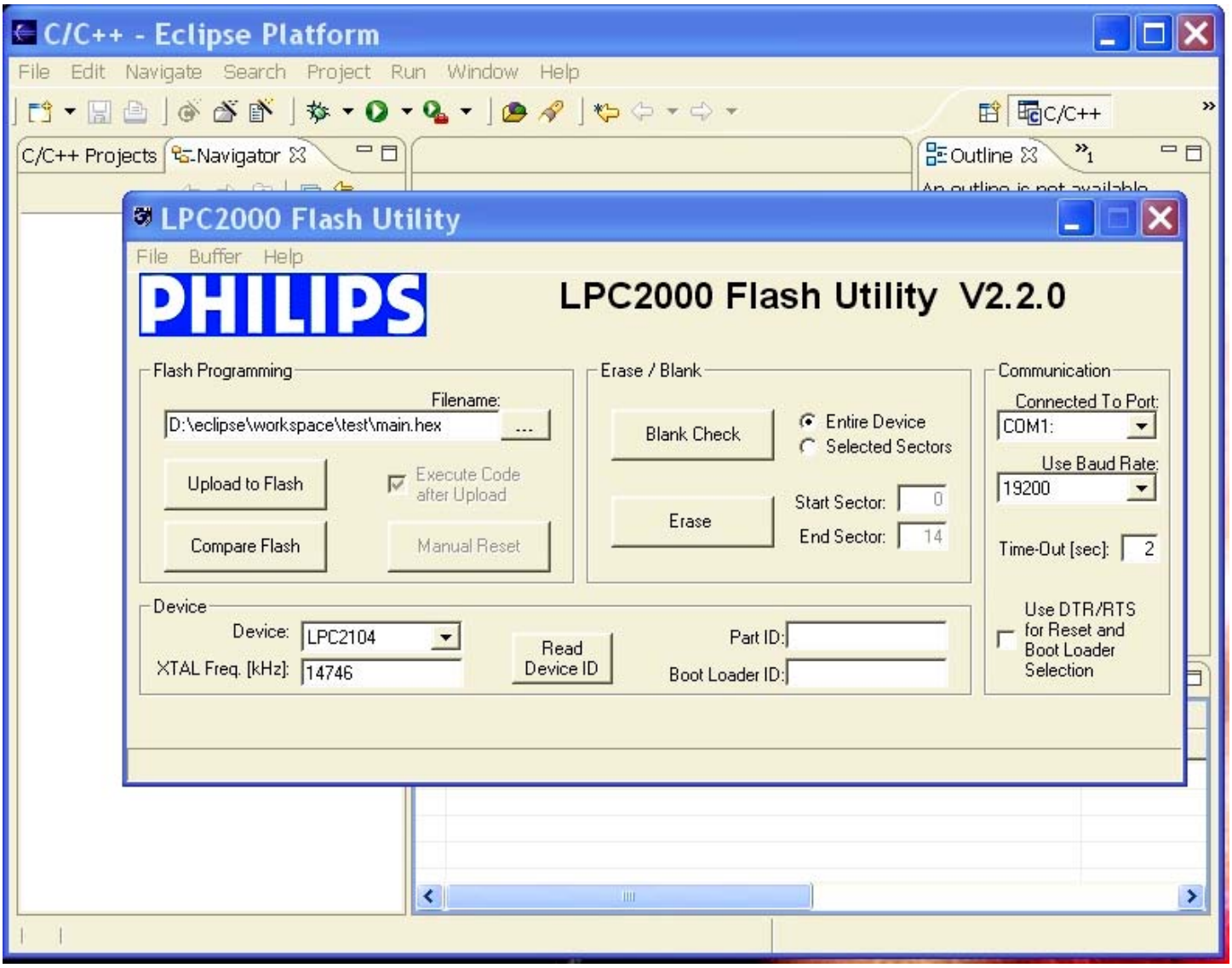
Click the selection box for LPC2000 Flash Utility. This will add it to the favorites list.



Now when we click on the **Run** pull-down menu and select **“**External Tools,” we see the **LPC2000 Flash Utility** at the top of the list.



Click on **LPC2000 Flash Utility** to verify that it runs.



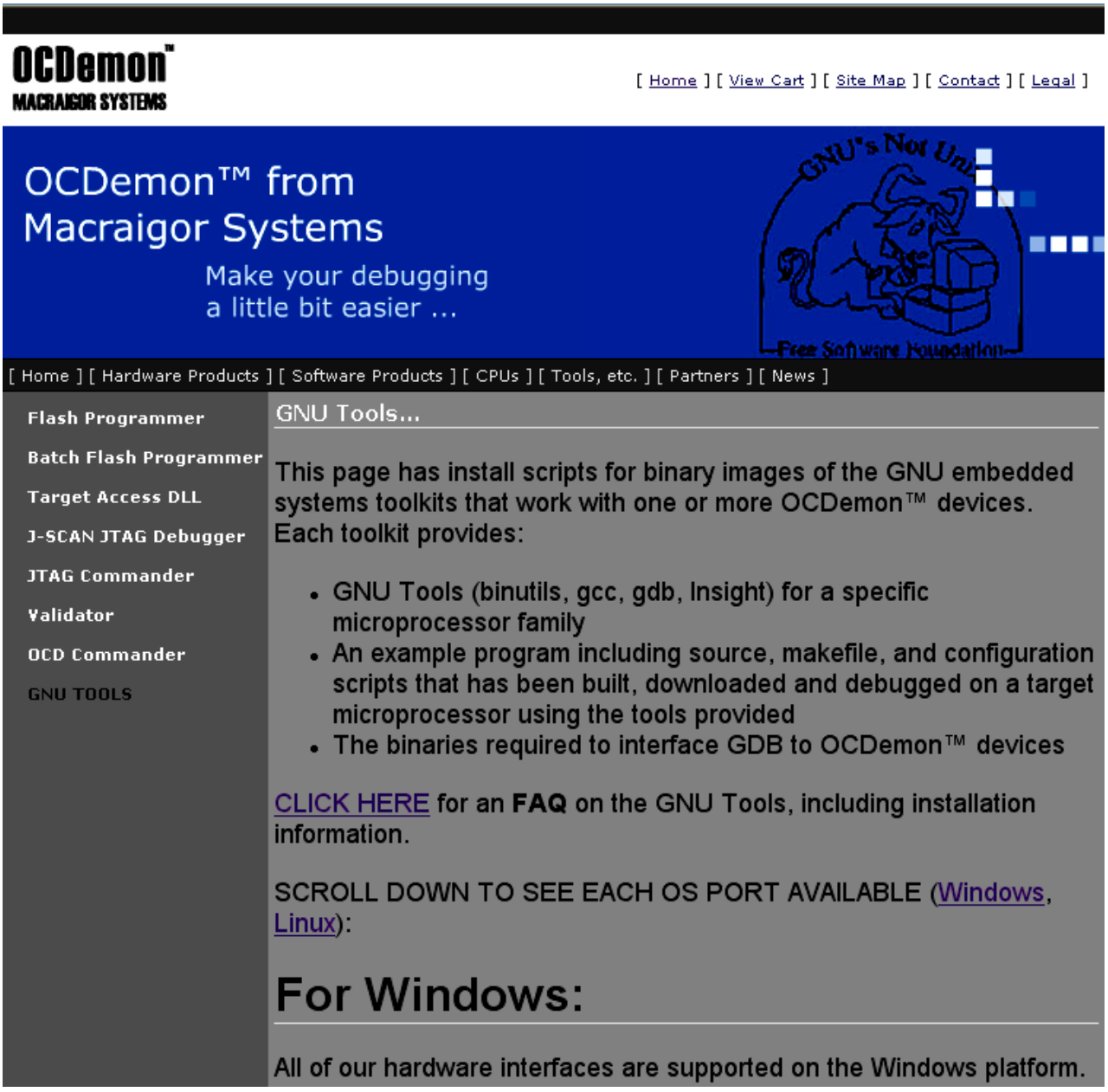
Now cancel the LPC2000 Flash Utility and quit Eclipse.

9 Installing the Macraigor OCDremote Utility

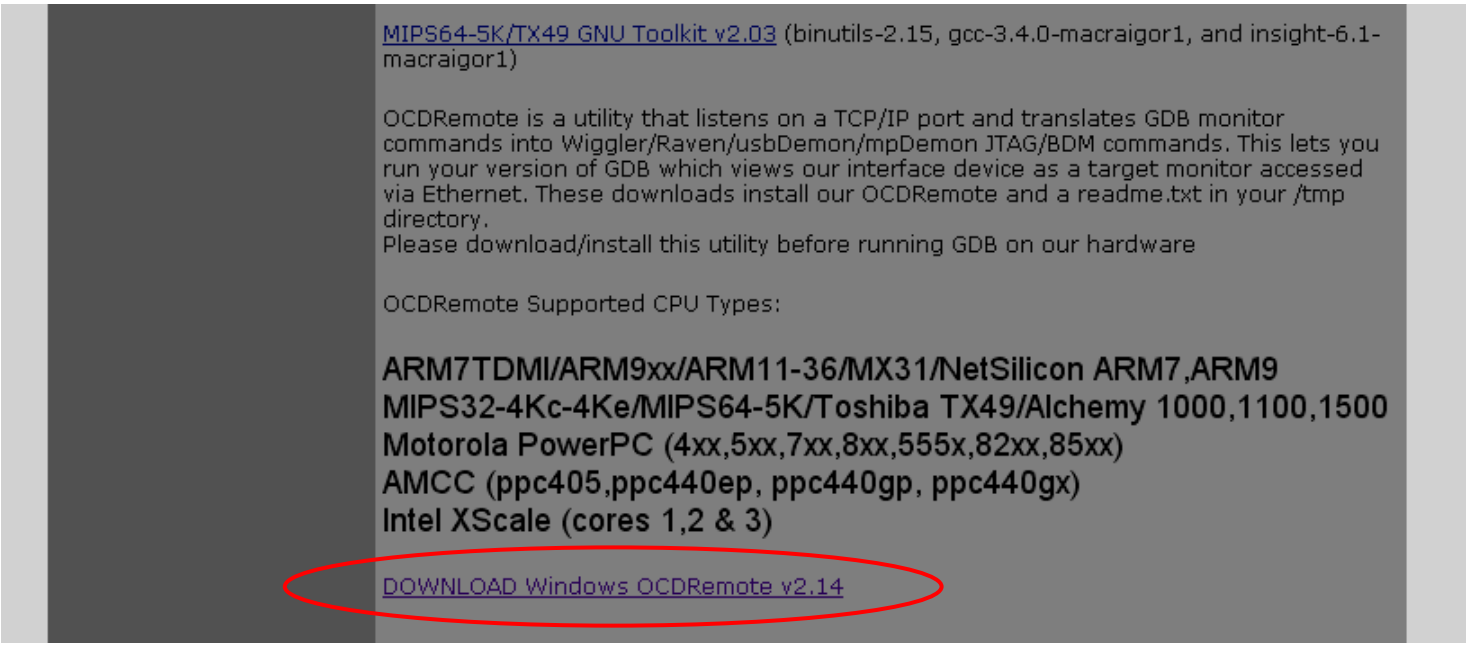
OCDRemote is a utility that listens on a TCP/IP port and translates GDB monitor commands into **Wiggler** JTAG commands. Macraigor has always made this utility available on the internet as “freeware.” The **OCDRemote** utility can be downloaded at:

http://www.macraigor.com/full_gnu.htm

You should see the following screen open up.

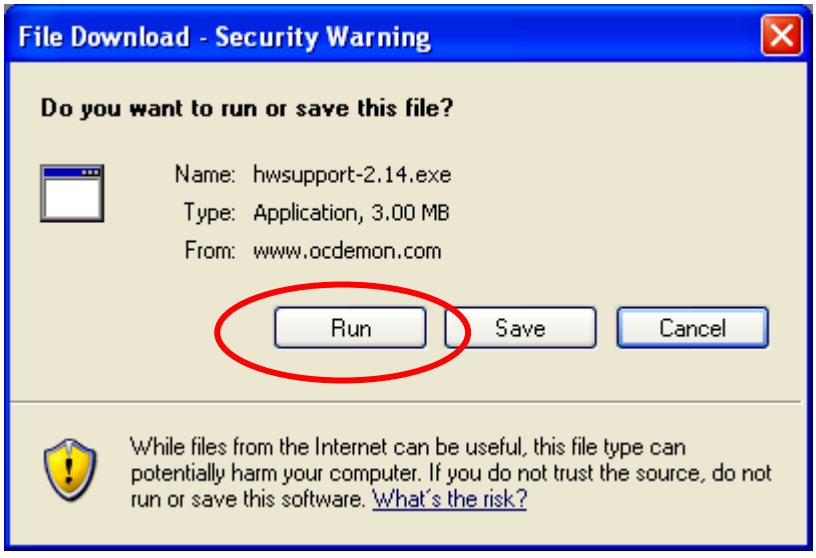


If you scroll the above screen down a bit, you should see the download for **OCDRemote**. Click on the link "**DOWNLOAD Windows OCDRemote v2.14**".

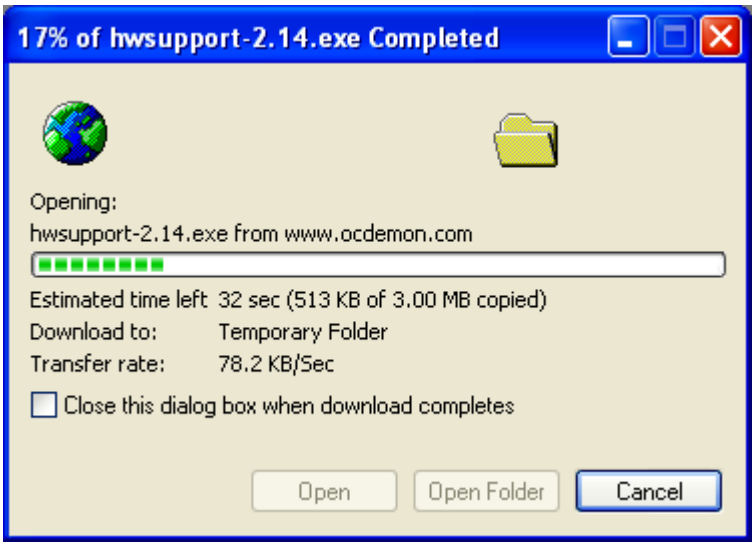


Make sure you download **OCDRemote** version **v2.14** since this is the one that supports hardware breakpoints.

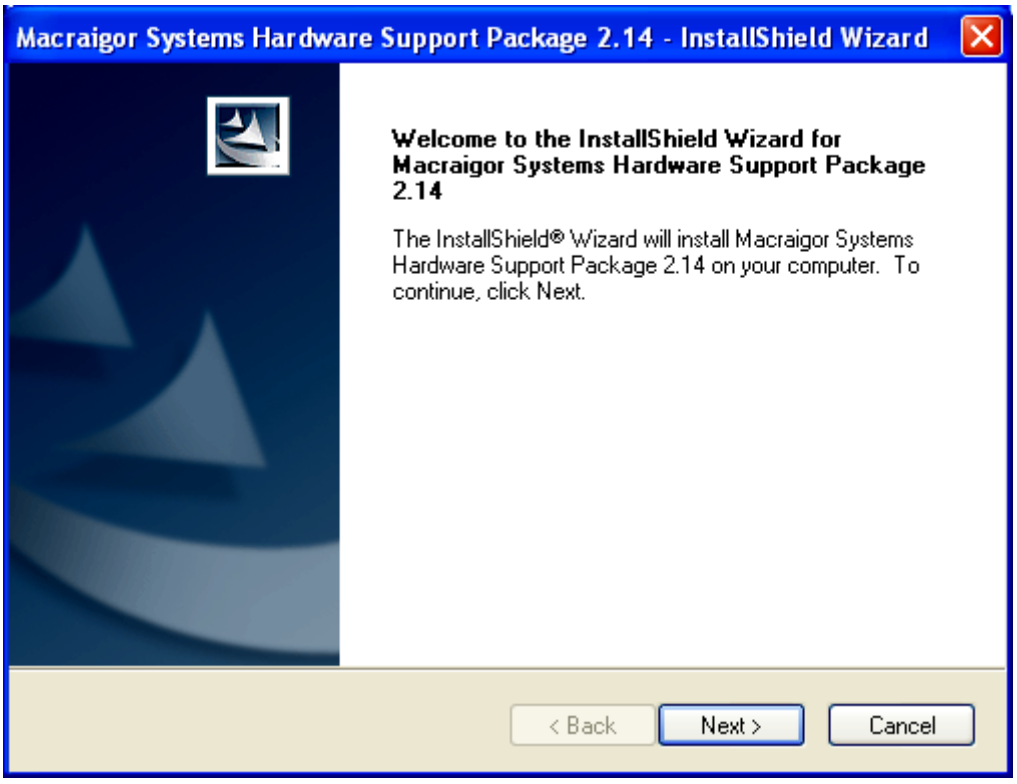
Click on "**Run**" so it will download and immediately install **OCDRemote**.



The download phase is quick since the **OCDRemote** is only a couple of megabytes.



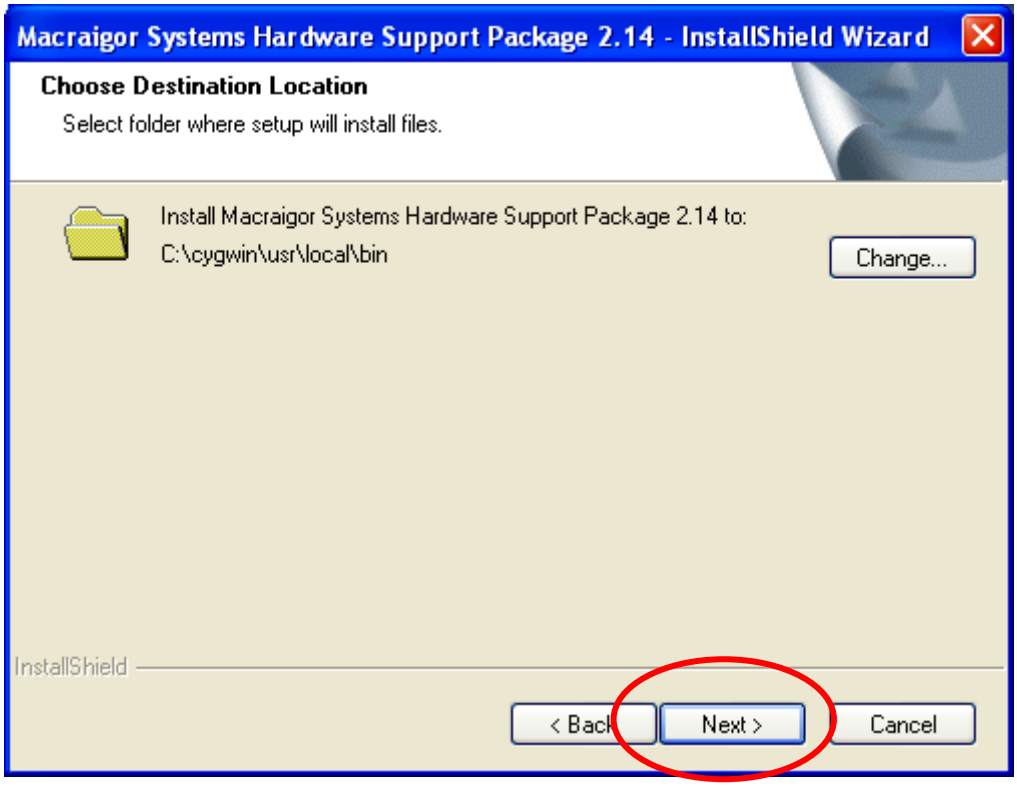
The Macraigor installer should start up; click "**Next**" to continue.



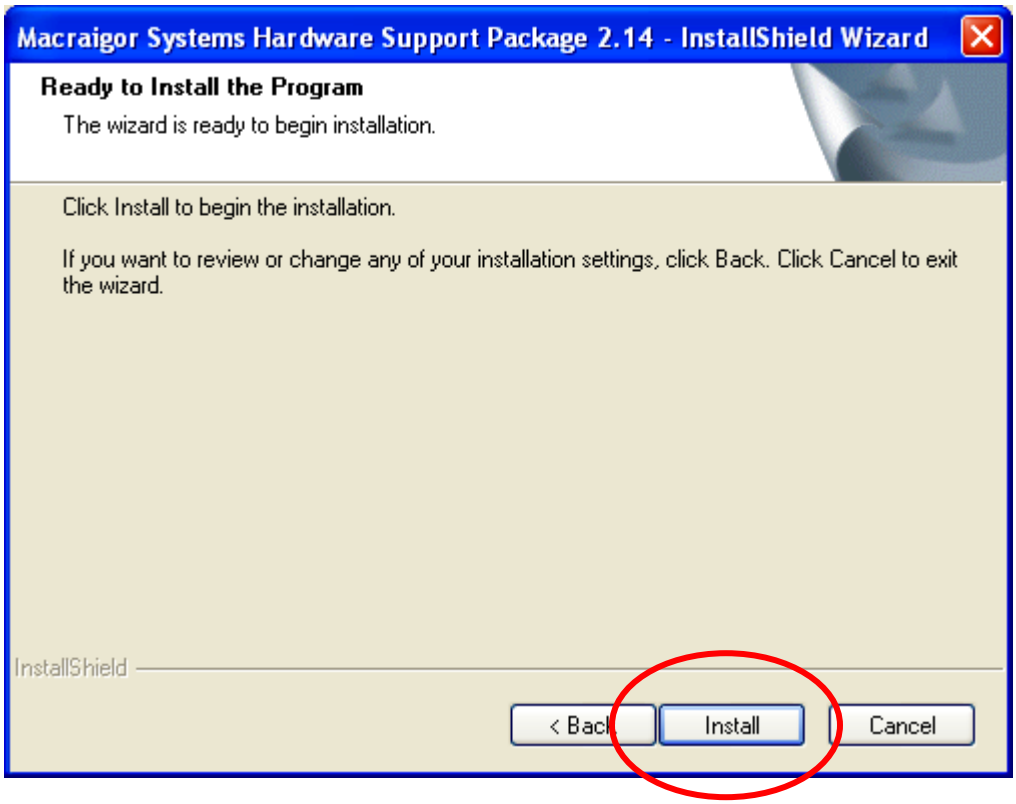
The next screen lets you choose where **OCDRemote** is installed. **OCDRemote** normally installs in **c:/cygwin/usr/local/bin**.

We'll have to make sure that this directory is on a Windows Path.

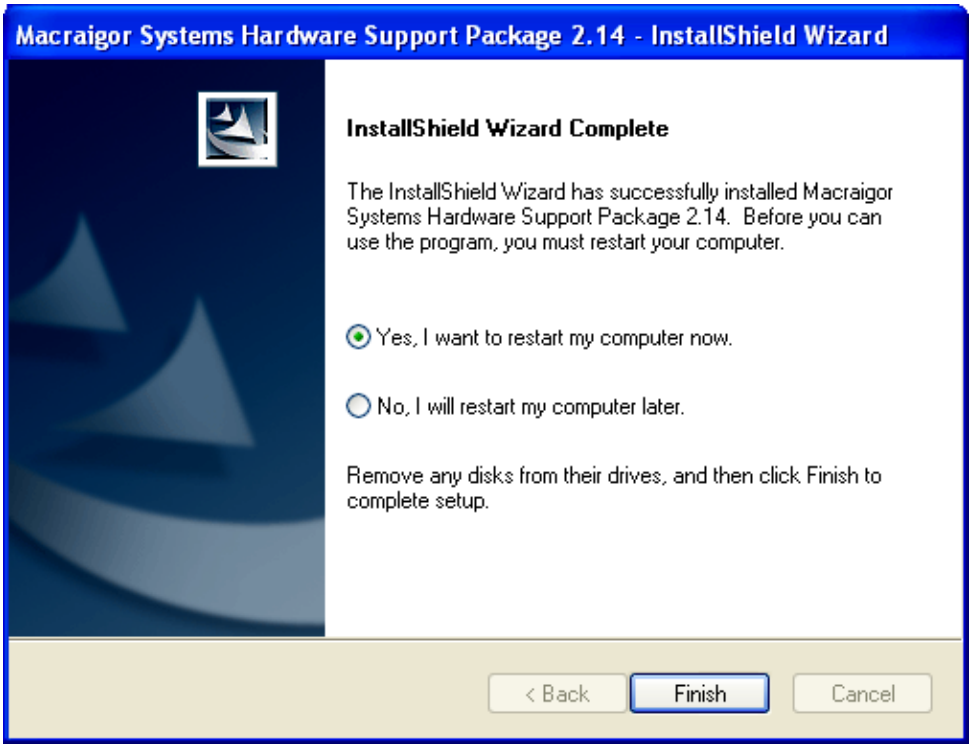
Click on “**Next**” to accept **c:/cygwin/usr/local/bin** as the **OCDRemote** installation directory.



Clicking on “**Install**” will complete the **OCDRemote** installation.



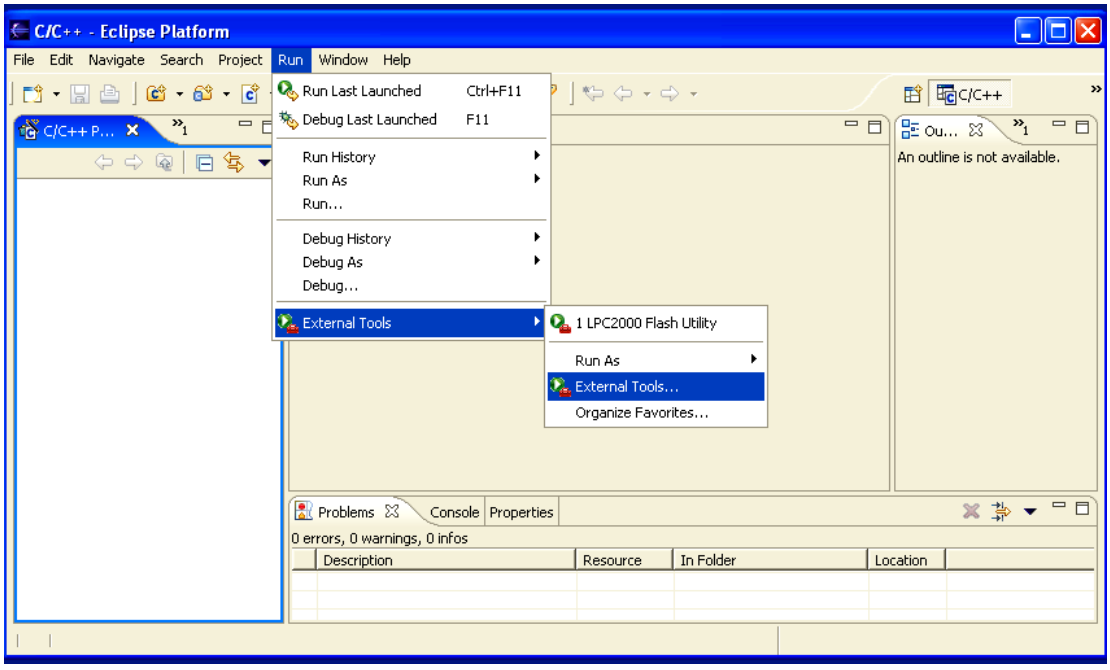
The Wizard completion screen lets you restart your computer to put **OCDRemote** into the Windows registry.



Just like the Philips ISP Flash Utility, we should install the Macraigor **OCDremote** utility as an “external tool” that can be accessed easily from the Eclipse CDT **RUN** pull-down menu.

Start up Eclipse and, if necessary, switch to the C/C++ perspective by clicking “**Window – Open Perspective – Other – C/C++**.” In a procedure similar to installing the Philips Flash Utility as an “**External Tool**”, click on “**Run – External Tools – External Tools …**”

This will bring up the External Tools dialog.

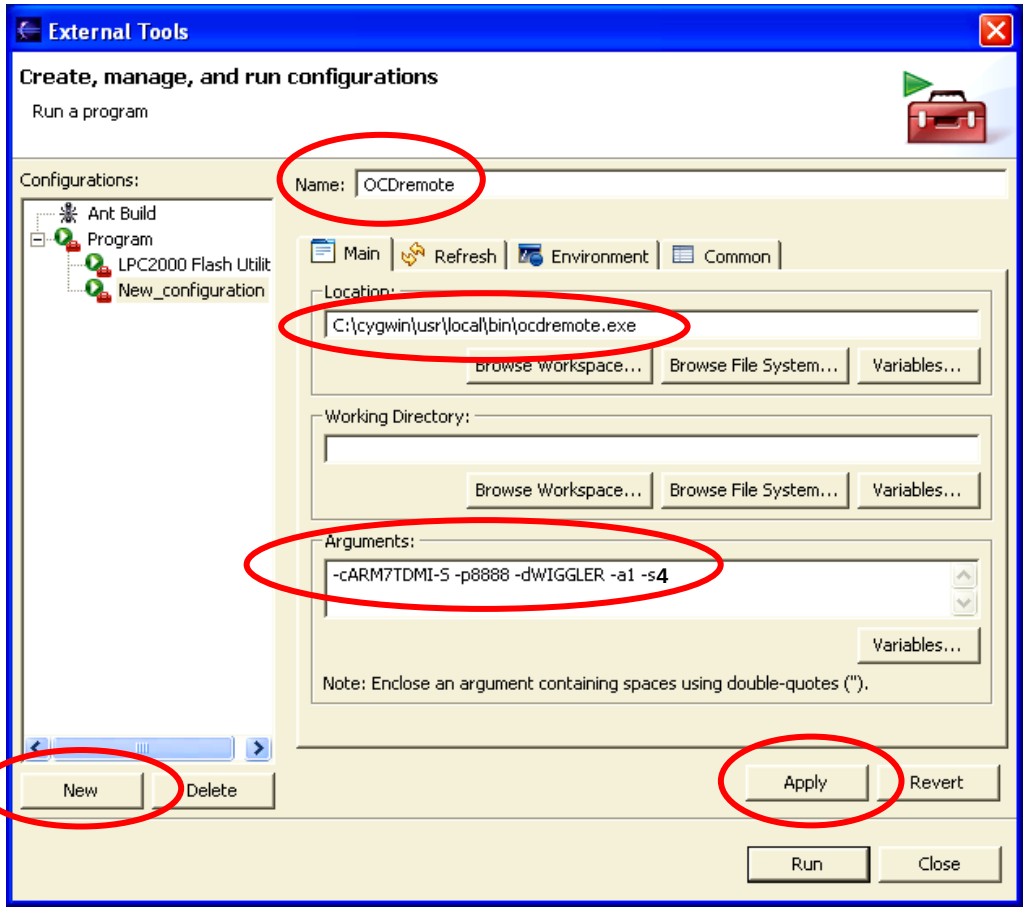


Click on “**New**” and replace the name with **OCDremote**. Use the “**browse file system**” to find it. It should be in the directory **c:/cygwin/usr/local/bin**.

The arguments needed to properly start the **OCDremote** are as follows:

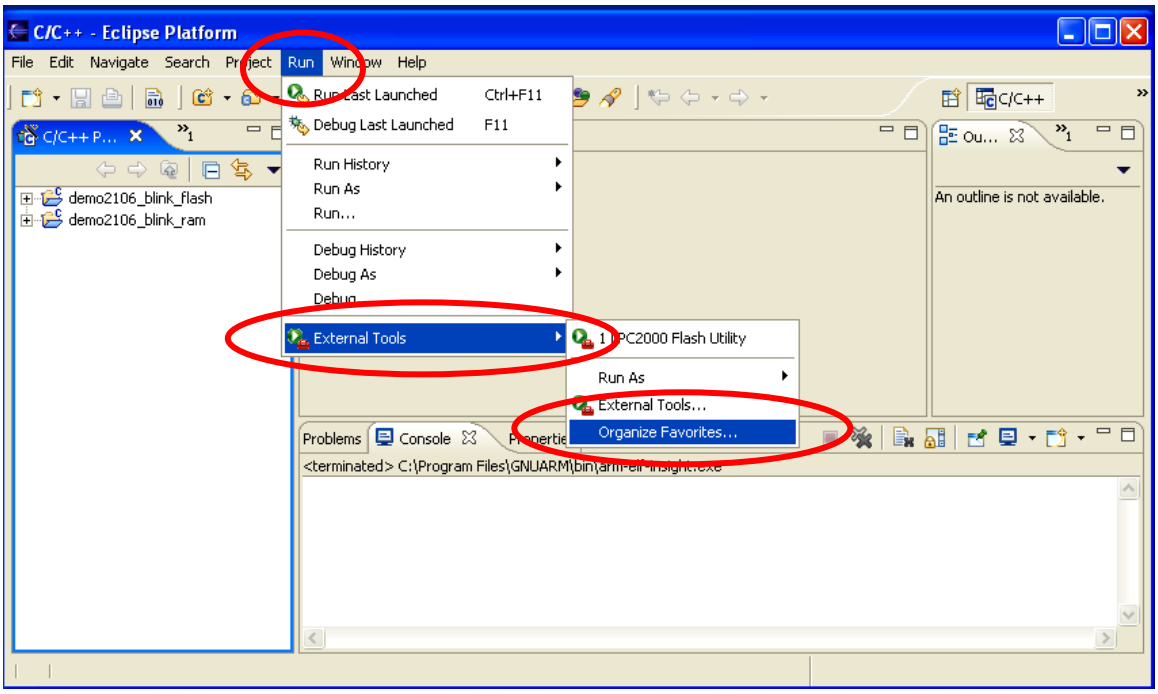
-cARM7TDMI-S	specifies the CPU being accessed
-p8888	specifies the pseudo TCP-IP port being used
-dWIGGLER	specifies the JTAG hardware being used
-a1	specifies LPT1 for the Wiggler
-s4	specifies 100 khz speed (-s8 is the slowest speed)

You will probably want to experiment with the speed setting. Click on “**Apply**” to finish the setup.

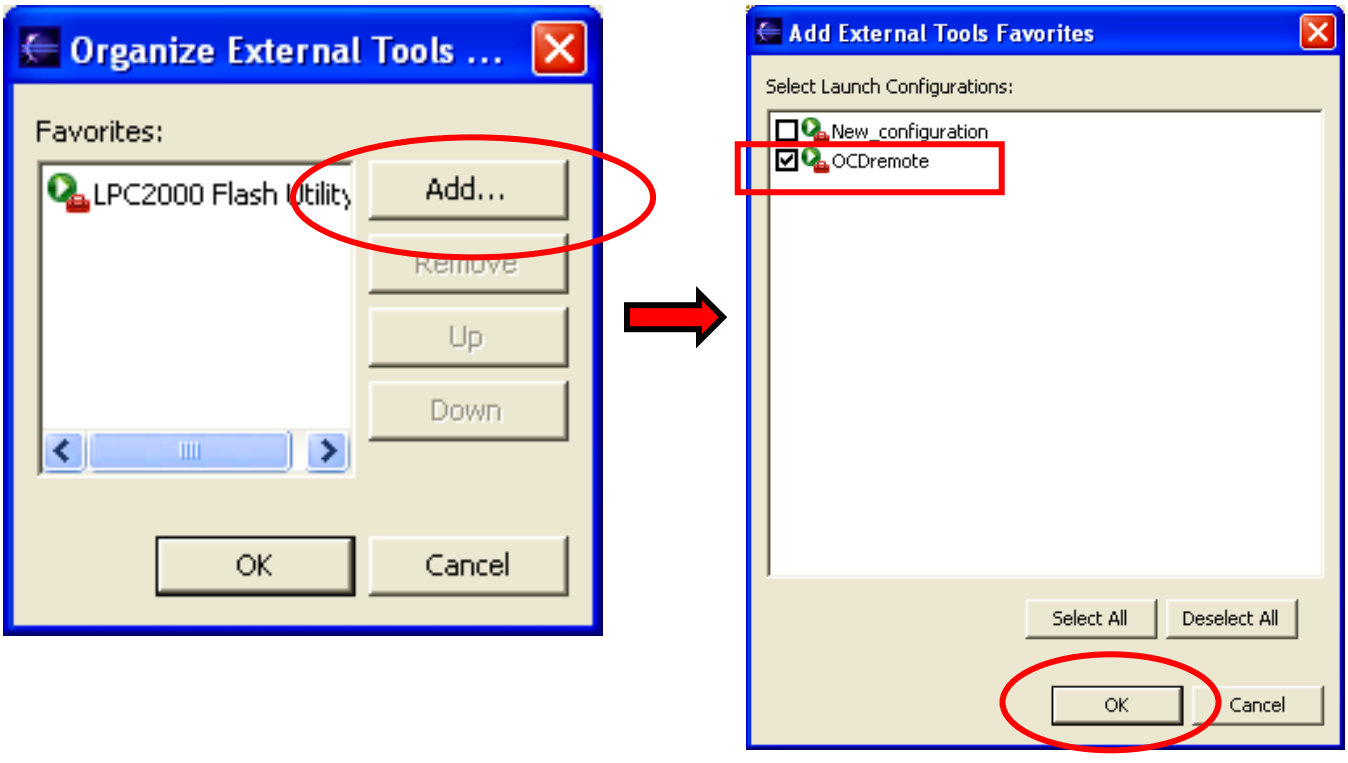


Just like the Philips LPC2000 Flash Utility, we’d like to include the **OCDremote** application in our list of “**favorite**” External Tools. This allows us to quickly start the **OCDremote** JTAG server from within Eclipse.

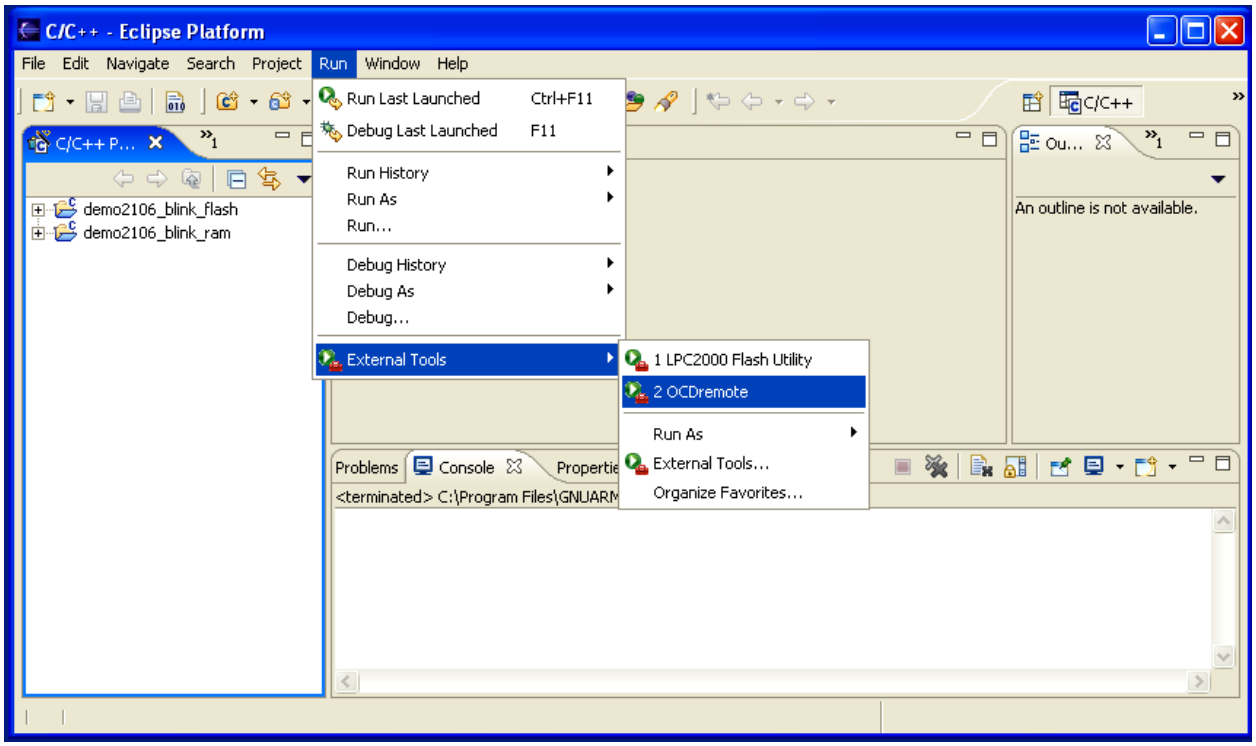
Click on “**Run – External Tools – Organize Favorites**”



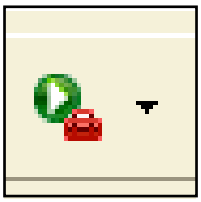
Now click on “**Add…**” in the Organize External Tools … window and follow that by checking “**OCDremote**” in the Add External Tools Configurations: window. Click on “**OK**” to add the OCDremote to the list of favorites.

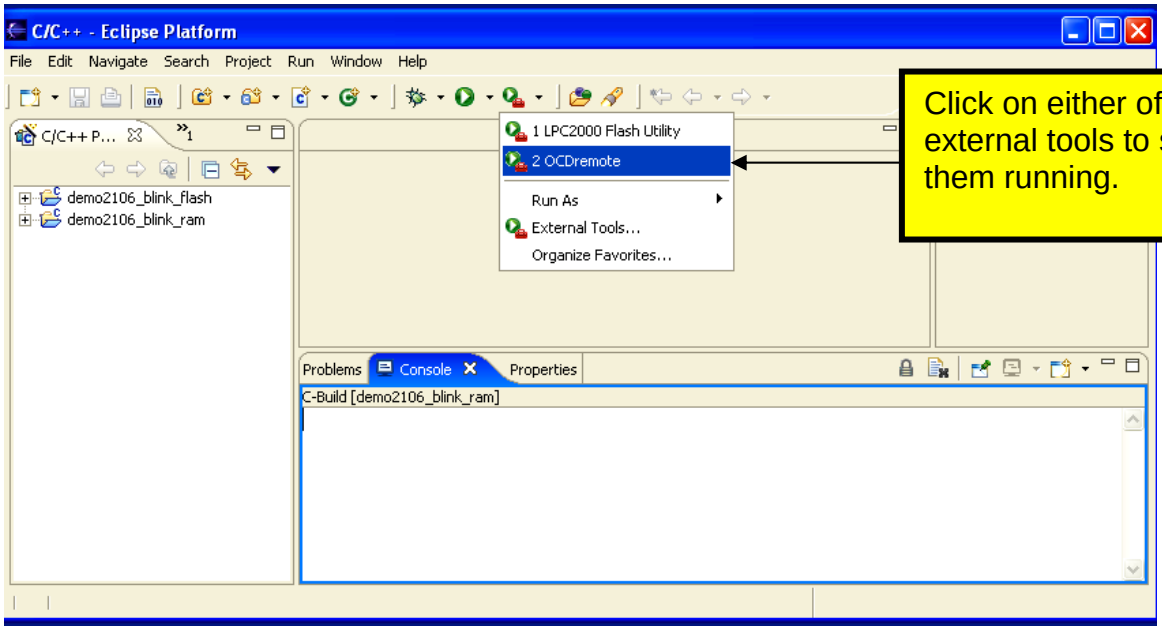


Now verify that the **OCDremote** is in the list of External Tools favorites. Click on "**Run – External Tools**" and see that it's now included in the list of favorites.



Now is a good time to point out that there's a handy shortcut button in Eclipse to run the External Tools. Click on the **External Tools** button's down arrow to expand the list of available tools.





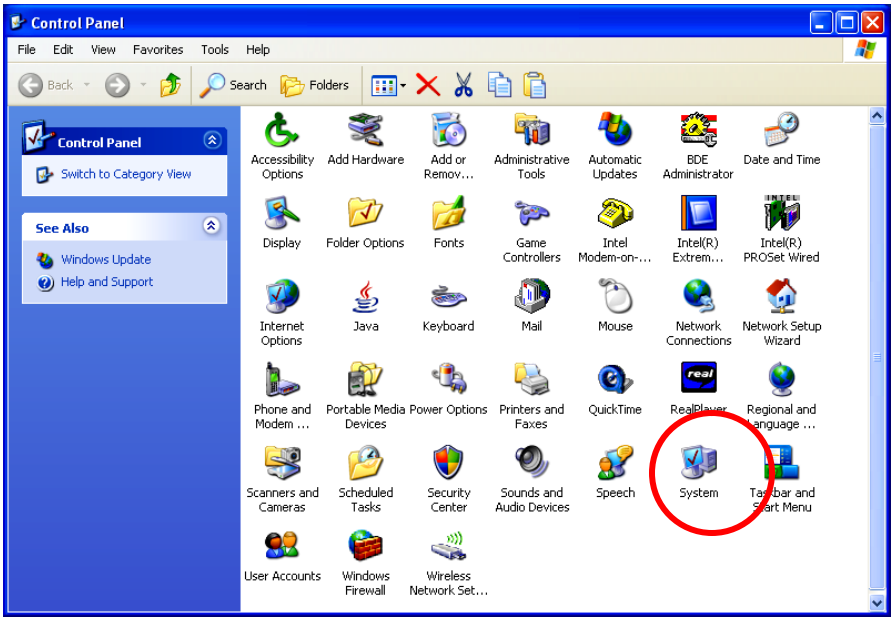
10 Verifying the PATH Settings

There is one final and very crucial step to make before we complete our tool building. We have to ensure that the Windows PATH environment variable has entries for the **Cygwin** toolset, the **GNUARM** toolset and the **OCDRemote** JTAG server.

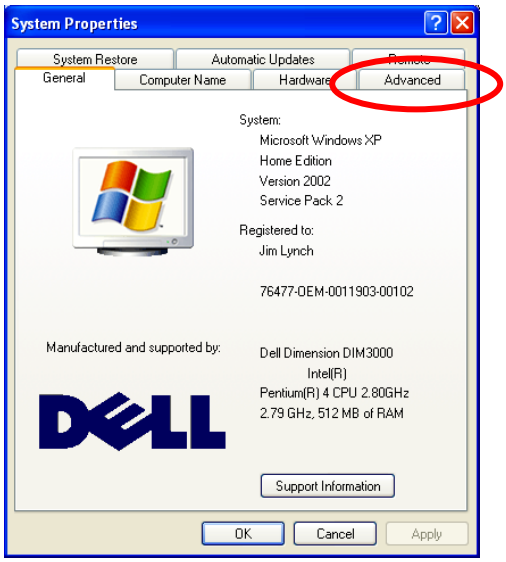
These are the three paths that **must** be present in the Windows environment:

c:\cygwin\bin
c:\program files\gnuarm\bin
c:\cygwin\usr\local\bin

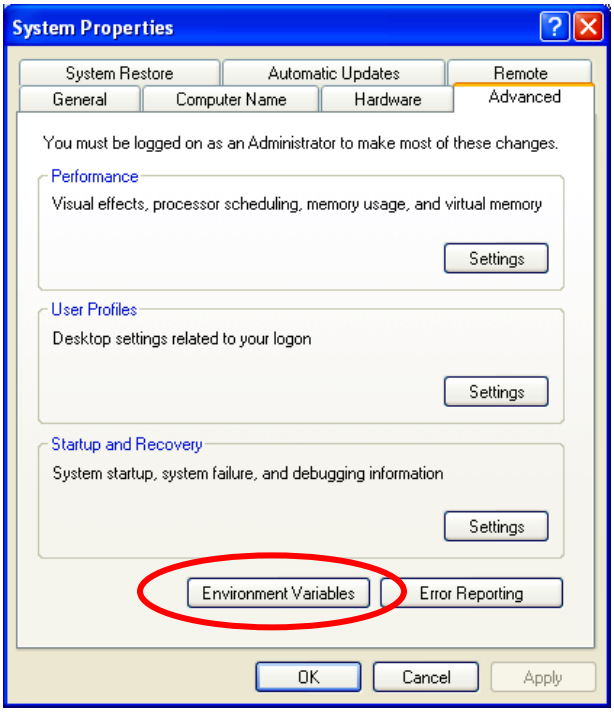
To verify that these paths are present in Windows and to make changes if required, start the Windows Control Panel by clicking "**Start – Control Panel**".



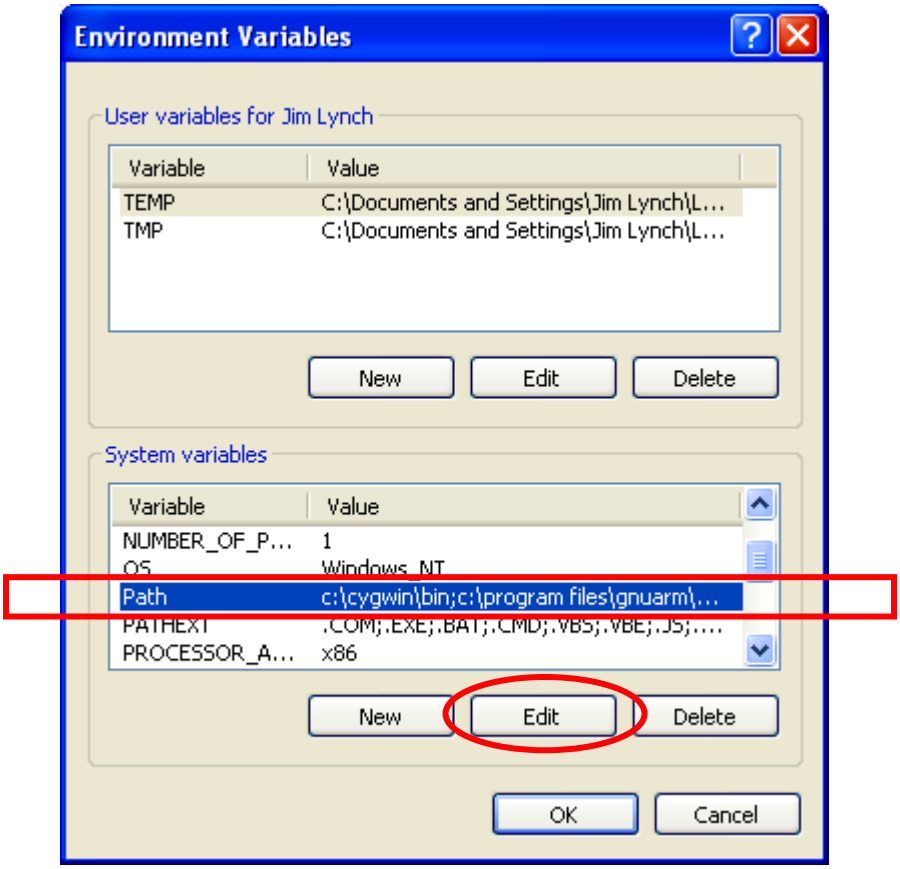
Now click on the "**Advanced**" tab below.



Now click on the “**Environment Variables**” button.



In the Environment Variables window, find the line for “**Path**” in the System Variables box on the bottom, click to select and highlight it and then click on “**Edit**”.



Take a very careful look at the “Edit System Variable” window (the Path Edit, in this case).

You should see the following paths specified, all separated by semicolons. The path is usually long and complex; you may find the bits and pieces for GNUARM interspersed throughout the path specification. I used cut and paste to place all my path specifications at the beginning of the specification (line); this is not really necessary.

You should see the following paths specified.

c:\cygwin\bin;c:\program files\gnuarm\bin;c:\cygwin\usr\local\bin

If any of the three is not present, now is the time to type them into the path specification.

I’ve found that not properly setting up the Path specification is the most common mistake made in configuring Eclipse to do cross-development.

This completes the setup of Eclipse and all the ancillary tools required to cross develop embedded software for the ARM microcomputer family (Philips LPC2000 family in specific).

If you stayed with me this far, your patience will soon be rewarded!

Or as Yoda would say, “***Rewarded soon, your patience will be!***”

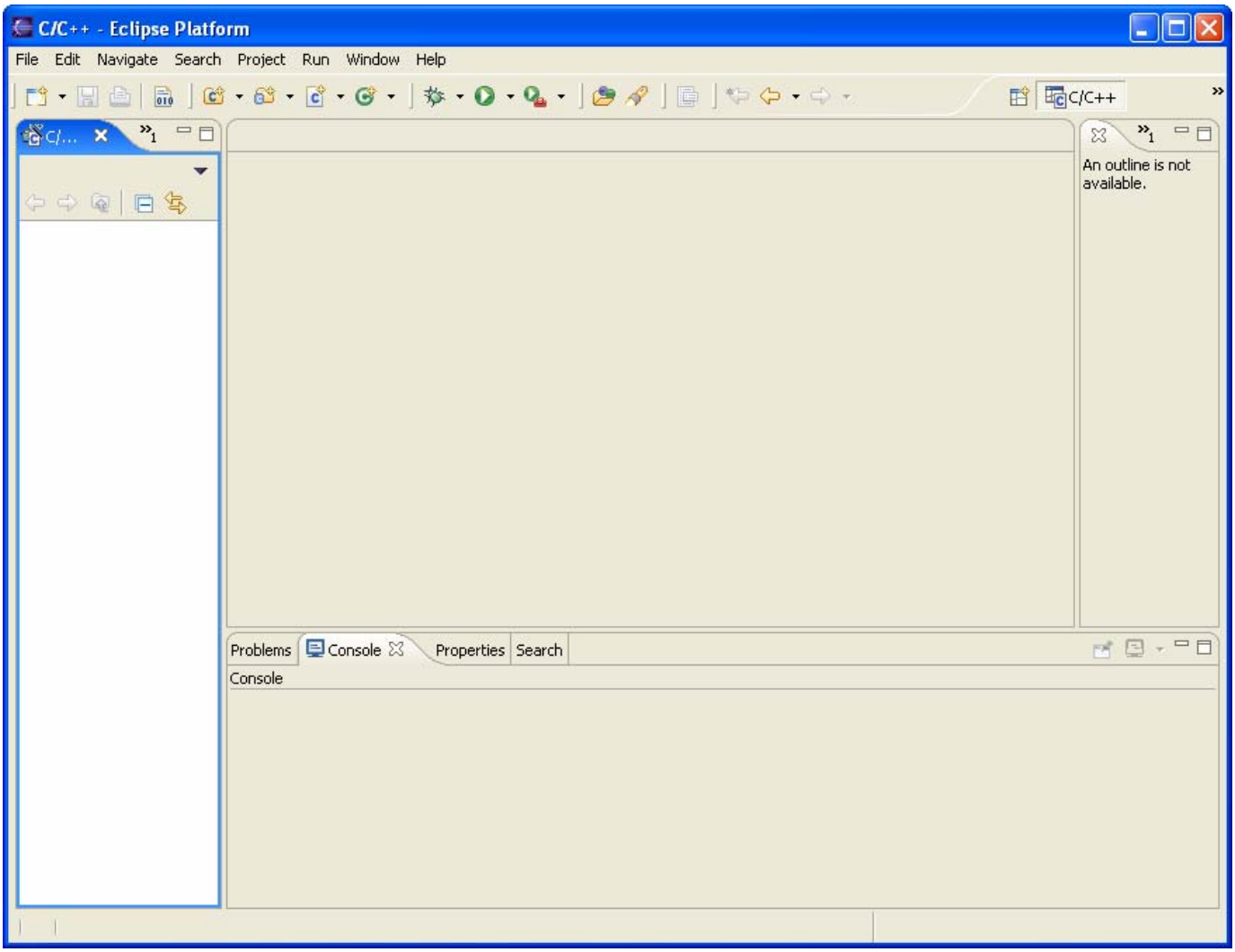
11 Creating a Simple Eclipse Project

At this point, we have a fully-functioning Eclipse IDE capable of building C/C++ programs for the ARM microprocessor (specifically for the Olimex LPC-P2106 prototype board).

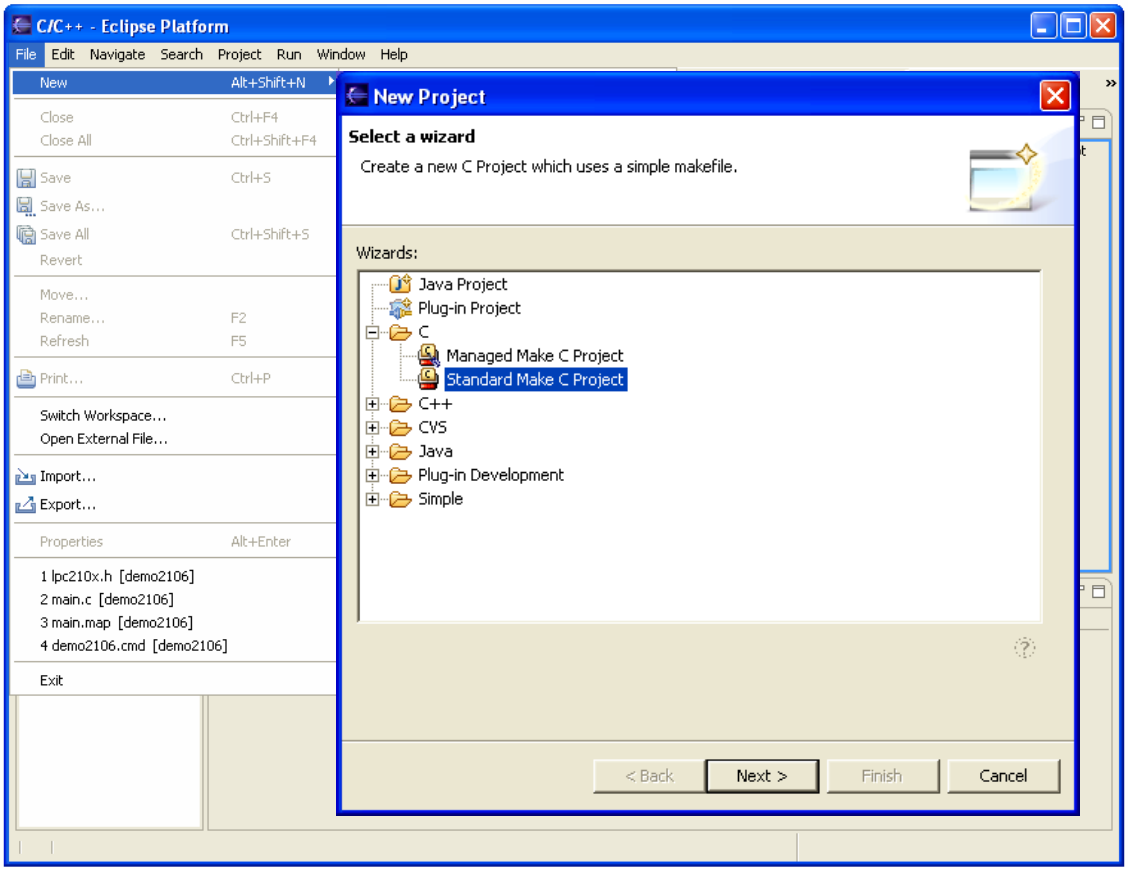
We will now create an Eclipse C project called "**demo2106_blink_flash**" that will blink the board's red LED_J which is I/O port P0.7. This demo uses no interrupts and runs totally out of onboard flash memory. It has been intentionally designed to be as simple and as straightforward as possible.

Click on our Eclipse desktop icon to start Eclipse.

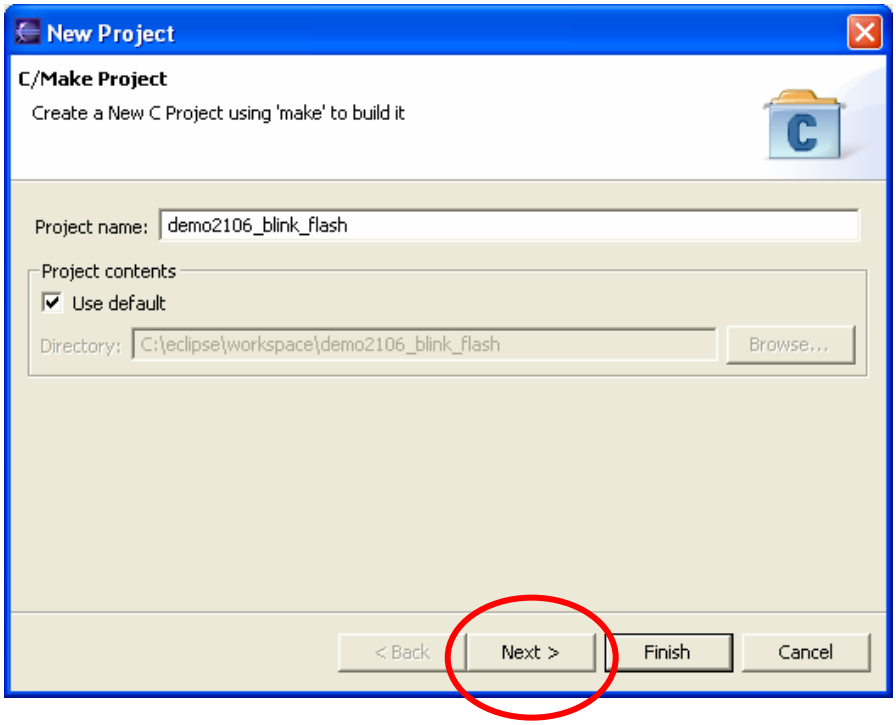
Eclipse should start and present the C/C++ perspective as shown below. If not, select "**Window - Open Perspective – Other - C/C++**" to change to the C++ perspective.



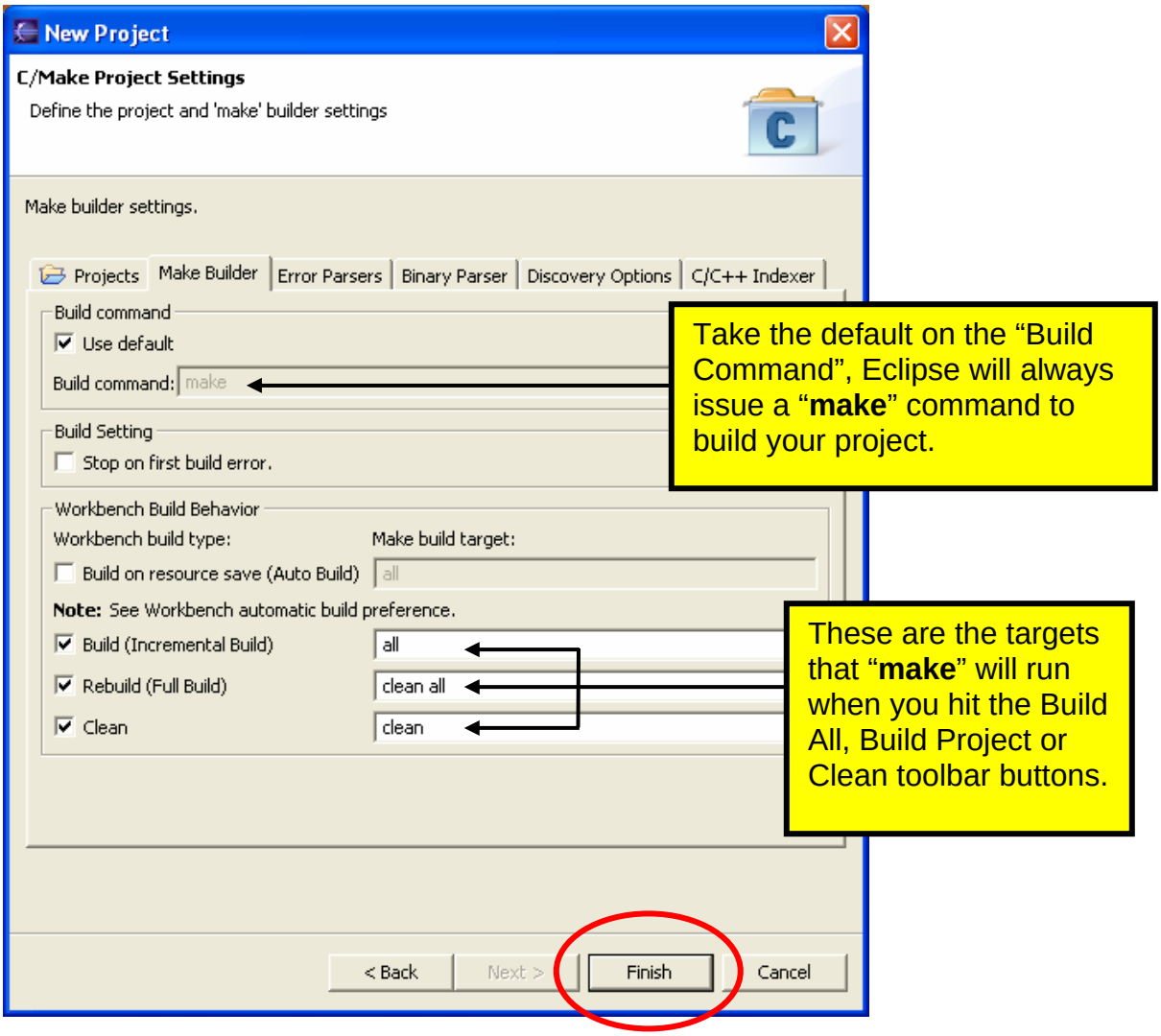
To create a project, select **File – New – New Project - Standard Make C Project** from the File pull-down menu and click "**Next**" to continue.



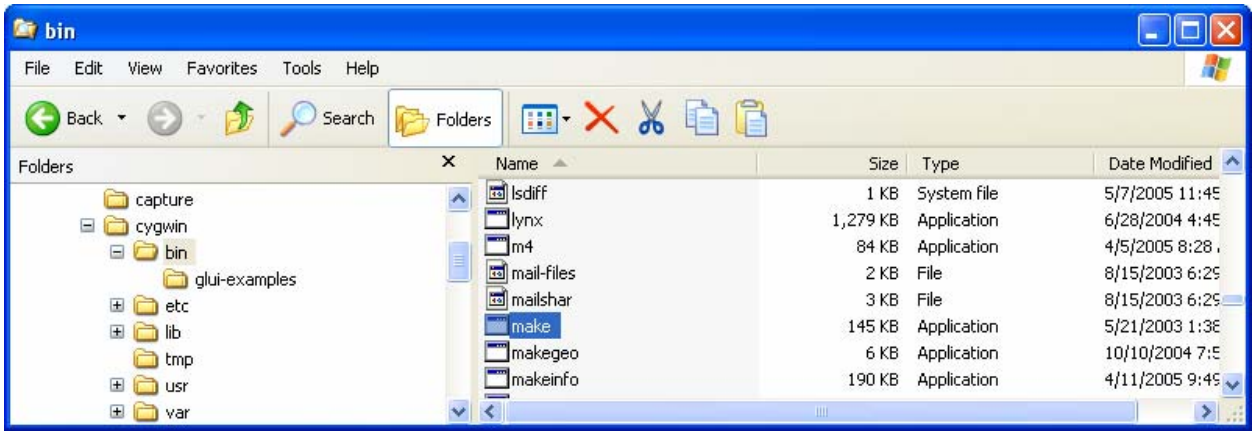
You should see the "New Project" dialog box and enter the project name (**demo2106_blink_flash**) in the box as shown below. Click on **Next** to continue.



The **New Project** dialog box appears next. If you click on the "**Make Builder**" tab, you'll notice that Eclipse build command is "**make**." Make is provided by the Cygwin GNU tools.



Let's remind ourselves that we installed the Cygwin GNU tools earlier in the tutorial and the Windows Explorer will show that the **make.exe** file is indeed in the directory **c:/cygwin/bin**, as shown below.

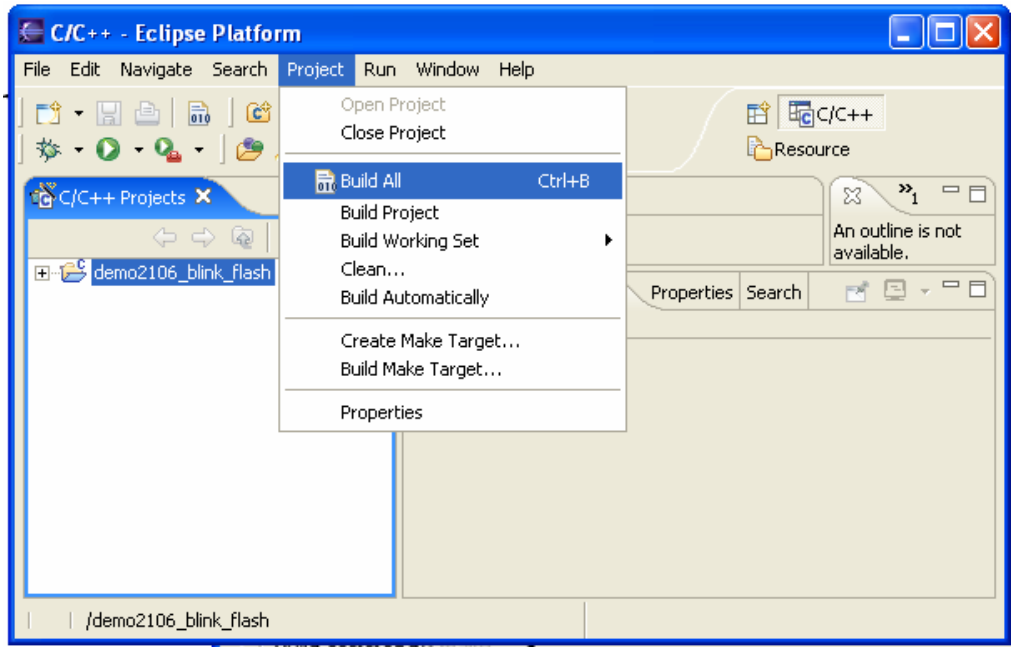


This is a good time to point out the differences between “Build All”, “Build Project” and “Clean.”

Build All Will execute the command “**make clean all**.”
It will first clean (delete) all object, list and output files.
Then it will rebuild everything, whether needed or not.

Build Project Will execute the command “**make all**.”
This will not clean (delete) anything.
It will only compile those source files that are “out-of-date.”

Clean Will execute the command “**make clean**.”
Will clean (delete) all object, list and output files.

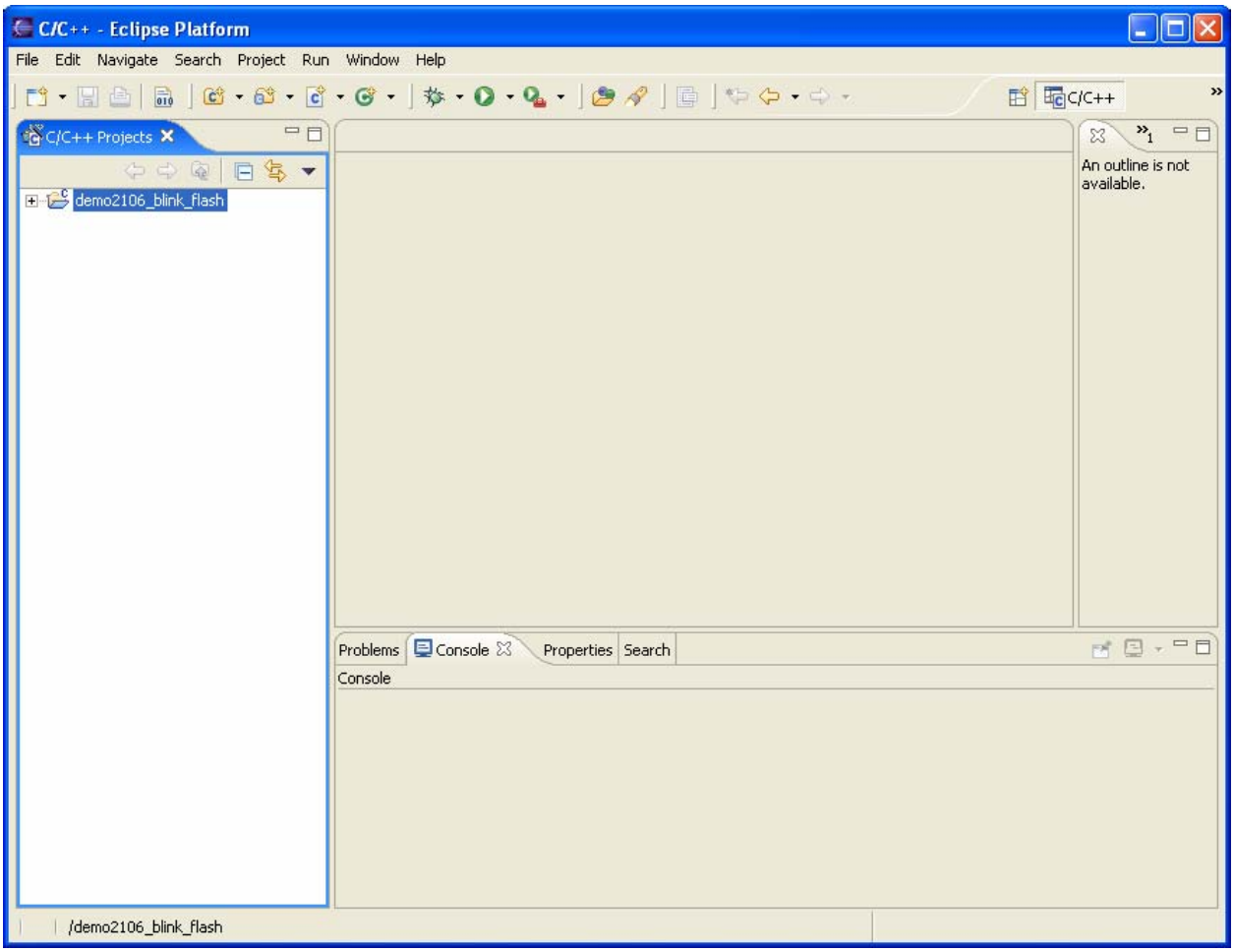


This is no different from opening up a DOS command window and typing the command in directly, such as.

```
> make clean all
```

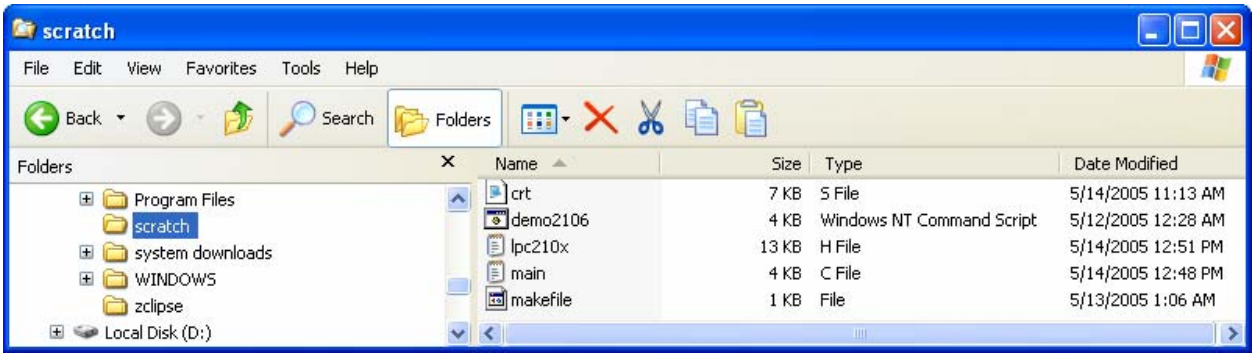
If you click “**Finish**” on the “New Project” dialog, Eclipse will return to the C/C++ Perspective.

Now the C/C++ perspective shows a bona fide project in the “C/C++ projects” box on the left. As of now, there are no source files created.

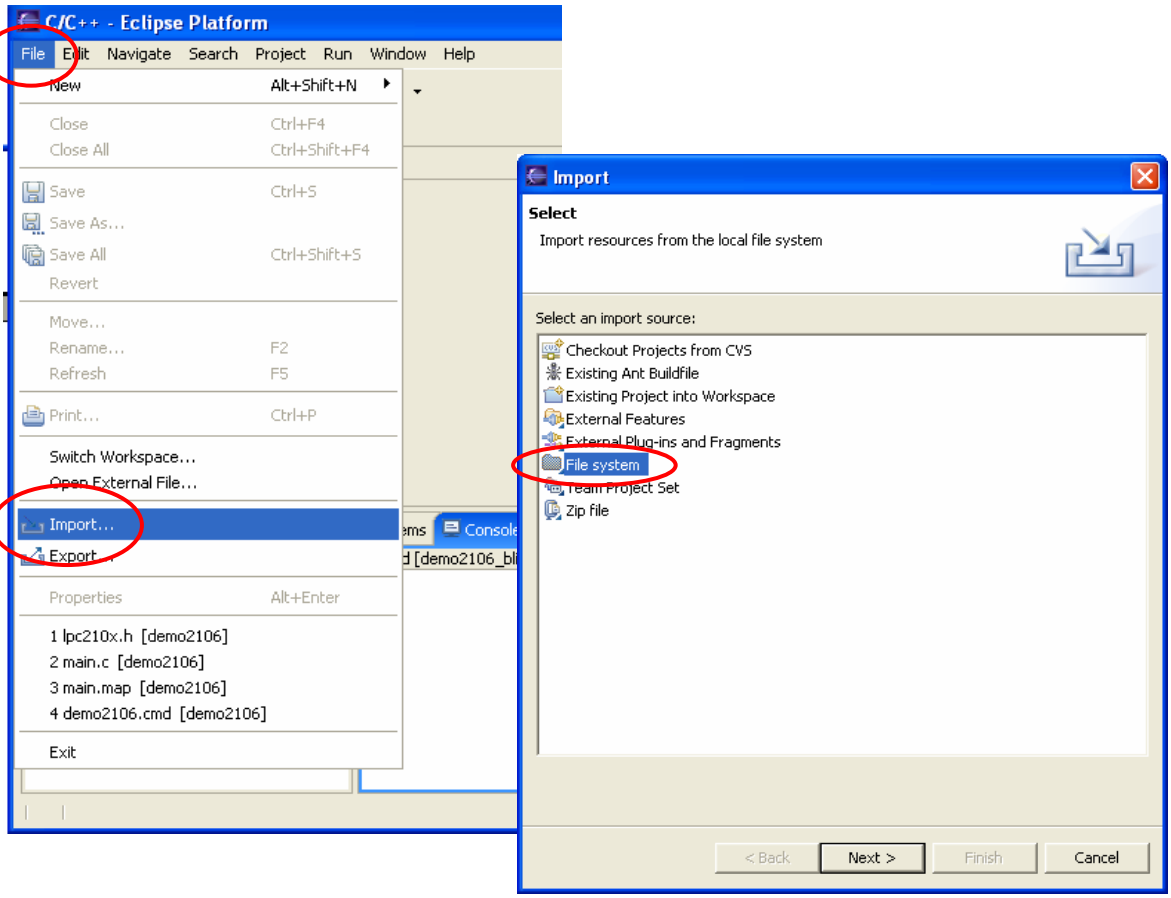


We can now use Eclipse/CDT's **import** feature to copy the source files into the project.

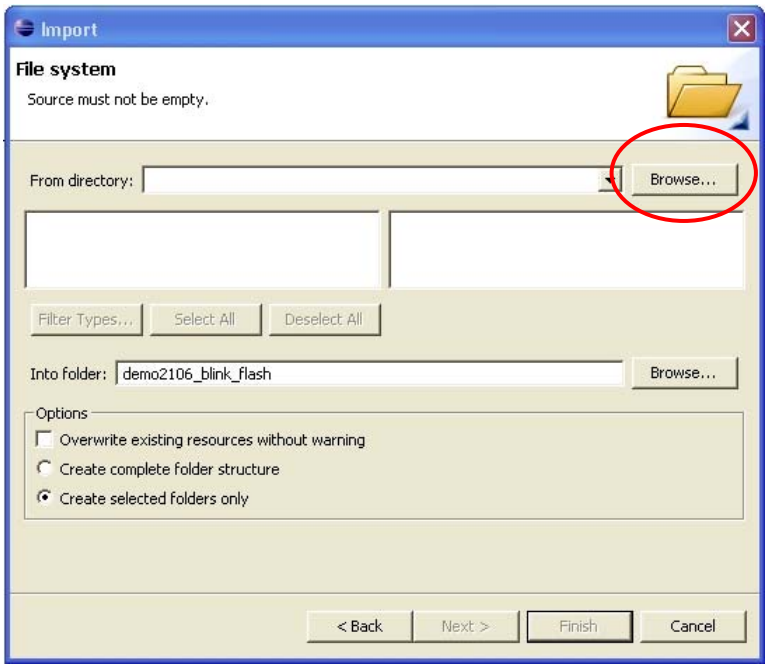
Assuming that you successfully unzipped the "**demo2106_blink_flash.zip**" project files associated with this tutorial to an empty directory such as **c:/scratch**, you should have the following source and make files in that directory.



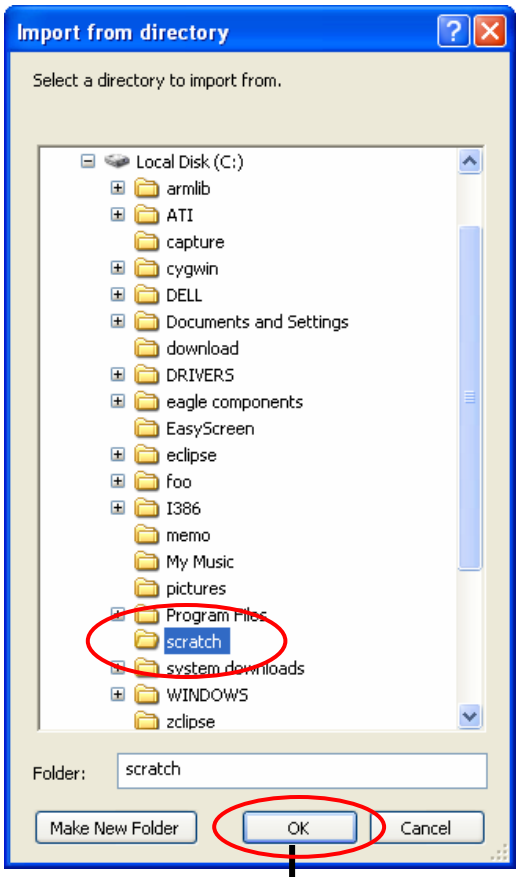
Click on the "**File**" pull-down menu and then click on "**Import.**" Then in the "**Import**" window, click on "**File System**."



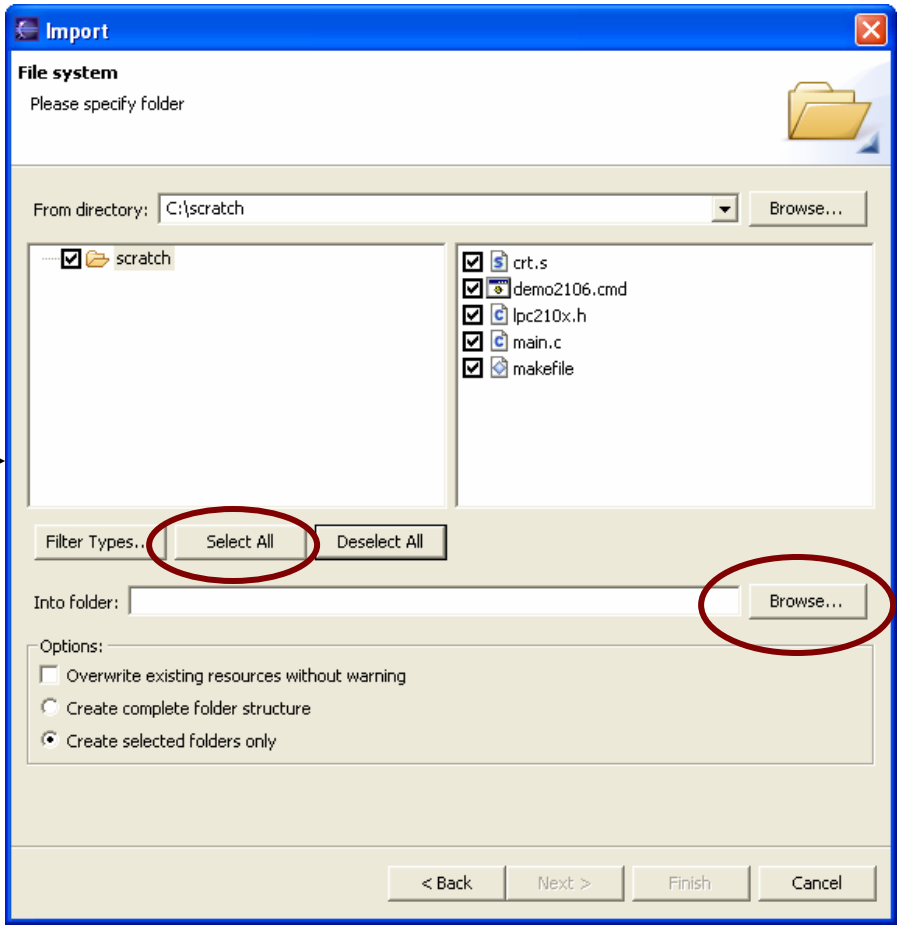
When the “**Import – File System**” window appears, click on the “**Browse**” button. Hunt for the sample project which is stored in the **c:/scratch/** directory.



Click on the directory “**scratch**” and hit the “**OK**” button in the “Import from directory” window on the left below.



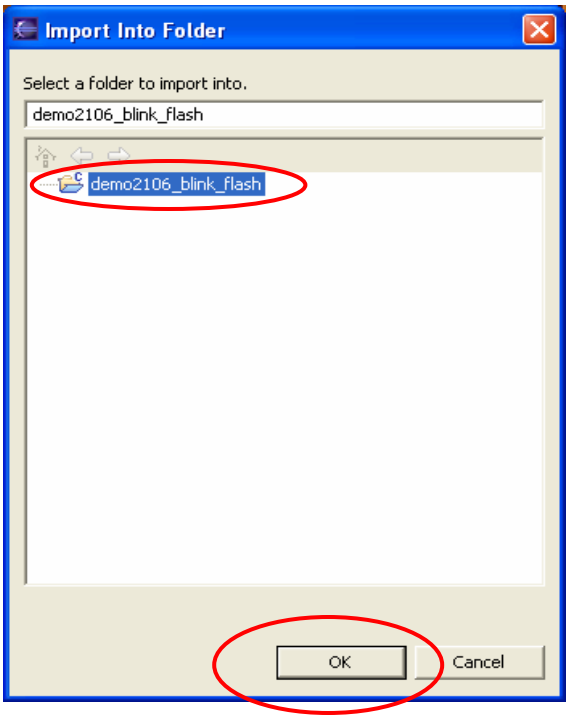
Click on “**Select All**” in the Import window below right to get the source files selected for import into our project.



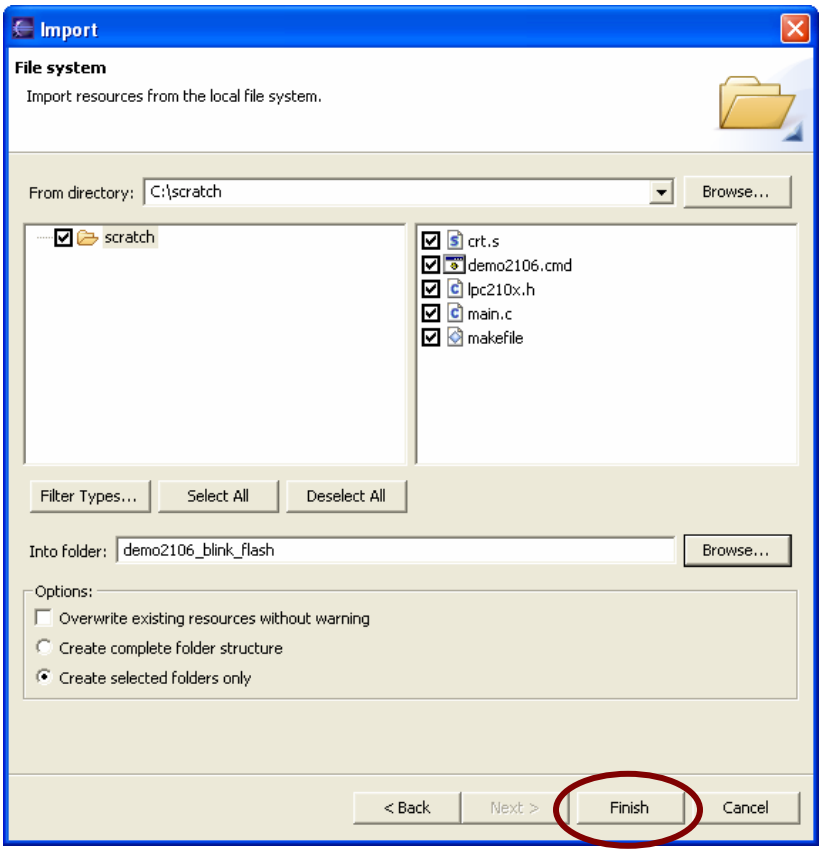
Now we have to indicate the destination for our source files. Click on “**Browse**” on the line to the right that says “**Into Folder**:”

The proper destination folder appears in the **Import Into Folder** window below.

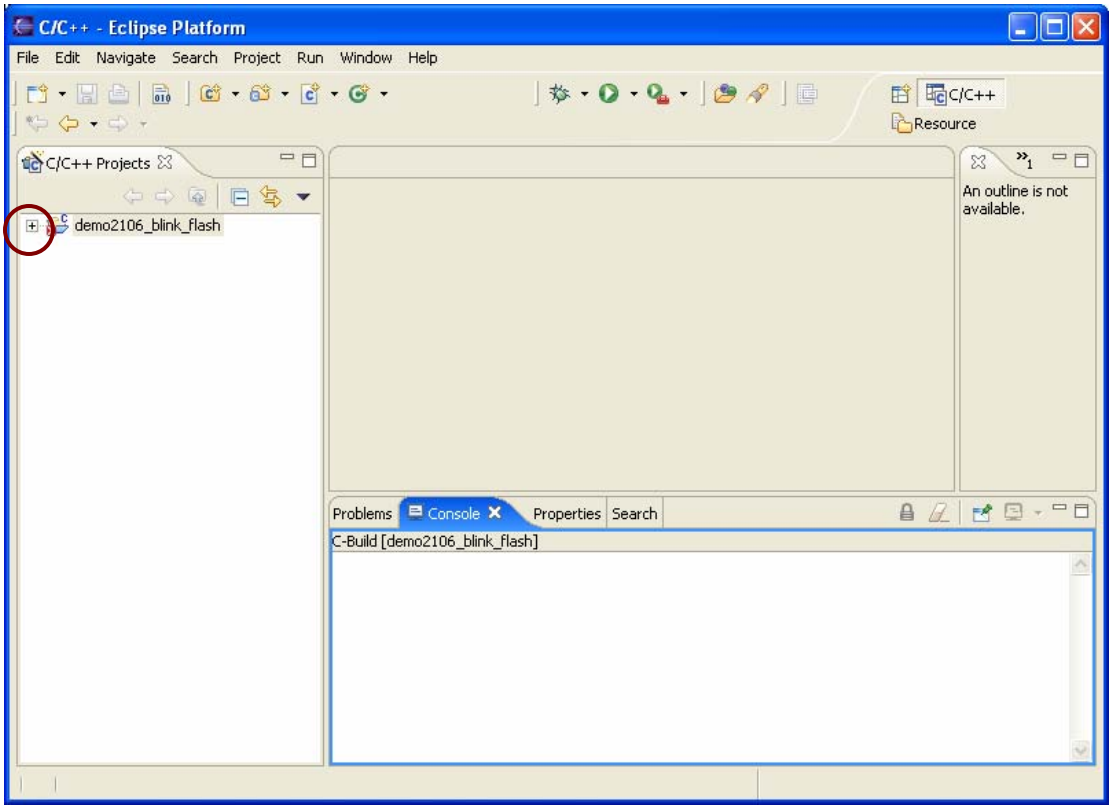
Click on the folder name "**demo2106_blink_flash**" and click "**OK**." The directory name "demo2106_blink_flash" should appear in the text box.



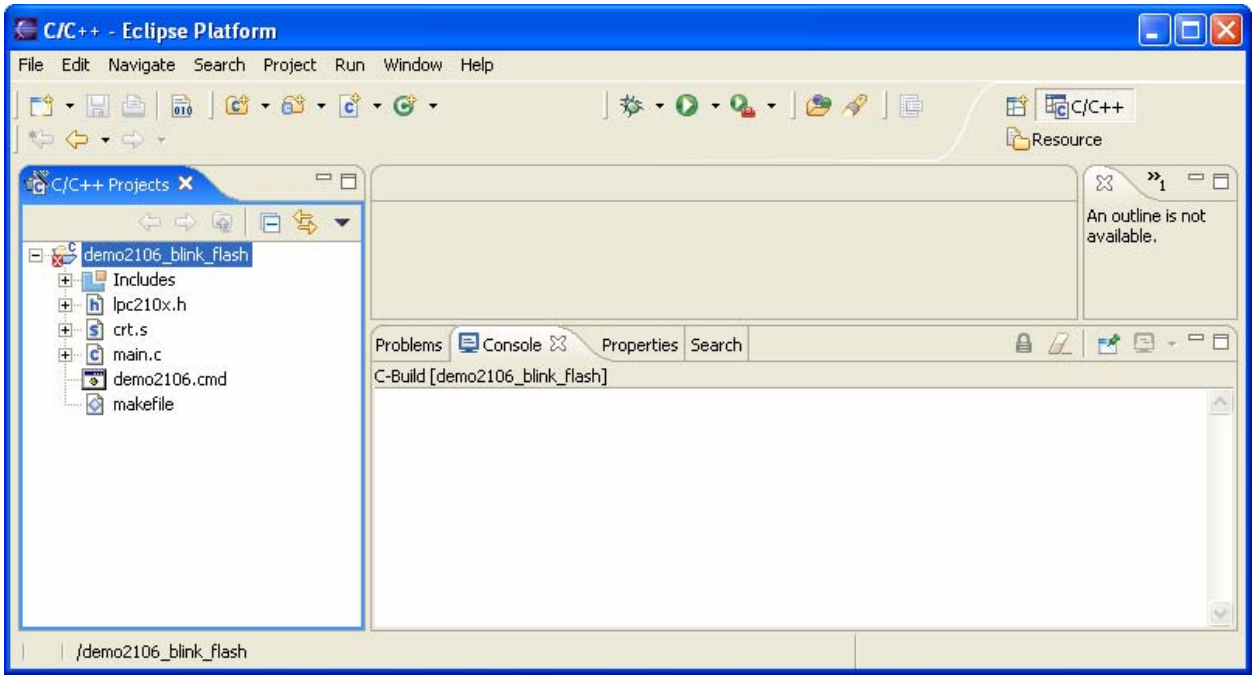
Now the Import dialog is completely filled out; we can click on "**Finish**" to actually import the source files into our project.



Now the C/C++ perspective main screen will reappear. Click on the "**+**" expand symbol in the navigator pane to see if our files have been transferred.



Success is at hand, the expanded Projects view in the Navigator pane on the left shows our imported files.



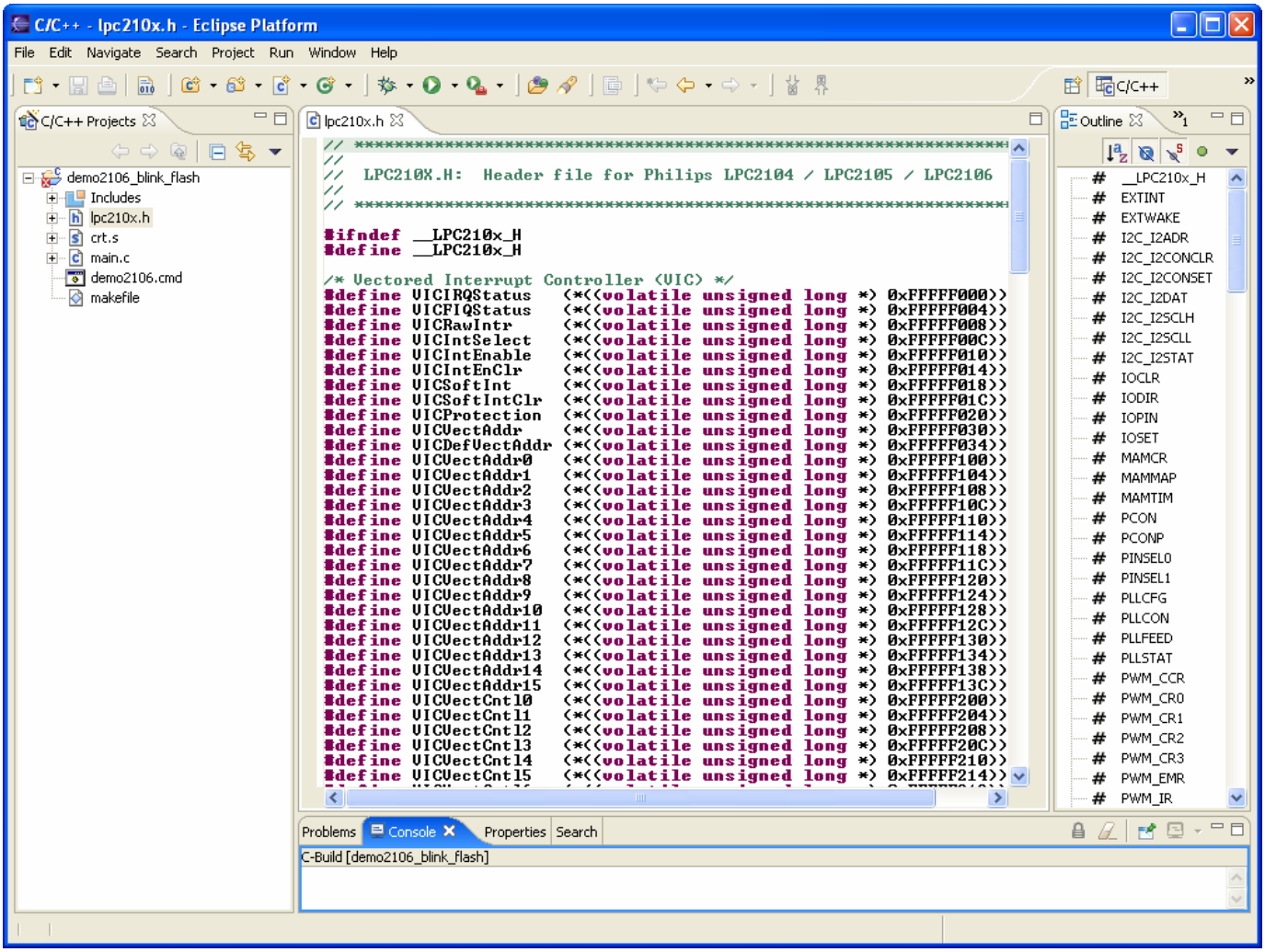
This is a good place to identify the imported source files.

Description of Project Files	
lpc210x.h	Standard LPC2106 header file
crt.s	Startup assembler file
main.c	Main C program
makefile	GNU makefile
demo2106_blink_flash.cmd	GNU Linker script file

12 Description of the LPC210X.H Include File

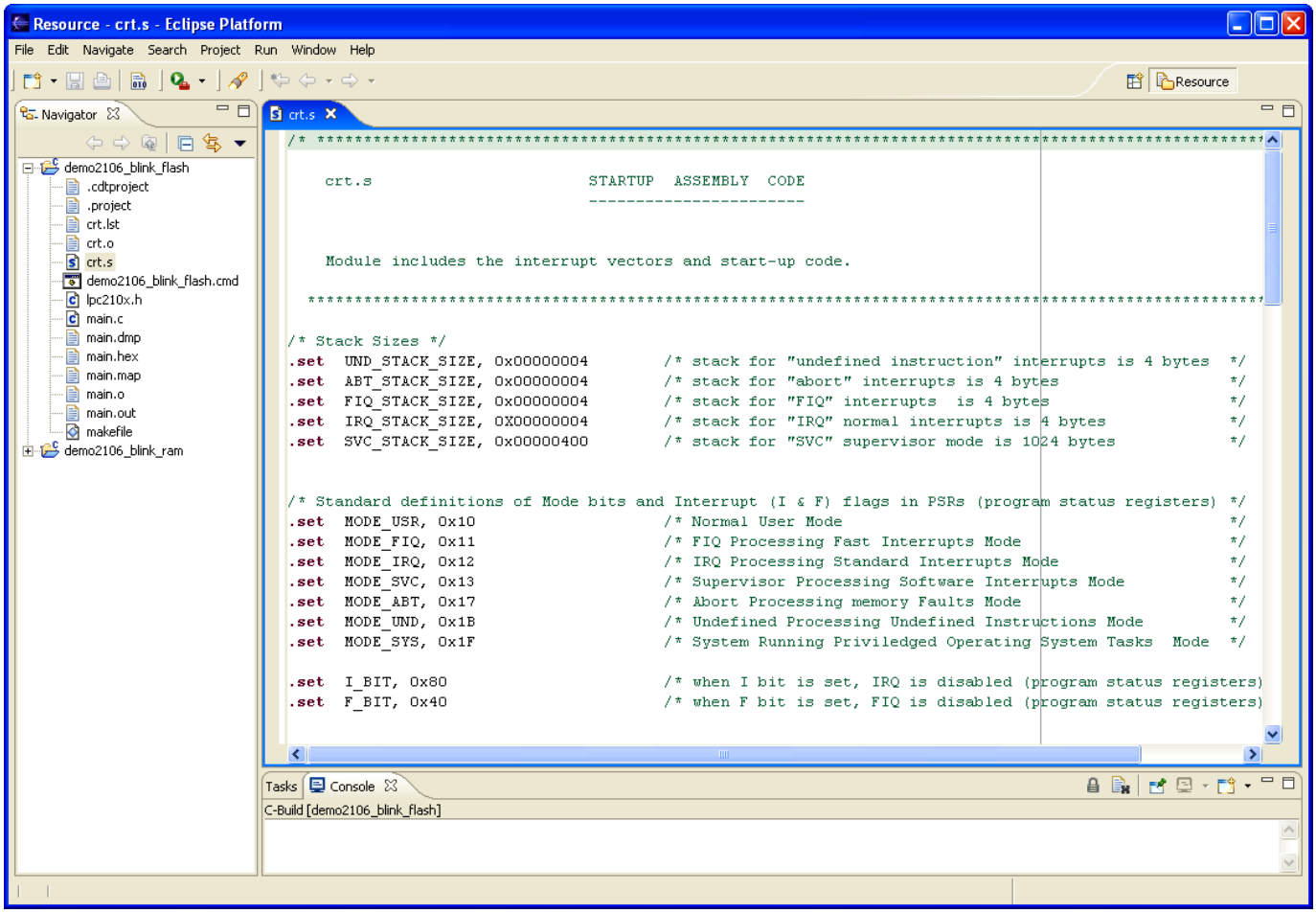
Let's look at the lpc210x.h header file. Double-click on it in the Project pane on the left'

ARM peripherals are memory-mapped, so all I/O registers are defined in this file so you don't have to type in the absolute memory addresses.



13 Description of the Startup File CRT.S

Now let's look on the startup assembler file, **crt.s**. Double-click on it.
This part of the **crt.s** file has some symbols set to the various stack sizes and mode bits.



This part of the **crt.s** file sets up the interrupt vectors.

Note that all of the code and data that follows goes into the **.text** section. It is also in ARM 32-bit code (not Thumb).

One label is made global, **_startup**. This will be available to other modules in the project and will also appear in the map.

The GNU assembler doesn't require you **.extern** anything. If a symbol is not defined in the assembler file, it is automatically assumed to be external.

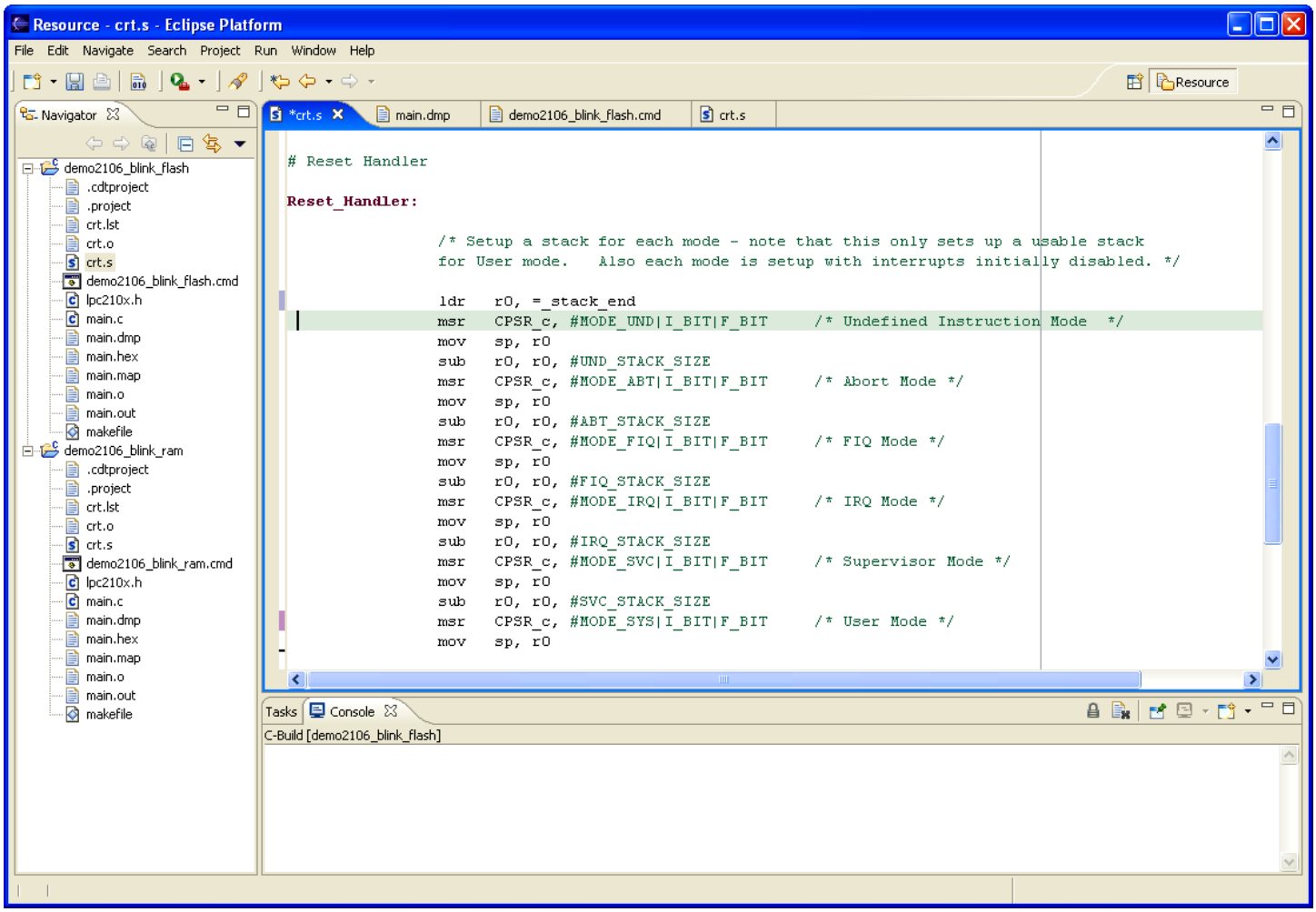
The vector table is 32 bytes long and is **required** to be placed at address 0x000000.

You will see later in this tutorial that the interrupt service routines referenced in the Vector Table are just endless-loop stubs in the main.c function and the interrupts are turned off.

The **NOP** instruction at address 14 is an empty spot to hold the checksum. Page 179 of the Philips LPC2106 manual states:

The reserved ARM interrupt vector location (0x0000 0014) should contain the 2's complement of the check-sum of the remaining interrupt vectors. This causes the checksum of all of the vectors together to be 0.

Before you fall on your sword, you'll be happy to know that the Philips Flash Loader will calculate that checksum and insert it for you. That's why we show it as a NOP.
This part of the **crt.s** file sets up the various interrupt modes and stacks.



The label **Reset_Handler** is the beginning of the code. Recall that the first interrupt vector at address 0x000000 loads the PC with the contents of the address Reset_Addr, which contains the address of the startup code at the label Reset_Handler. This trick, used in the entire vector table, loads a 32-bit constant into the PC and thus can jump to any address in memory space.

```
_vectors:      ldr    PC, Reset_Addr
                 :
Reset_Addr:    .word  Reset_Handler
```

Whenever the LPC2106 is reset, the instruction at 0x000000 is executed first; it jumps to **Reset_Handler**. From that point, we are off and running!

The first part of the startup code above sets up the stacks and the mode bits.

The symbol **_stack_end** will be defined in the linker command script file demo2106.cmd. Here is how it will be defined. Knowing that the Philips ISP Flash Loader will use the very top 288 bytes of RAM for its internal stack and variables, we'll start our application stacks at **0x4000FEE0**.
(Note: 0x40010000 – 0x120 = 0x4000FEE0)

```
/* define a global symbol _stack_end, placed at the very end of RAM (minus 4 bytes)  */
stack_end = 0x4000FEE0 – 4;
```

Working that out with the Windows calculator, the _stack_end is placed at 4000FEDC.

The code snippet that sets up the stacks and modes is a bit complex, so let's explain it a bit.

First we load R0 with the address of the end of the stack, as described above.

```
ldr   r0, =_stack_end
```

Now we put the ARM into Undefined Instruction mode by setting the MODE_UND bit in the Current Program Status Register (CPSR). The four modes undefined, irq, abort and svc all have their own private copies of R13 (sp) and r14 (link return). The FIQ mode has private copies of registers R8 – R14. Thus, by writing R0 into the stack pointer sp (R13), it will use 0x4000FEDC as the initial stack pointer if we ever have processing of an undefined instruction. By subtracting the undefined stack size (4 bytes) from R0, we're limiting the stack for UND mode to just 4 bytes.

```
msr   CPSR_c, #MODE_UND|I_BIT|F_BIT     /*  This puts the CPU in undefined mode */
mov   sp, r0                            /* stack pointer for UND mode is 0x40000FEDC  */
sub   r0, r0, #UND_STACK_SIZE           /* Register R0 is now 0x4000FED8  */
```

Now we put the ARM into Abort mode by setting the MODE_ABT bit in the CPSR. As mentioned above, abort mode has its own private copies of R13 and R14. We now set the abort mode stack pointer to 0x4000FED8. Again by subtracting the abort stack size from R0, we're limiting the stack for ABT mode to just 4 bytes.

```
msr   CPSR_c, #MODE_ABT|I_BIT|F_BIT     /* this puts CPU in Abort mode  */
mov   sp, r0                            /* stack pointer for ABT mode is 0x4000FED8  */
sub   r0, r0, #ABT_STACK_SIZE           /* Register R0 is now 0x4000FED4  */
```

Now we put the ARM into FIQ (fast interrupt) mode by setting the MODE_FIQ bit in the CPSR. As mentioned above, FIQ mode has its own private copies of R14 through R8. We now set the abort mode stack pointer to 0x4000FED4. Again by subtracting the abort stack size from R0, we're limiting the stack for FIQ mode to just 4 bytes. We're not planning to support FIQ interrupts in this example.

```
msr   CPSR_c, #MODE_FIQ|I_BIT|F_BIT     /* this puts CPU in FIQ mode  */
mov   sp, r0                            /* stack pointer for FIQ mode is 0x4000FED4
sub    r0, r0, #FIQ_STACK_SIZE          /* Register R0 is now 0x4000FED0  */
```

Now we put the ARM into IRQ (normal interrupt) mode by setting the MODE_IRQ bit in the CPSR. As mentioned above, IRQ mode has its own private copies of R13 and R14. We now set the IRQ mode stack pointer to 0x4000FDE0. Again by subtracting the IRQ stack

size from R0, we're limiting the stack for IRQ mode to just 4 bytes. We're not planning to support IRQ interrupts in this example.

```
msr   CPSR_c, #MODE_IRQ|I_BIT|F_BIT      /* this puts the CPU in IRQ mode  */
mov   sp, r0                             /* stack pointer for IRQ mode is 0x4000FED0  */
sub   r0, r0, #IRQ_STACK_SIZE            /* R0 is now 0x4000FECC  */
```

Now we put the ARM into SVC (Supervisor) mode by setting the MODE_SVC bit in the CPSR. As mentioned above, SVC mode has its own private copies of R13 and R14. We now set the supervisor mode stack pointer to 0x4000FDDC. Again by subtracting the SVC stack size(4 bytes) from R0, we're sizing the stack for SVC mode to 4 bytes.

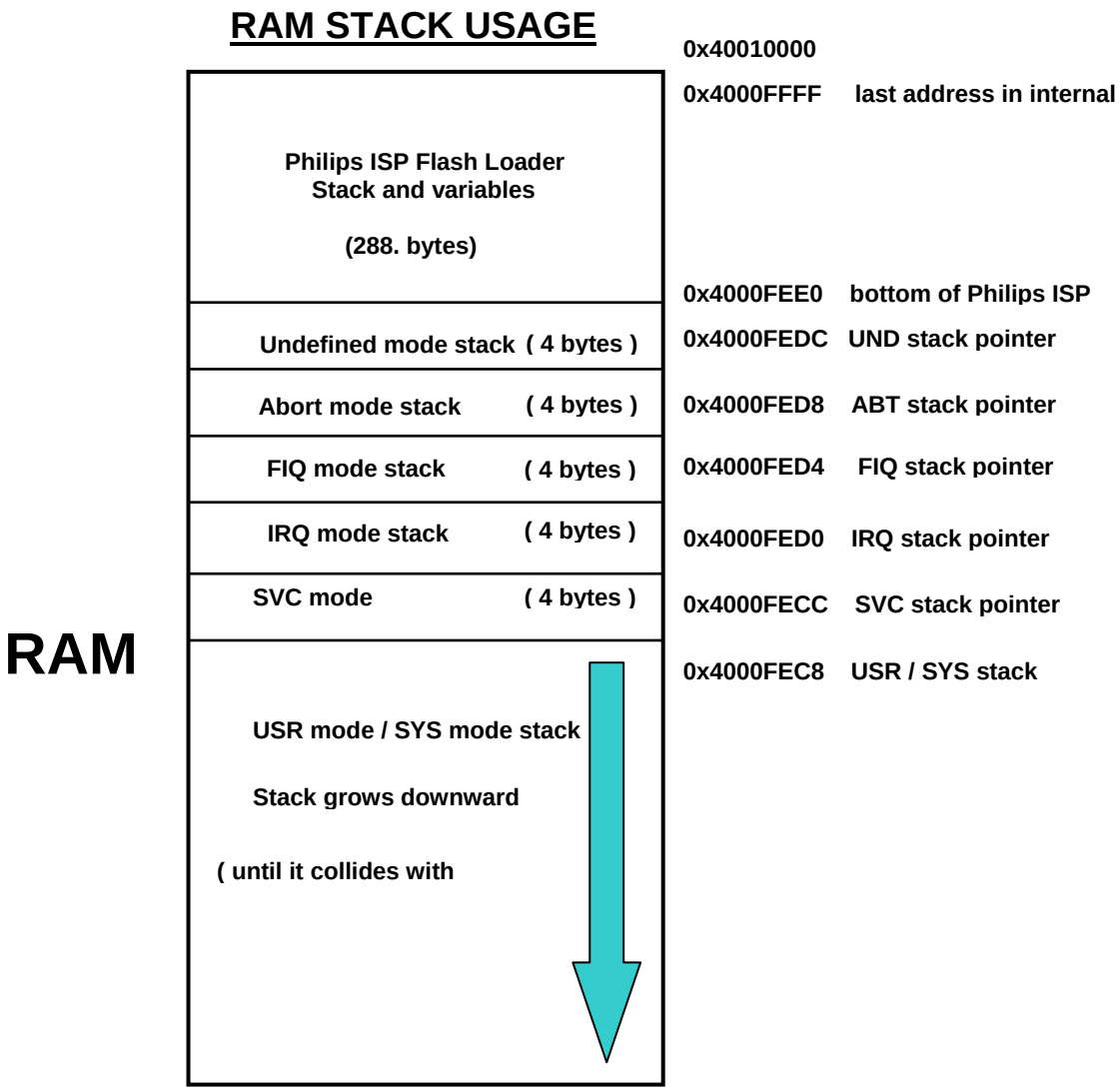
```
msr   CPSR_c, #MODE_SVC|I_BIT|F_BIT      /* This puts the CPU in SVC mode */
mov   sp, r0                             /* stack pointer for SVC mode is 0x4000FECC  */
sub   r0, r0, #SVC_STACK_SIZE            /* R0 is now 0x4000FEC8  */
```

The ARM "User" mode and the ARM "System" mode share the same registers and stack. For this very simple example, we'll run the application in "User" mode. Setting up the stack for User mode also sets up the stack for System mode.

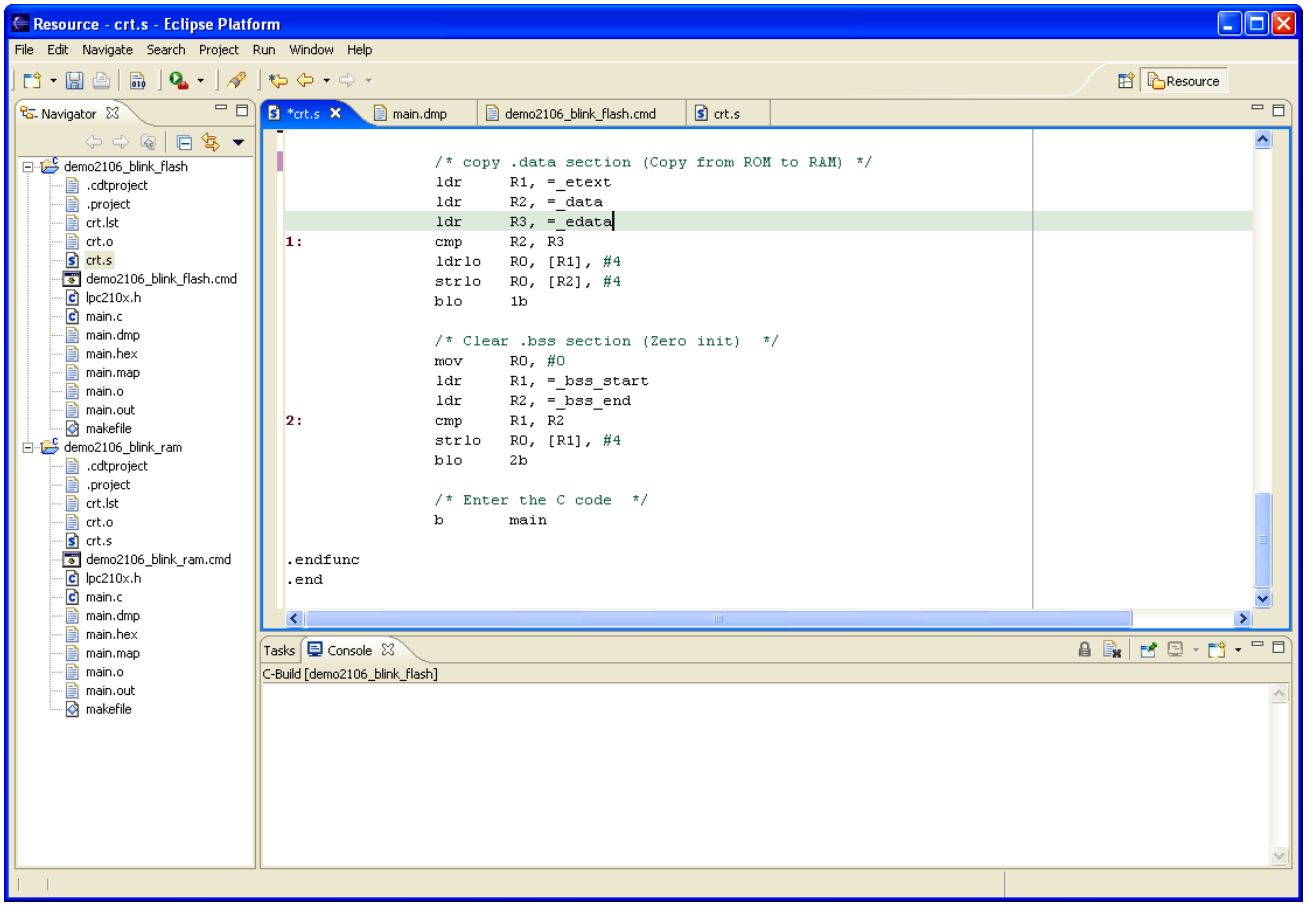
Now we put the ARM into USR (user) mode by setting the MODE_USR bit in the CPSR. We now set the USR mode stack pointer to 0x4000FEC8.

```
msr   CPSR_c, #MODE_USR|I_BIT|F_BIT      /* User Mode  */
mov   sp, r0
```

To summarize the above operations, let's draw a diagram of the stacks we just created.



The next part of the startup file crt.s to investigate is the setup of the **.data** and **.bss** sections, as shown below.



The **.data** section contains all the initialized static and global variables. The GNU linker will create a exact copy of the variables in flash with the correct initial values loaded. The onus is on the programmer to copy this initialized flash copy of the data to RAM.

The location of the start of the **.data** section in flash is defined by symbol **_etext** (defined in the linker command script **demo2106.cmd**). Likewise, the location of the start and end of the **.data** section in destination RAM is given by the symbols **_data** and **_edata**. Both of these symbols are defined in the linker command script.

The **.bss** section contains all the uninitialized static and global variables. All we have to do here is clear this area. Likewise, the location of the start and end of the **.bss** section in destination RAM is given by the symbols **_bss_start** and **_bss_end**. Both of these symbols are defined in the linker command script.

Two simple assembly language loops load the **.data** section in RAM with the initializers in flash and clear out the **.bss** section in RAM.

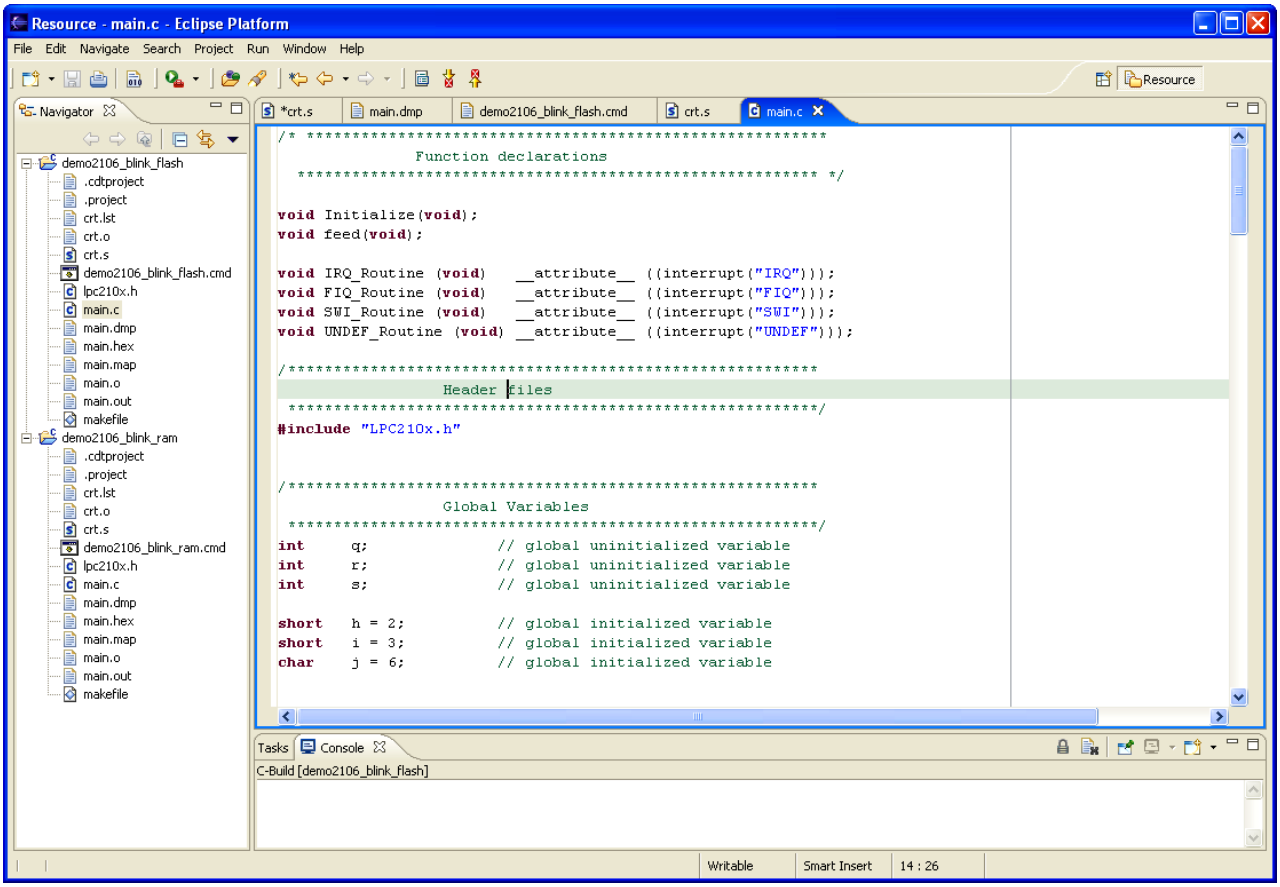
The GNU linker specifies two addresses for sections, the Virtual Memory Address (**VMA**) and the Load memory Address (**LMA**). The **VMA** is the final destination for the section; for the **.data** section, this is the RAM address where it will reside. The **LMA** is where it will be loaded in Flash memory, the exact copy with the initial values. The GNU Linker will sort this out for us.

14 Description of the Main Program main.c

Now let's look at the main program.

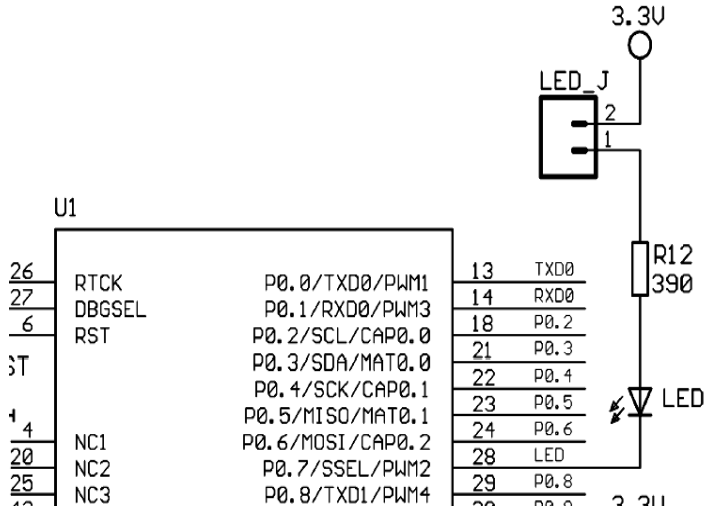
The main program starts out with a few function prototypes. Note that the interrupt routines mentioned in the crt.s assembler program reside in the **main()** program. We've used the GNU C compiler syntax that identifies the interrupt routines and makes sure that the compiler will save and restore registers, etc. whenever the interrupt is asserted.

I've also included a few do-nothing variables, both initialized and uninitialized, to illustrate that the compiler will put the initialized variables into the **.data** section and the uninitialized ones into the .bss section.



We're going to try to toggle a single I/O bit, specifically P0.7 which is the Olimex red LED. By the way, with this hardware arrangement:

P0.7 = 1 // turn off LED
P0.7 = 0 // turn on LED



The Philips LPC2106 has 32 I/O pins, labeled **P0.0** through **P0.31**. Most of these pins have two or three possible uses. For example, pin **P0.7** has three possible uses; digital I/O port, SPI Slave Select and PWM output 2. Normally, you select which function to use with the Pin Connect Block. The Pin Connect Block is composed of two 32-bit registers, PINSEL0 and PINSEL1. Each Pin Select register has two bits for each I/O pin, allowing at least three functions for each pin to be specified.

For example, pin **P0.7** is controlled by **PINSEL0**, bits 14 – 15. The following specification would select PWM2 output.

```
PINSEL0 = 0x00008000;   // set PINSEL0 bits 14 – 15 to 01
```

Fortunately, the Pin Connect Block resets to zero, meaning that all port pins are General-Purpose I/O bits. So we don't have to bother with the Pin Select registers in this example.

We do have to set the I/O Direction for port **P0.7**, this can be done in this way.

```
IODIR |= 0x00000080;      // set IO Direction register, P0.7 as output
                          // 1 = output,   0 = input
```

The ARM I/O ports are manipulated by register **IOSET** and register **IOCLR**. You never directly write to the I/O Port! You set a bit in the **IOSET** register to set the port bit and you set a bit in the **IOCLR** register to clear the port bit. This little nuance will trip up novice and experienced programmers alike. Alert readers will ask; "What if both bits are set in IOSET and IOCLR?" The answer is "Last one wins." The last IOSET or IOCLR instruction will prevail.

Why did ARM design the port bits this way? This scheme allows you to modify a bit without perturbing the others!

To turn the LED **P0.7** off, we can write:

```
IOSET = 0x00000080;       // turn P0.7 (red LED) off
```

Likewise, to turn the LED **P0.7** on, we can write:

```
IOCLR = 0x00000080;       // turn P0.7 (red LED) on
```

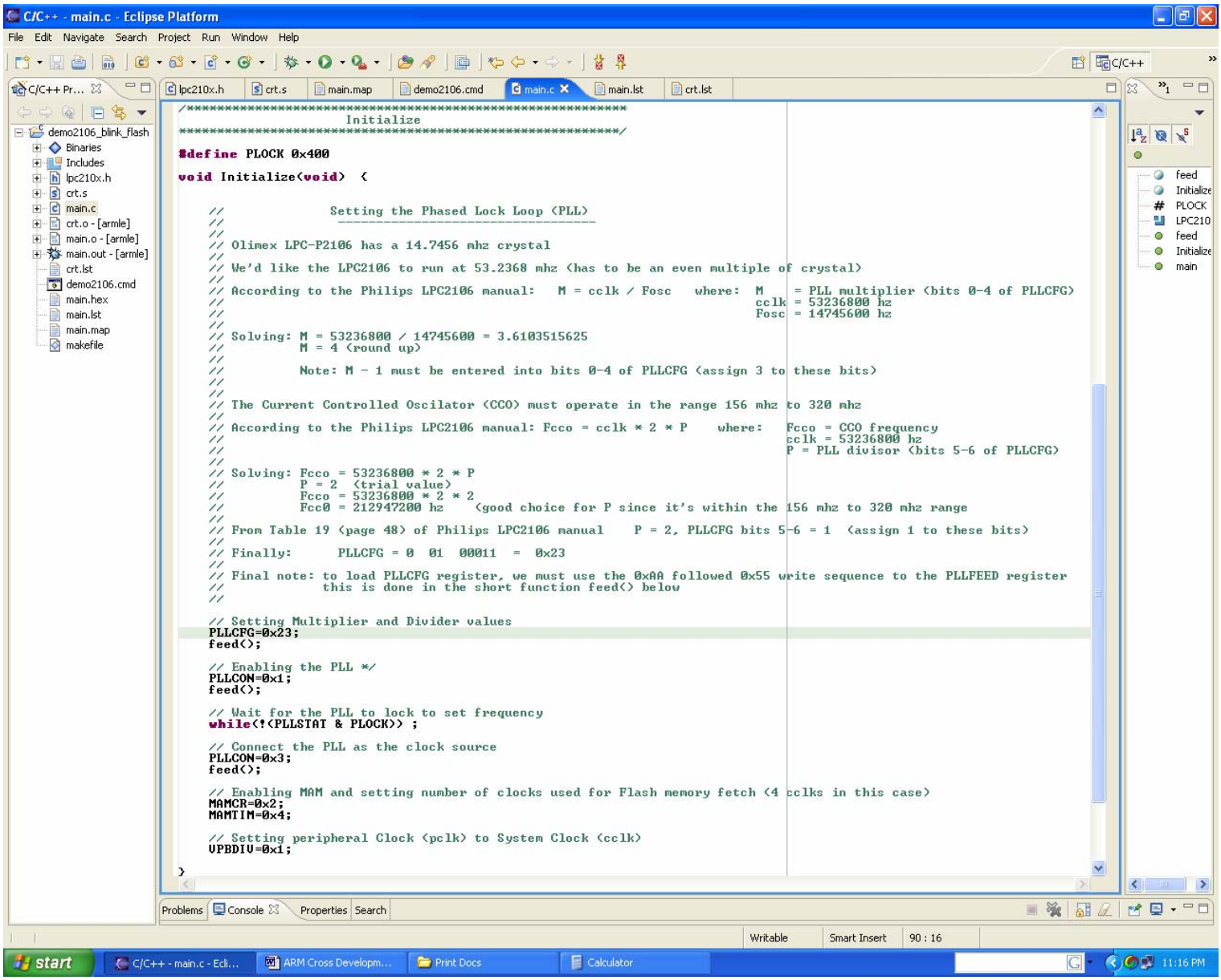
As you can see, it's fairly simple to manipulate I/O bits on the ARM processor.

To blink the LED, a simple FOREVER loop will do the job. I selected the loop counter values to get a one half second blink on – off time.

```
// endless loop to toggle the red  LED P0.7
while (1) {

        for (j = 0; j < 500000; j++ );          // wait 500 msec
        IOSET = 0x00000080;                             // red led off
        for (j = 0; j < 500000; j++ );          // wait 500 msec
        IOCLR = 0x00000080;                             // red led on
}
```

This scheme is very inefficient in that it hog-ties the CPU while the wait loops are counting up.

The **Initialize();** function requires some explanation.



We have to set up the Phased Lock Loop (PLL) and that takes some math.

Olimex LPC-P2106 board has a 14.7456 Mhz crystal

We'd like the LPC2106 to run at 53.2368 Mhz (has to be an even multiple of crystal, in this case 3x)

According to the Philips LPC2106 manual: M = cclk / Fosc where: M = PLL multiplier (bits 0-4 of PLLCFG)

cclk = 53236800 hz
Fosc = 14745600 hz

Solving: M = 53236800 / 14745600 = 3.6103515625
M = 4 (round up)

Note: M - 1 must be entered into bits 0-4 of PLLCFG (assign 3 to these bits)
The Current Controlled Oscillator (CCO) must operate in the range 156 Mhz to 320 Mhz

According to the Philips LPC2106 manual: **Fcco = cclk * 2 * P** **where:** **Fcco = CCO frequency**

cclk = 53236800 hz

P = PLL divisor (bits 5-6 of PLLCFG)

Solving: **Fcco = 53236800 * 2 * P**
P = 2 (trial value)
Fcco = 53236800 * 2 * 2
Fcc0 = 212947200 hz (good choice for P since it's within the 156 mhz to 320 mhz range

From Table 19 (page 48) of Philips LPC2106 manual P = 2, PLLCFG bits 5-6 = 1 (assign 1 to these bits)

Finally: **PLLCFG = 0 01 00011 = 0x23**

Final note: to load PLLCFG register, we must use the 0xAA followed 0x55 write sequence to the PLLFEED register
this is done in the short function feed() below

With the math completed, we can set the Phase Locked Loop Configuration Register (**PLLCFG**)

```
// Setting Multiplier and Divider values
PLLCFG = 0x23;
feed();
```

To set values into the PLLCON and PLLCFG registers, you have to write a two-byte sequence to the PLLFEED register:

```
PLLFEED = 0xAA;
PLLFEED = 0x55;
```

This sequence is coded in a short function **feed();**
The net effect of the above setup is to run the ARM CPU at 53.2 Mhz.

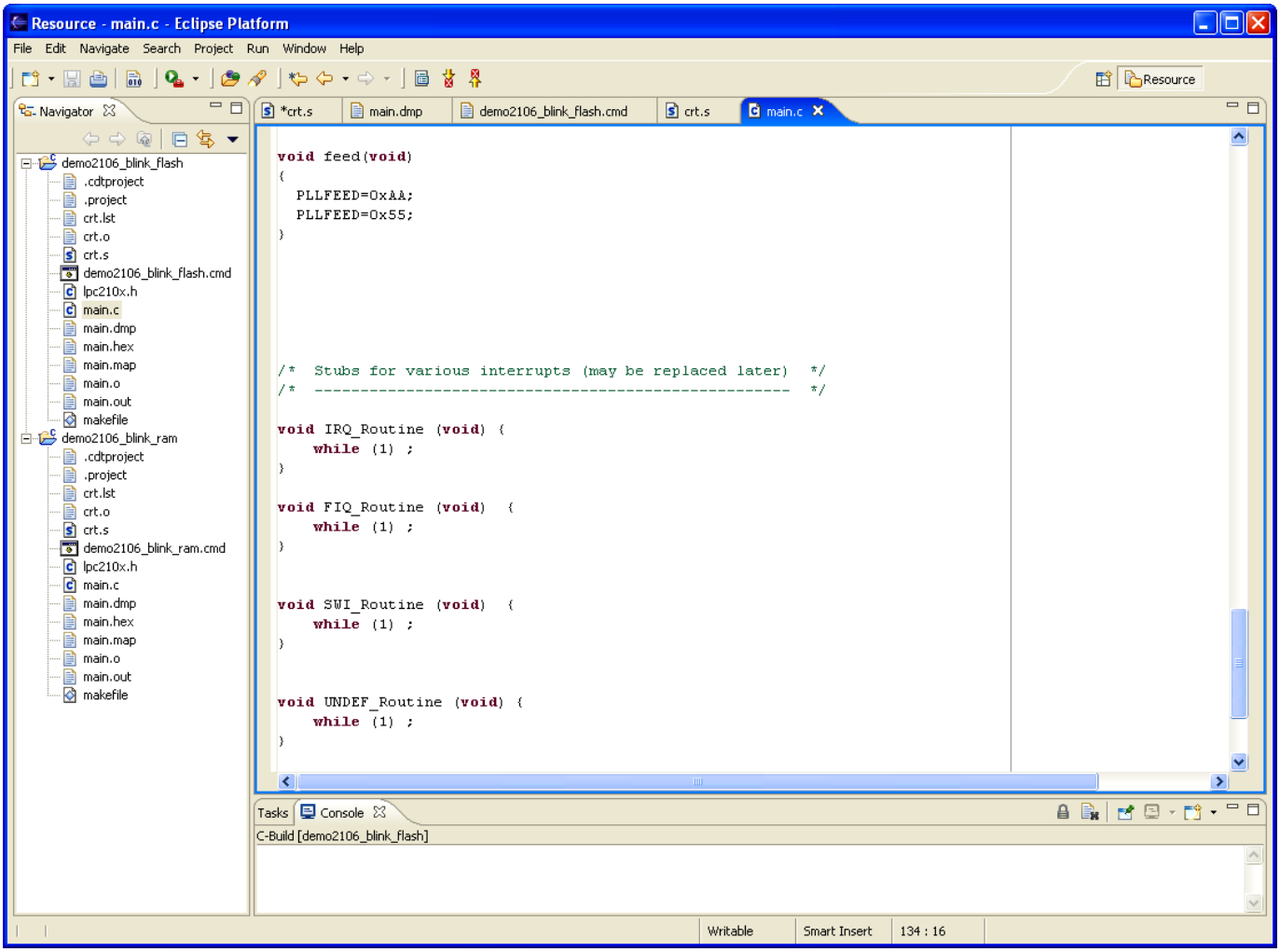
Next we fully enable the Memory Accelerator module and set the Flash memory to run at ¼ the clock speed. Now you see why some people prefer to execute out of RAM where it's much faster.

```
//  Enabling MAM and setting number of clocks used for Flash memory fetch
//  (4 cclks in this case)
MAMCR=0x2;
MAMTIM=0x4;
```

The clock speed of the peripherals is also run at 53.2 Mhz which is the full clock speed.

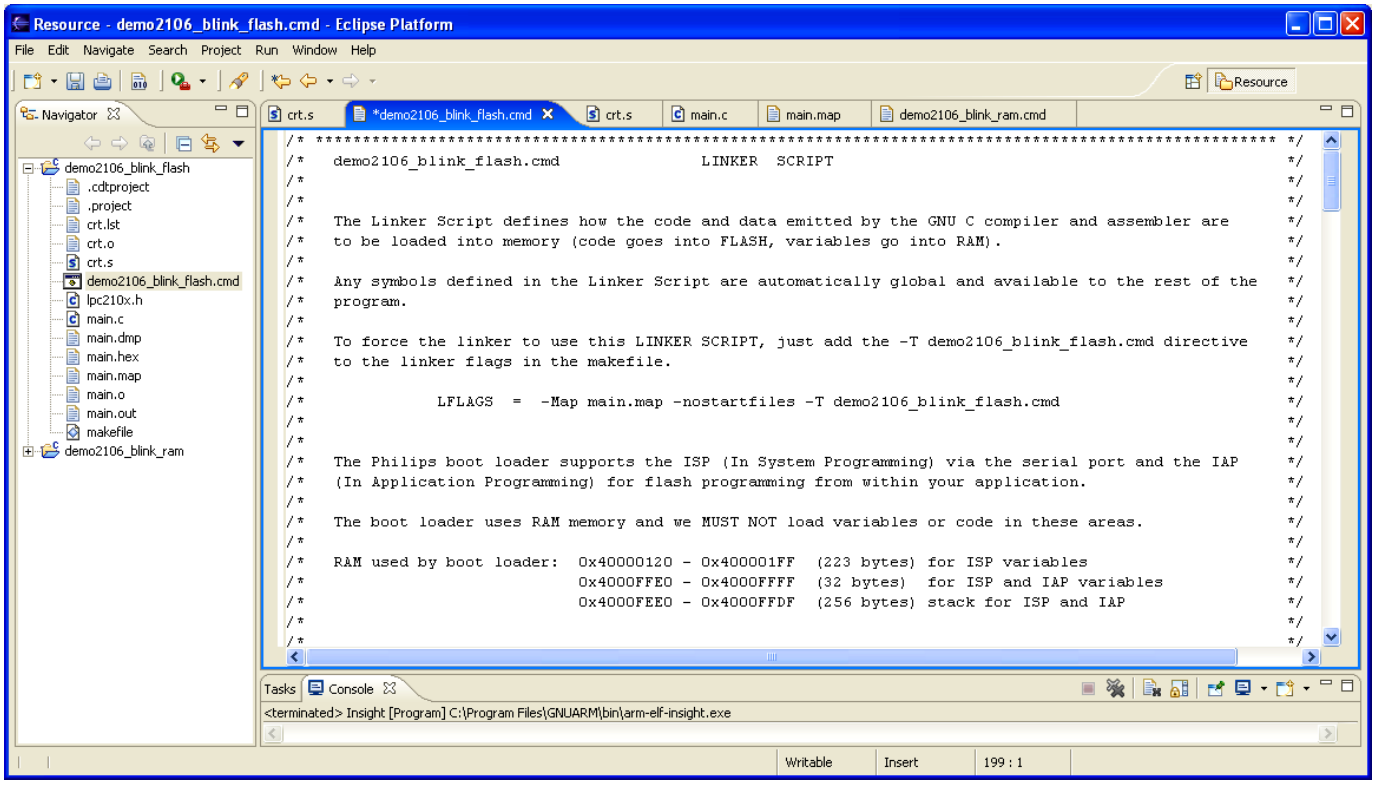
```
// Setting peripheral Clock (pclk) to System Clock (cclk)
VPBDIV=0x1;
```

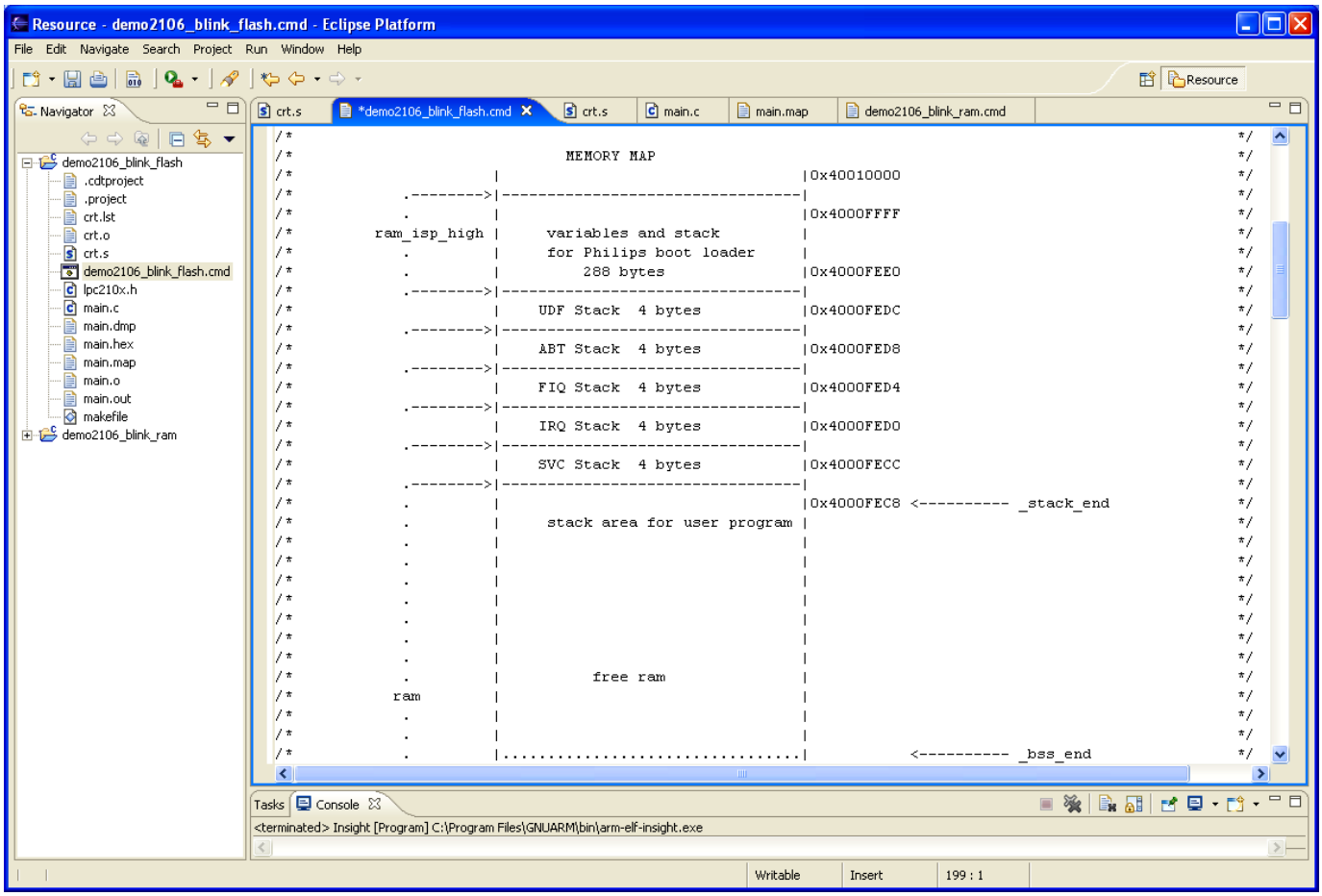
In the final snippet of the main() code, you can see the dummy interrupt service routines. They are just simple endless loops; we don't intent to allow interrupts in this simple example.

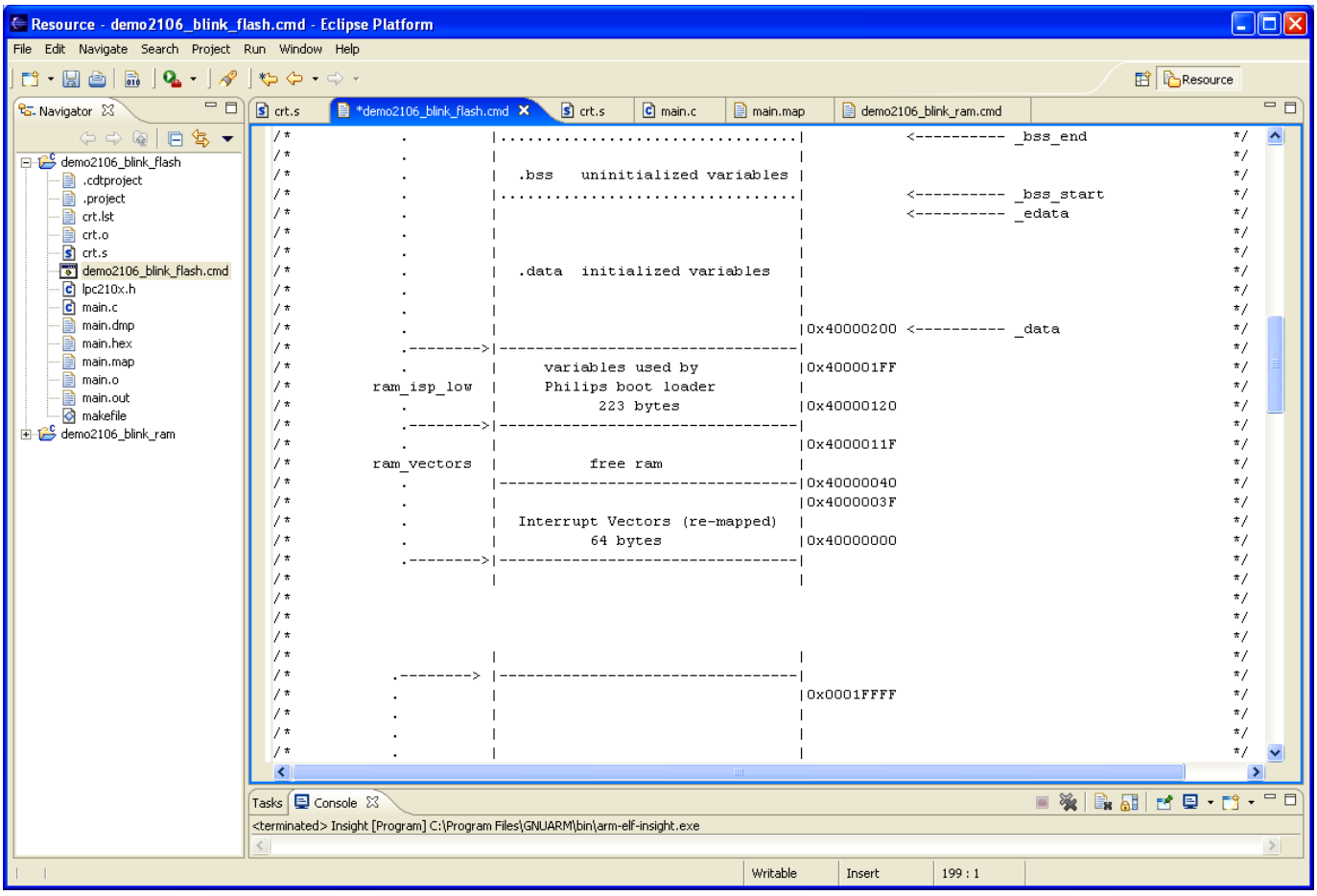


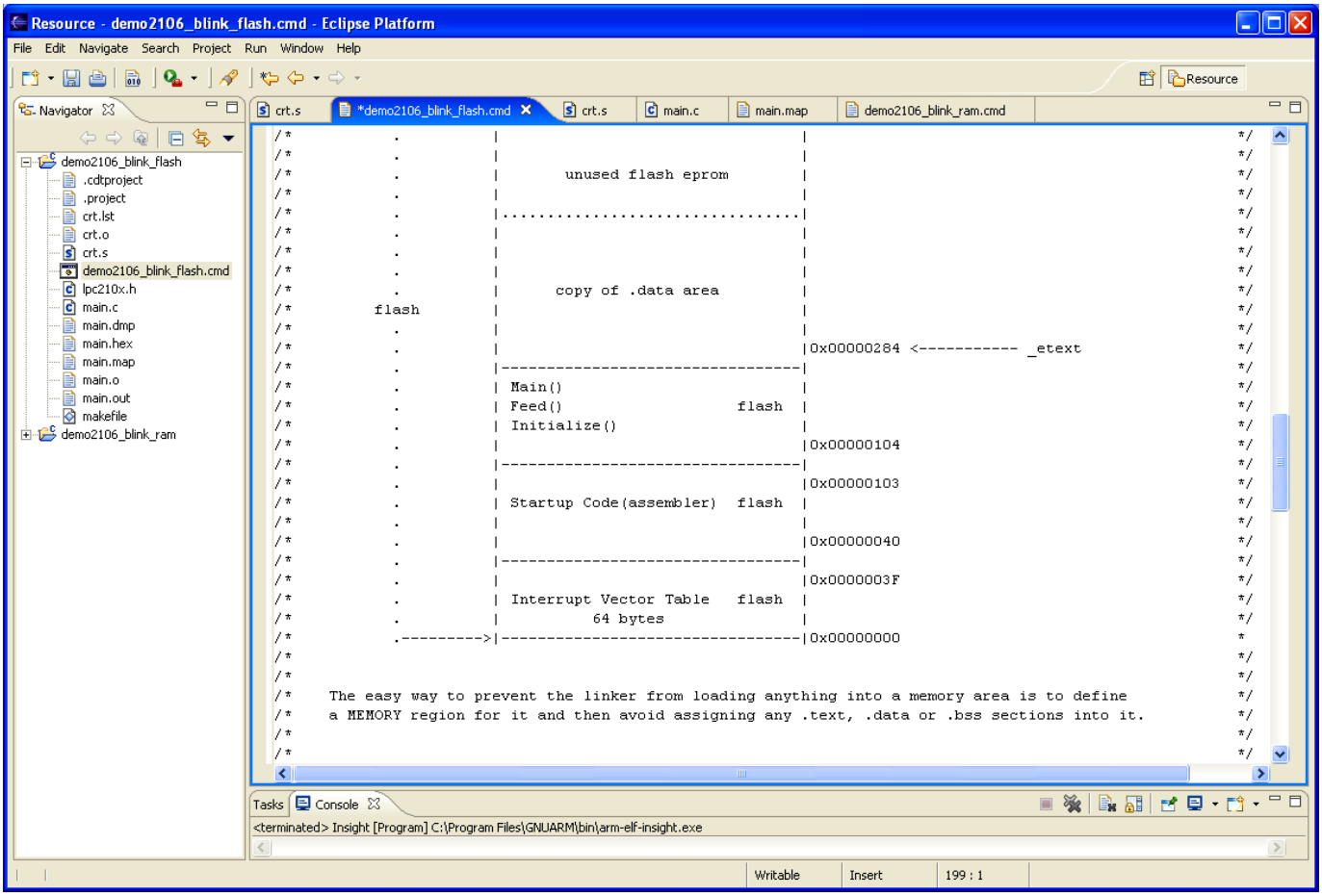
15 Description of the Linker Script demo2106_blink_flash.cmd

Let's look now at the linker command script, **demo2106_blink_flash.cmd**. I've included extensive annotation to make it very clear how the memory is organized.

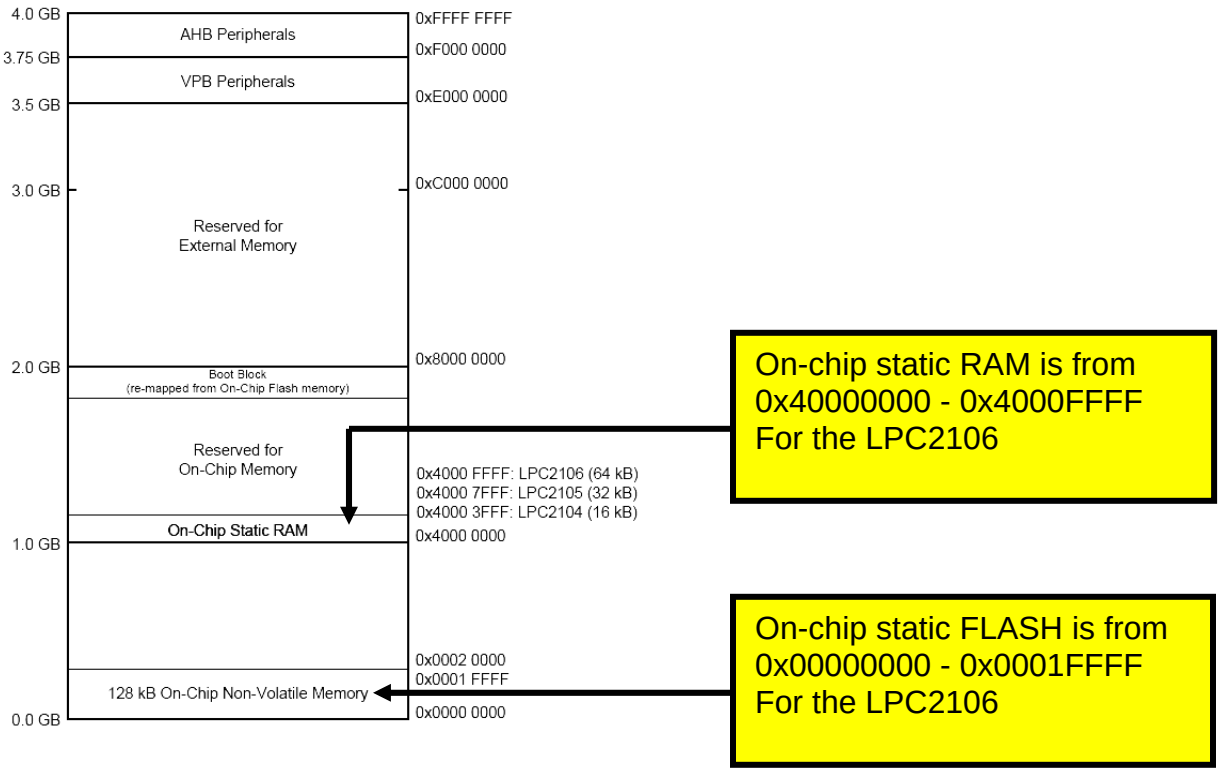


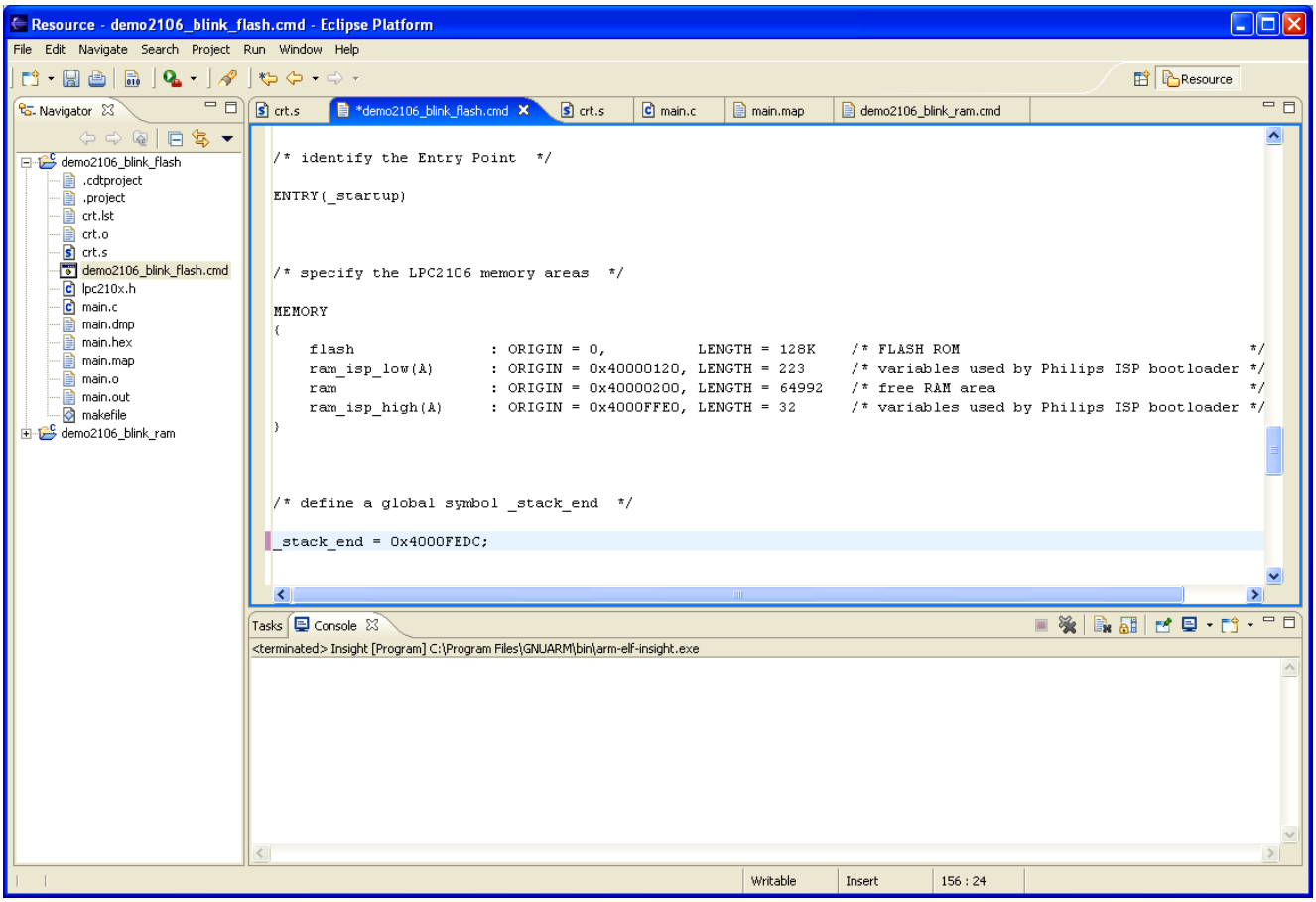



Resource - demo2106_blink_flash.cmd - Eclipse Platform
File Edit Navigate Search Project Run Window Help
Resource
Navigator
demo2106_blink_flash
.cdtproject
.project
crt.lst
crt.o
crt.s
demo2106_blink_flash.cmd
lpc210x.h
main.c
main.dmp
main.hex
main.map
main.o
main.out
makefile
demo2106_blink_ram
crt.s
*demo2106_blink_flash.cmd
crt.s
main.c
main.map
demo2106_blink_ram.cmd
/* . | | <---------- _bss_end */
/* . | .bss uninitialized variables | */
/* . | | <---------- _bss_start */
/* . | | <---------- _edata */
/* . | .data initialized variables | */
/* . | | 0x40000200 <---------- _data */
/* . | variables used by | 0x400001FF */
/* ram_isp_low | Philips boot loader | */
/* . | 223 bytes | 0x40000120 */
/* . | free ram | 0x4000011F */
/* ram_vectors | | 0x40000040 */
/* . | Interrupt Vectors (re-mapped) | 0x4000003F */
/* . | 64 bytes | 0x40000000 */
/* . | | 0x0001FFFF */
Tasks
Console
<terminated> Insight [Program] C:\Program Files\GNUARM\bin\arm-elf-insight.exe
Writable
Insert
199 : 1


Resource - demo2106_blink_flash.cmd - Eclipse Platform
File Edit Navigate Search Project Run Window Help
Resource
Navigator
demo2106_blink_flash
.cdtproject
.project
crt.lst
crt.o
crt.s
demo2106_blink_flash.cmd
lpc210x.h
main.c
main.dmp
main.hex
main.map
main.o
main.out
makefile
demo2106_blink_ram
crt.s
*demo2106_blink_flash.cmd
crt.s
main.c
main.map
demo2106_blink_ram.cmd
unused flash eprom
copy of .data area
flash
0x00000284 <---------- _etext
Main()
Feed() flash
Initialize()
0x00000104
0x00000103
Startup Code(assembler) flash
0x00000040
0x0000003F
Interrupt Vector Table flash
64 bytes
0x00000000
The easy way to prevent the linker from loading anything into a memory area is to define
a MEMORY region for it and then avoid assigning any .text, .data or .bss sections into it.
Tasks
Console
<terminated> Insight [Program] C:\Program Files\GNUARM\bin\arm-elf-insight.exe
Writable
Insert
199 : 1

The first order of business in the linker command script is to identify the memory available, this is easy in a Philips LPC2106 – the RAM and FLASH memory are on-chip and at fixed locations. Page 29 of the **Philips LPC2106 User Manual** shows the physical memory layout.





First we define an entry point; specifically _startup as defined in the assembler function **crt.s**.

```
ENTRY(_startup)
```

The Linker command script uses the following directives to lay out the physical memory.

```
MEMORY
{
        flash             : ORIGIN = 0, LENGTH = 128K                /* FLASH ROM  */
        ram_isp_low(A)    : ORIGIN = 0x40000120, LENGTH = 223        /* variables used by Philips ISP */
        ram               : ORIGIN = 0x40000200, LENGTH = 64992      /* free RAM area        */
        ram_isp_high(A) : ORIGIN = 0x4000FFE0, LENGTH = 32           /* variables used by Philips ISP  */
}
```

You might expect that we'd define only a flash and a ram memory area. In addition to those, we've added two dummy memory areas that will prevent the linker from loading code or variables into the RAM areas used by the Philips ISP Flash Utility (sometimes called a boot loader). See page 180 in the Philips LPC2106 User Manual for a description of the Boot Loader's RAM usage.

As you'll see in a minute, we'll be moving various sections **(.text** section, **.data** section, etc.) into flash and ram.

Note that we created a global symbol (all symbols created in the linker command script are global) called _**stack_end**. It's just located after the stack/variable area used by the Philips ISP Flash Utility (boot loader) as mentioned above.

```
_stack_end = 0x4000FEDC;
```

Now that the memory areas have been defined, we can start putting things into them. We do that by creating output sections and then putting bits and pieces of our code and data into them.

We define below four output sections:

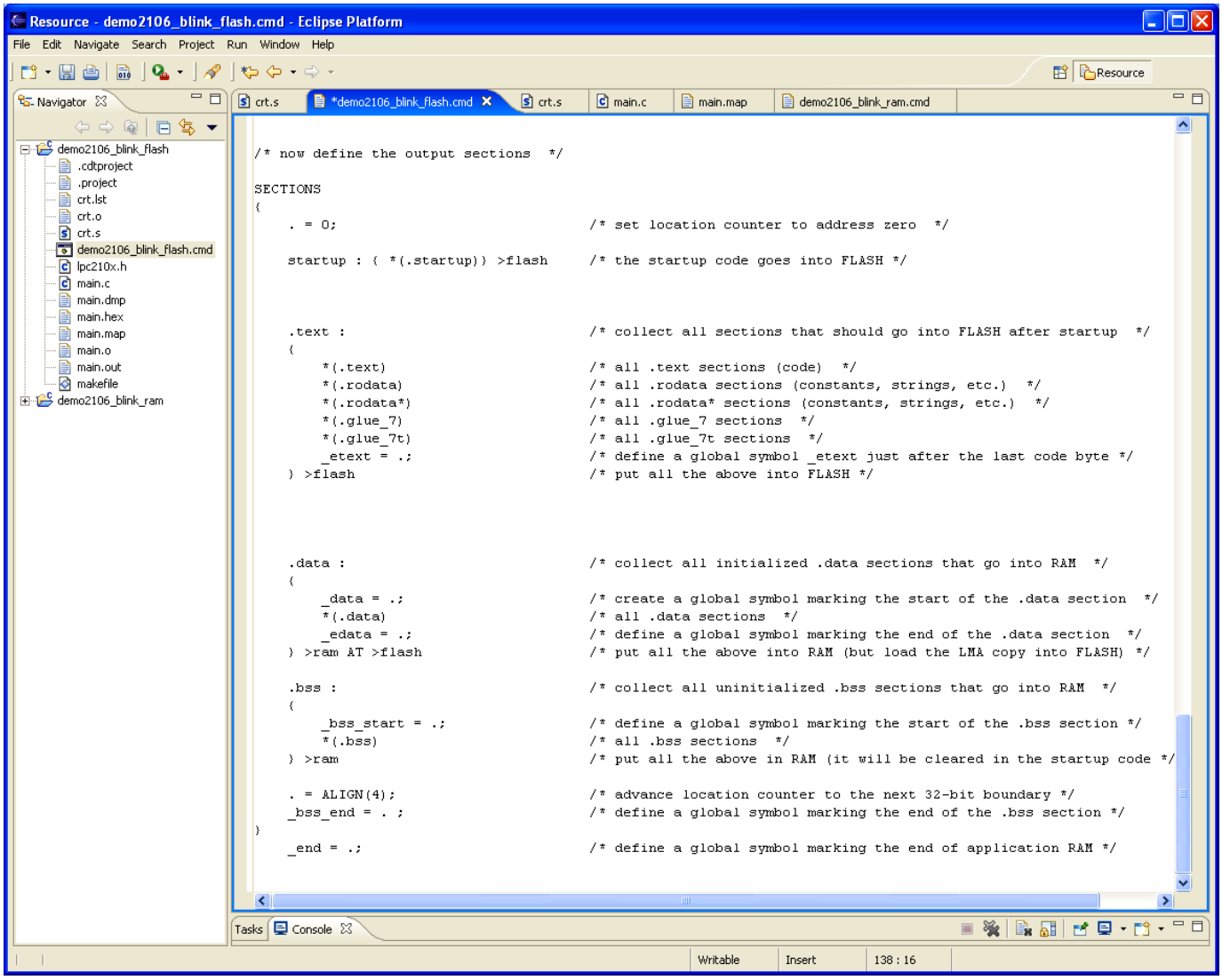
startup - this output section holds the code in the startup function, defined in **crt.s**

.text - this output section holds all other executable code generated by the compiler

.data - this output section contains all initialized data generated by the compiler

.bss - this output section contains all uninitialized data generated by the compiler

The next part of the Linker Command Script defines the sections and where they go in memory.



The first thing done within the SECTIONS command is to set the location counter.

The dot means “right here” and this sets the location counter at the beginning to 0x000000.

. = 0; /* set location counter to address zero */

Now we create our first output section, located at address 0x000000. This creates a output section named “**startup**” and it includes all sections emitted by the assembler and compiler named **.startup**. In this case, there is only one such section created in crt.s.

This startup output section is to go into FLASH at address 0x000000. Remember that the startup section has the interrupt vectors (must be placed at 0x000000) and the startup code also sets the stacks, modes and copies the **.data** and **.bss** sections.

startup : { *(.startup) } >flash

Now we can follow the vector table and assembler startup code with all code generated by the assembler and C compiler; this code is normally emitted in **.text** sections. However, constants and strings go into sections such as **.rodata** and **.glue_7** so these are included for completeness. These code bits all go into FLASH memory.

```
.text :         /* collect all sections that should go into FLASH after startup  */
{
        *(.text)            /* all .text sections (code)  */
        *(.rodata)          /* all .rodata sections (constants, strings, etc.)  */
        *(.rodata*)         /* all .rodata* sections (constants, strings, etc.)  */
        *(.glue_7)          /* all .glue_7 sections   */
        *(.glue_7t)         /* all .glue_7t sections  */
        _etext = .;         /* define a global symbol _etext after the last code byte */
} >flash                    /* put all the above into FLASH */
```

We follow the **.text:** output section (all the code and constants, etc) with a symbol definition, which is automatically global in the GNU toolset. This basically sets the next address after the last code byte to be the global symbol _**etext** (end-of-text).

There are two variable areas, **.data** and **.bss**. The initialized variables are contained in the **.data** section, which will be placed in RAM memory. The big secret here is that an exact copy of the **.data** section will be loaded into FLASH right after the code section just defined. The onus is on the programmer to copy this section to the correct address in FLASH; in this way the variables are "initialized" at startup just after a reset.

The **.bss** section has no initializers. Therefore, the onus is on the programmer to clear the entire **.bss** section in the startup routine.

Initialized variables are usually emitted by the assembler and C compiler as **.data** sections.

```
.data :
{
        _data = .;      // global symbol locates the start of .data section in RAM

        *(.data)        // tells linker to collect all .data sections together

        _edata = .;     // global symbol locates the end of .data section in RAM

} >ram AT>flash         // load data section into RAM, load copy of .data section
                        // into FLASH for copying during startup.
```

Note first that we created two global symbols, _**data** and _**edata**, that locate the beginning and end of the **.data** section in RAM. This helps us create a copy loop in the **crt.s** assembler file to load the initial values into the **.data** section in RAM.

The command **>ram** specifies the Virtual Memory Address that the .data section is to be placed into RAM (think of it as the final destination in RAM and all code references to any variables will use the RAM address.

The command **AT >flash** specifies the load memory address; essentially an exact copy of the RAM memory area with every variable initialized placed in flash for copying at startup.

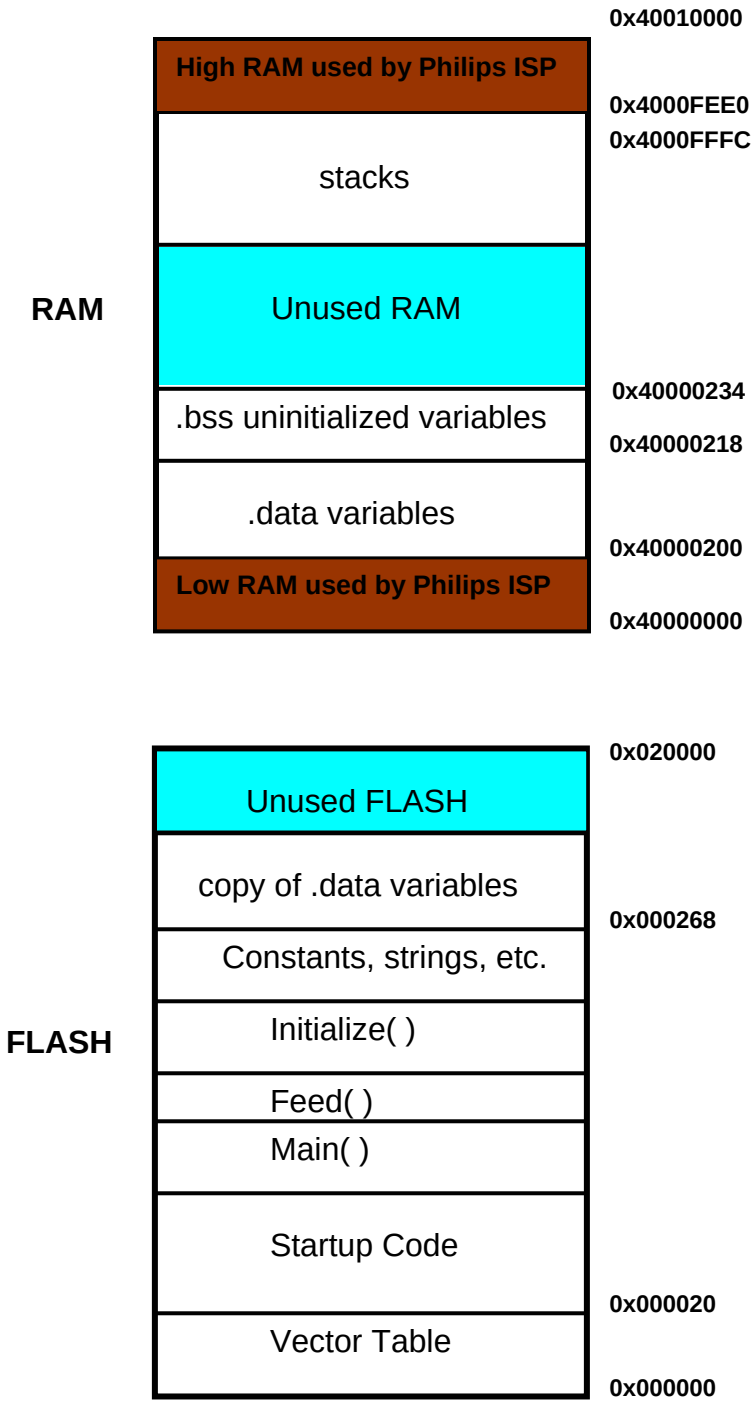
You might say “why not let the Philips boot loader load the initial values of the **.data** section in RAM directly from the hex file?” The answer is that would work once and only once. When you power off and reboot your embedded application, the RAM values are lost.

The copy of the **.data** area loaded into flash for copying during startup is placed by the GNU linker at the next available flash location. This is conveniently right after the last byte of the **.prog** section containing all our executable code.

The **.bss** section is all variables that are not initialized. It is loaded into RAM and we create two global symbols **_bss_start** and **_bss_end** to locate the beginning and end for clearing by a loop in the startup code.

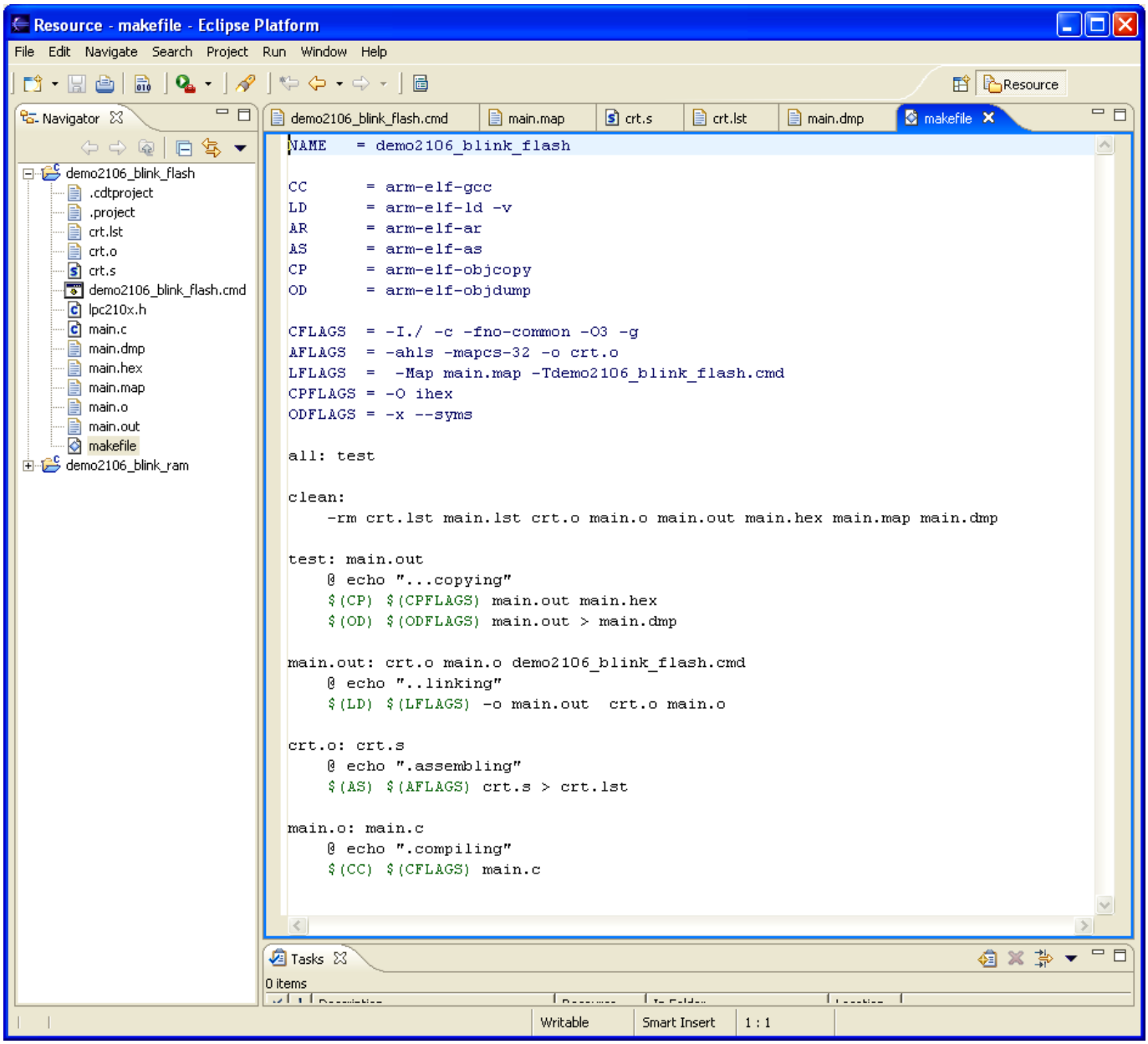
```
        .bss :
        {
                _bss_start = .;
                *(.bss)
        } >ram

        . = ALIGN(4);
}
        _bss_end = . ;
        _end = .;
```

Now let's diagram just where everything is in RAM and FLASH memory.



16 Description of the Makefile

The makefile is the last source file we need to look at. I built the makefile to comply with the GNU make utility and be as simple as possible.



The general idea of the makefile is that a **target** (could be a file) is associated with one or more dependent files. If any of the dependent files are newer than the target, then the **commands** on the following lines are executed (to recompile, for instance). Command lines are indented with a **Tab** character!

```
main.o:    main.c
           arm-elf-gcc   -I./  -c  -O3  -g     main.c
```

In the example above, if main.c is newer than the target main.o, the command or commands on the next line or lines will be executed. The command arm-elf-gcc will recompile the file main.c with several compilation options specified. If the target is

up-to-date, nothing is done. Make works its way downward in the makefile, if you've deleted all object and output files, it will compile and link everything.

GNU make has a helpful "**variables**" feature that helps you reduce typing. If you define the following variable:

CFLAGS = -I./ -c -fno-common -O3 -g

You can use this multiple times in the makefile by writing the variable name as follows:

$(CFLAGS) will substitute the string **-I./ -c -O3 -g**

Therefore, the command-

arm-elf-gcc $(CFLAGS) main.c

is exactly the same as

arm-elf-gcc -I./ -c -O3 -g main.c

Likewise, we can replace the compiler name **arm-elf-gcc** with a variable too.

CC = arm-elf-gcc

Now the command line becomes

$(CC) $(CFLAGS) main.c

Now our "rule" for handling the main.o and main.c files becomes:

Commands MUST be indented with a TAB character!

```
main.o: main.c
	@ echo ".compiling"
	$(CC) $(CFLAGS) main.c
```

It's worth emphasizing that forgetting to insert the **TAB** character before the commands is the most common rookie mistake in using the GNU Make system.

The compilation options being used are:

-I./ = specifies include directories to search first (project directory in this case)

-c = do not invoke the linker, we have a separate make rule for that

-fno-common = gets rid of a pesky warning

-O3 = sets the optimization level (Note: set to **–O0** for debugging!)

-g = generates debugging information

The assembler is used to assemble the file crt.s, as shown below:

```
crt.o: crt.s
        @ echo ".assembling"
        $(AS) $(AFLAGS) crt.s > crt.lst
```

In the example above, if the object file **crt.o** is older than the dependent assembler source file **crt.s**, then the commands on the following lines are executed.

If we expand the make variables used, the lines would be:

```
crt.o: crt.s
        @ echo ".assembling"
        arm-elf-as    -ahls -mapcs-32 -o crt.o    crt.s   > crt.lst
```

The **> crt.lst** directive creates a assembler list file.

The assembler options being used are:

-ahls = listing control, turns on high-level source, assembly and symbols

-mapcs-32 = selects 32-bit ARM function calling method

-o crt.o = create an object output file named crt.o

The GNU linker is used to prepare the output from the assembler and C compiler for loading into Flash and RAM, as shown below:

```
main.out: crt.o main.o demo2106_blink_flash.cmd
        @ echo "..linking"
        $(LD) $(LFLAGS) -o main.out  crt.o main.o
```

If the target output file **main.out** is older than the two object files or the linker command file, then the commands on the following lines are executed.

The Linker options being used are:

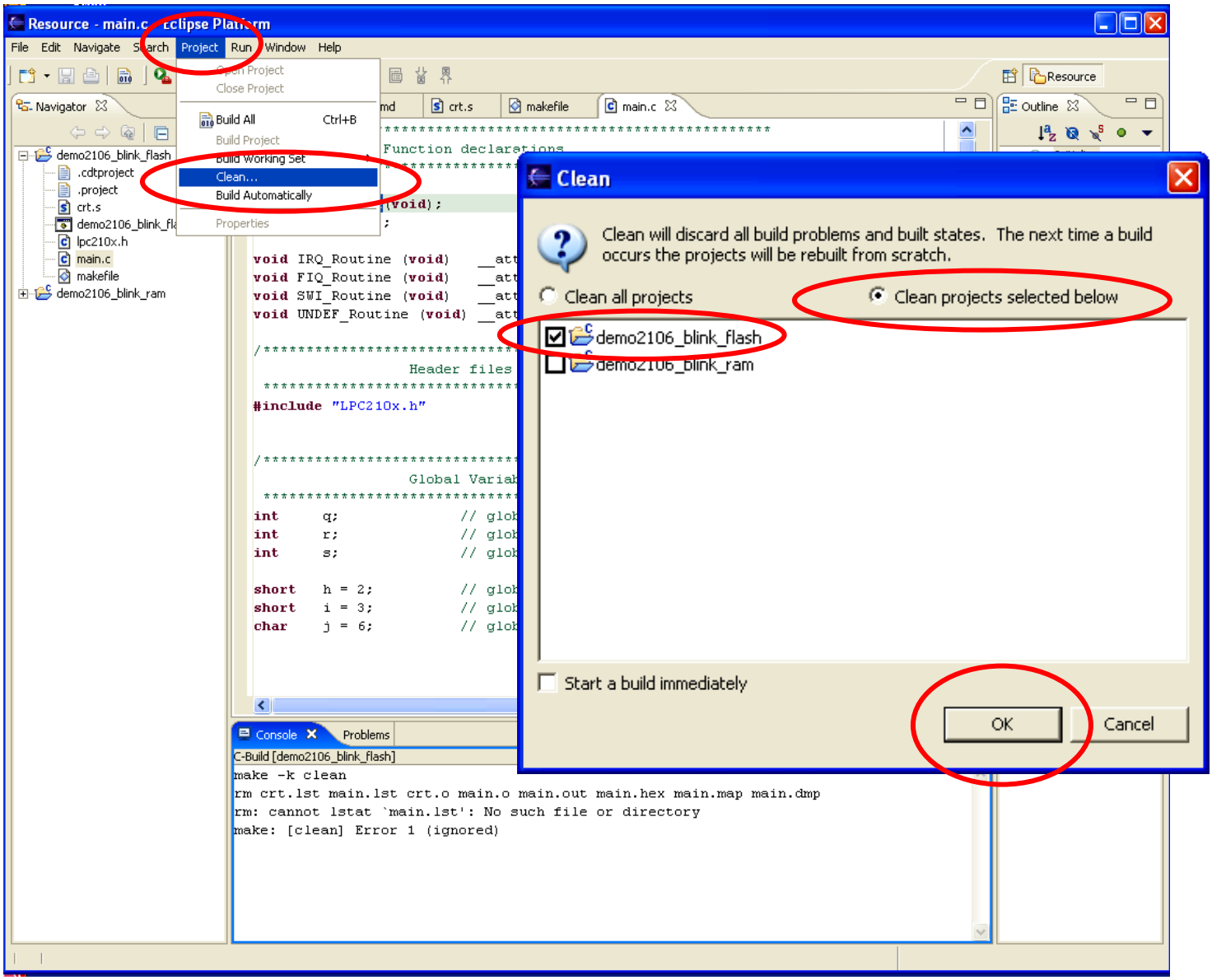
-Map main.map = creates a map file

-T demo2106_blink_flash.cmd = identifies the name of the linker script file

Note that I've kept this GNU makefile as simple as possible. You can clearly see the assembler, C compiler and linker steps. They are followed by the **objcopy** utility that makes the hex file for the Philips ISP boot loader and an **objdump** operation to give a nice file of all symbols, etc.

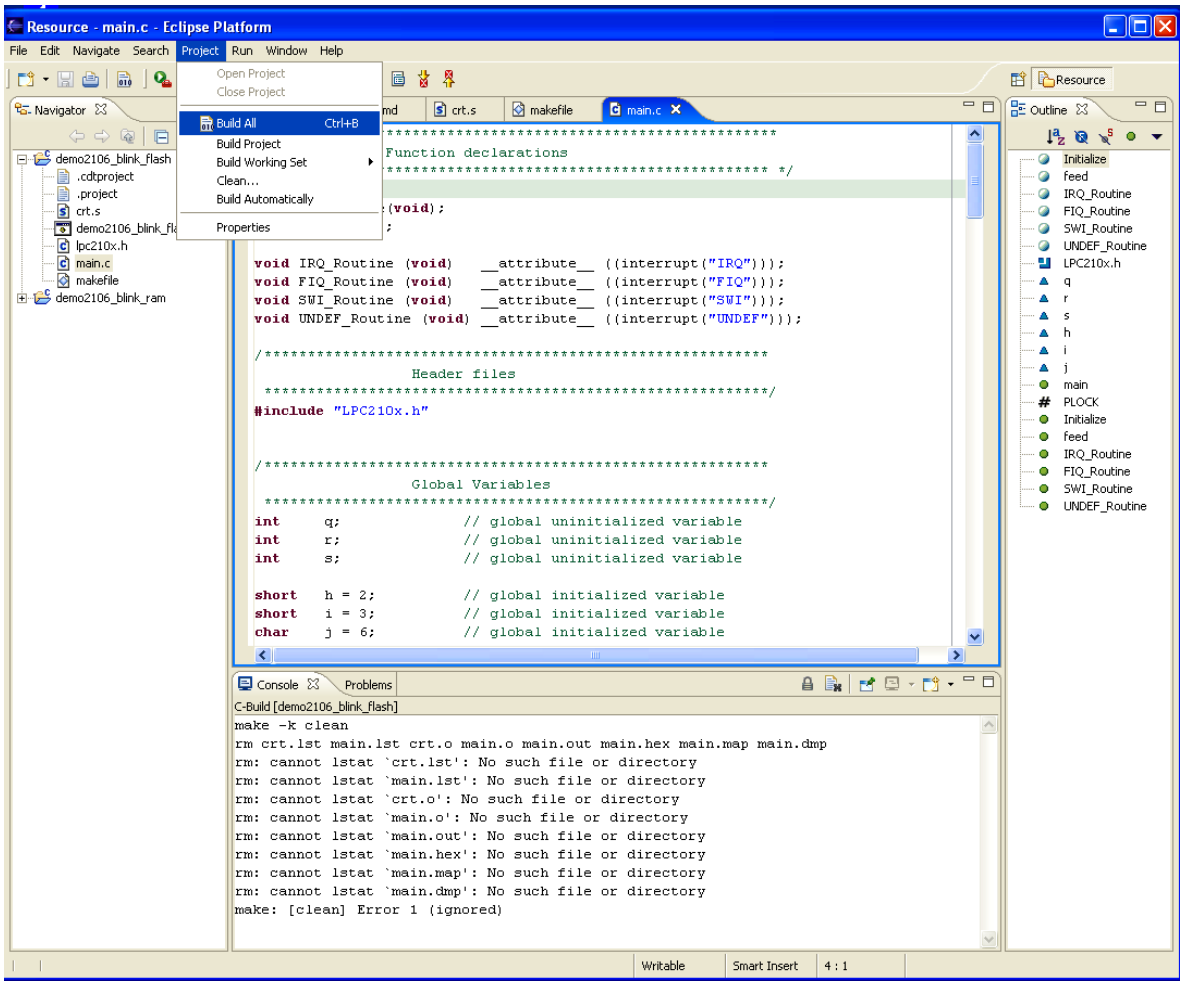
17 Compiling and Linking the Sample Application

OK, now it's time to actually do something. First, let's "**Clean**" the project; this gets rid of all object and list files, etc. Click on "**Project – Clean …**" and fill out the Clean dialog window.

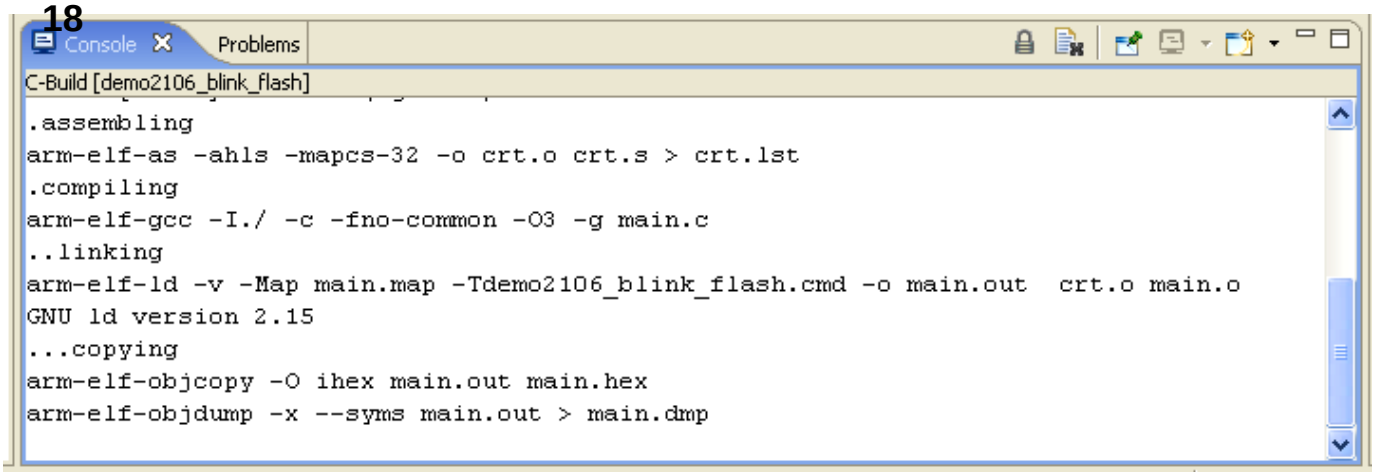


You can see the results of the "Clean" operation in the Console window at the bottom. Expect to see some warnings if there isn't anything to delete.

To build the project, click on “Project – Build All”. Since we deleted all the object files and the main.out file via the clean operation, this “Build-all” will assemble the crt.s startup file, C compile the main.c function, run the linker and then run the **objcopy** utility to make a hex file suitable for downloading with the Philips ISP Flash Utility.

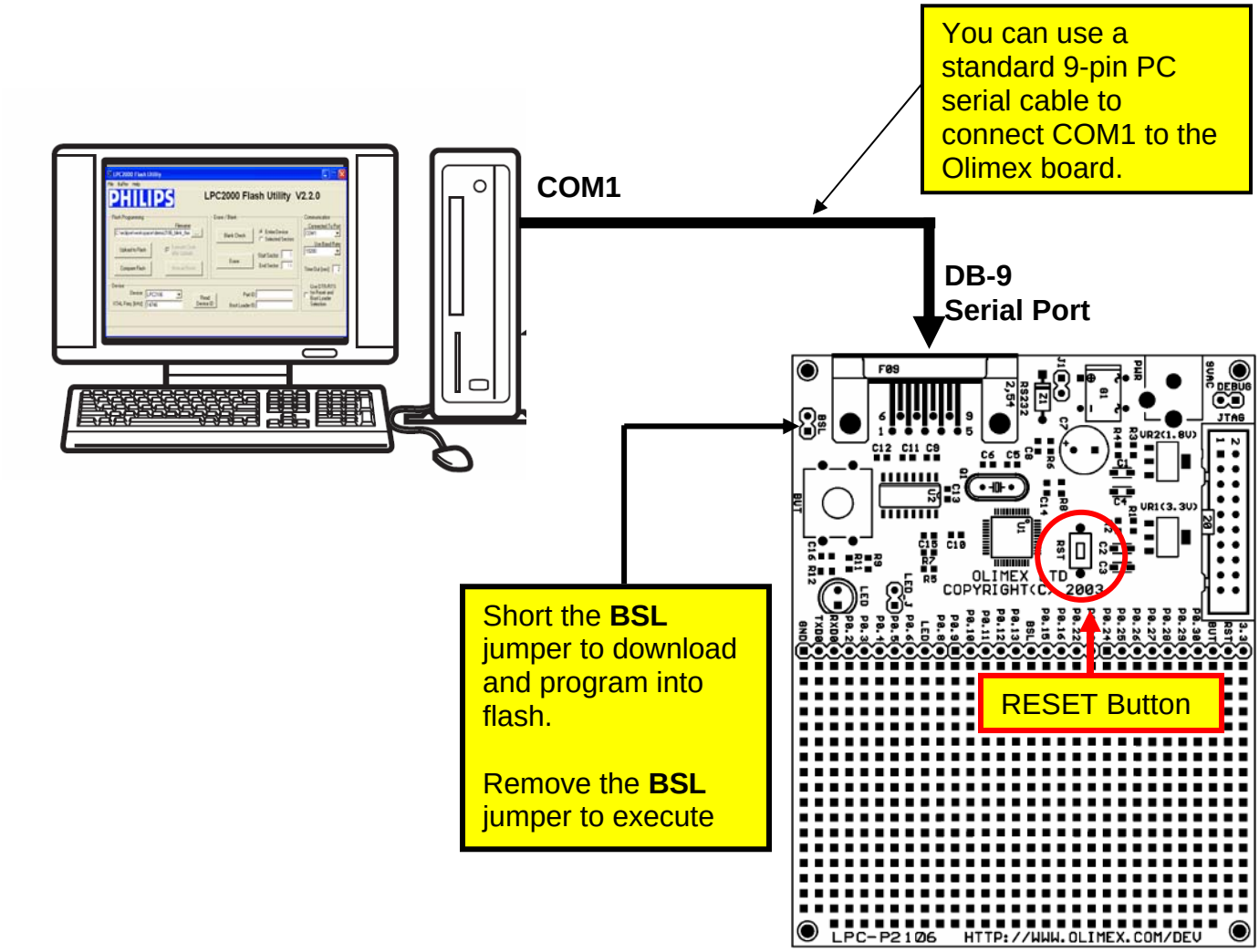


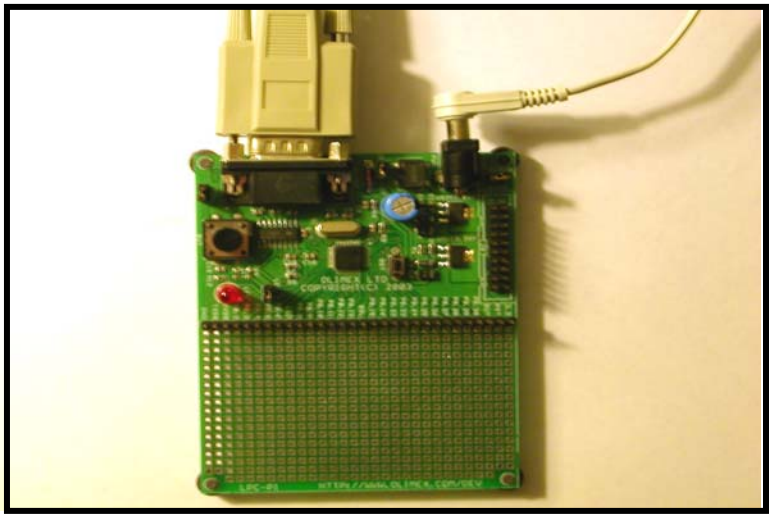
We can see the results in the Console Window at the bottom.



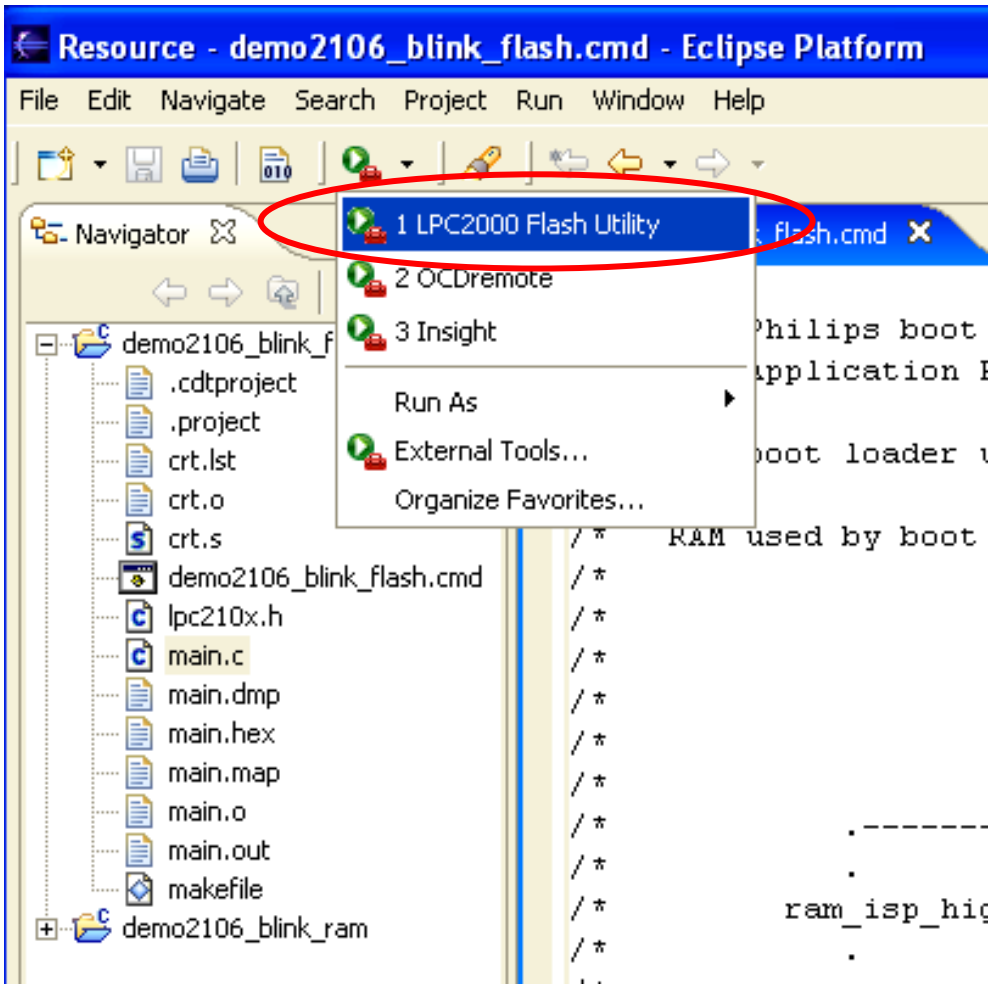
18 Setting Up the Hardware

For this tutorial, we'll be using the Olimex **LPC-P2106 Prototype Board**. Connect a straight-through 9-pin serial cable from your computer's COM1 port to the DB-9 connector on the Olimex board. Attach the 9-volt power supply to the PWR connector. Install the BSL jumper and the JTAG jumper.

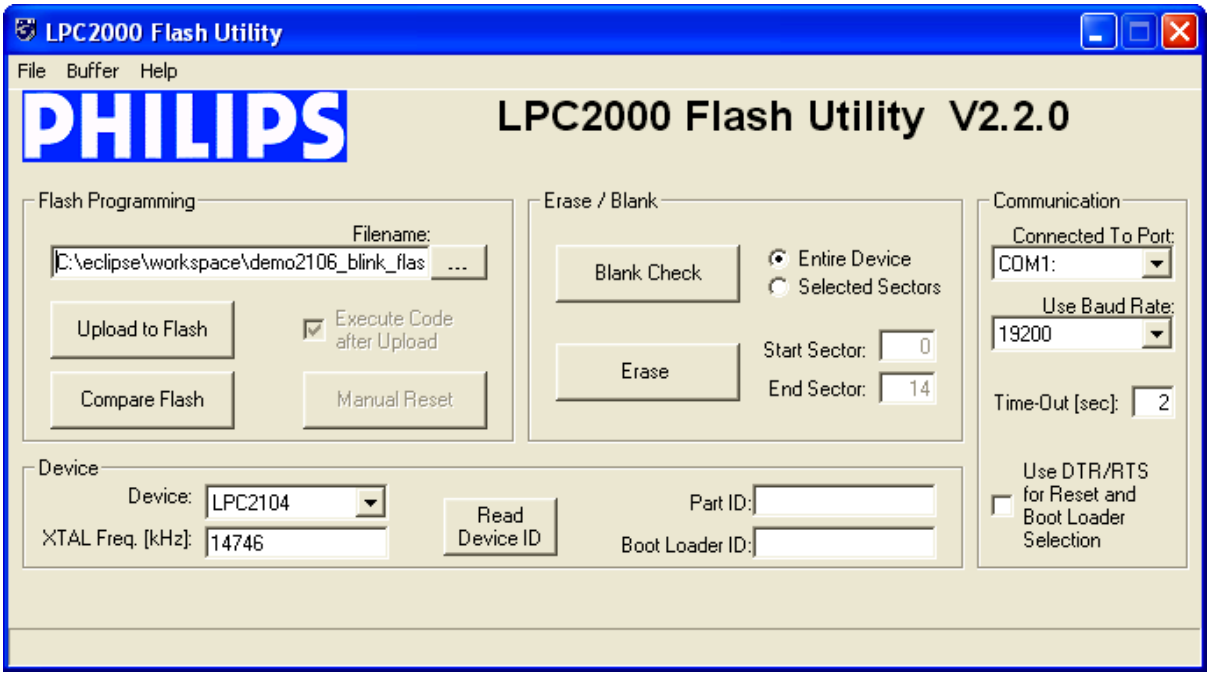




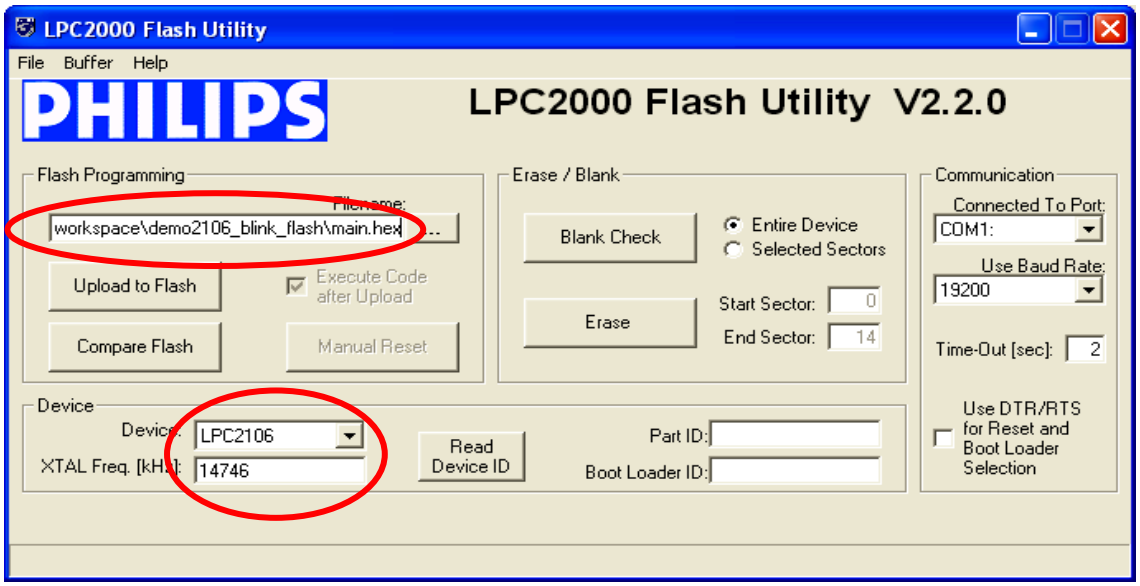
To run the Philips LPC2000 Flash Utility, it's easiest to just click on the "**External Tools**" button and its down arrow to pull-down the available tools. Click on "**LPC2000 Flash Utility**" to start the Philips Boot Loader.



The Philips LPC2000 ISP Flash Programming will start up.



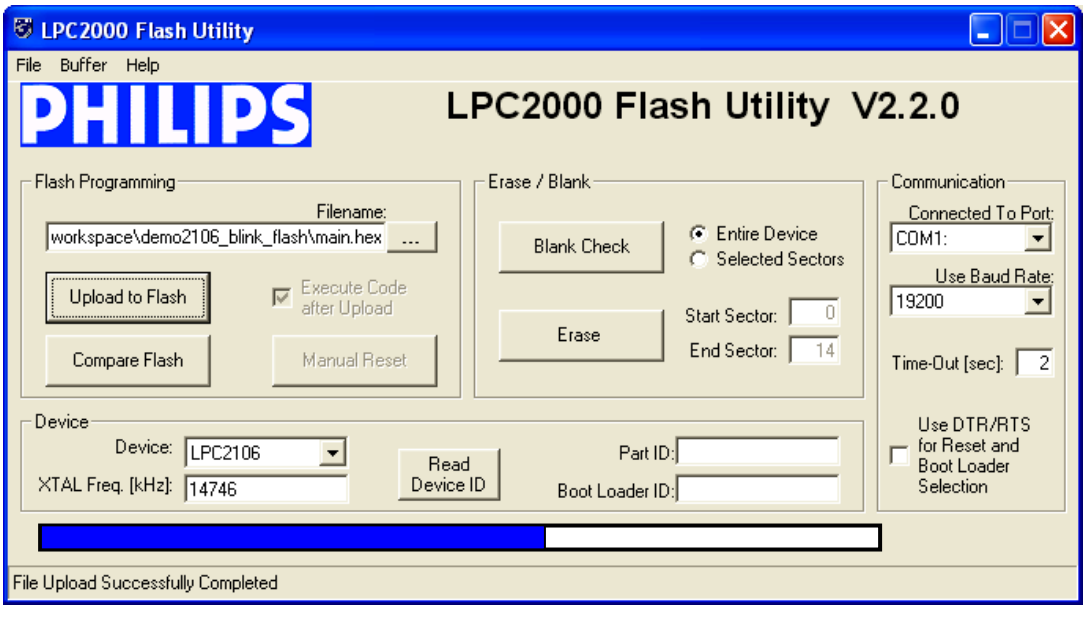
Now fill out the LPC2000 Flash Utility screen. Browse the workspace for the **main.hex** file. Set the Device to **LPC2106**. Set the crystal frequency to **14746**, as per the Olimex schematic. The default baud rate, COM port and Time-out are OK as is.



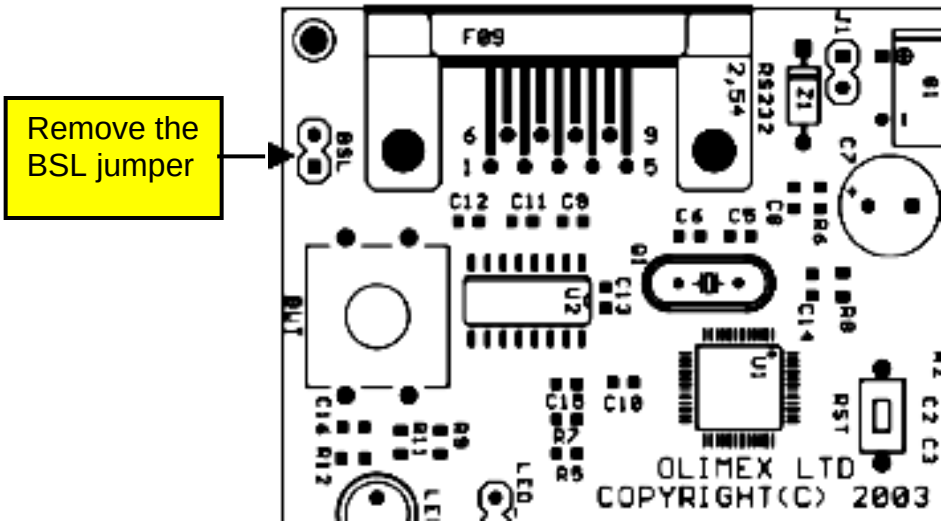
Now click on "**Upload to Flash**" to start the download.

The Philips ISP Flash Utility will now ask you to reset the target system. This is the tiny **RST** button near the CPU chip.

The download will now proceed; you'll see a blue progress bar at the bottom and then the status line will say "File Upload Successfully Completed".

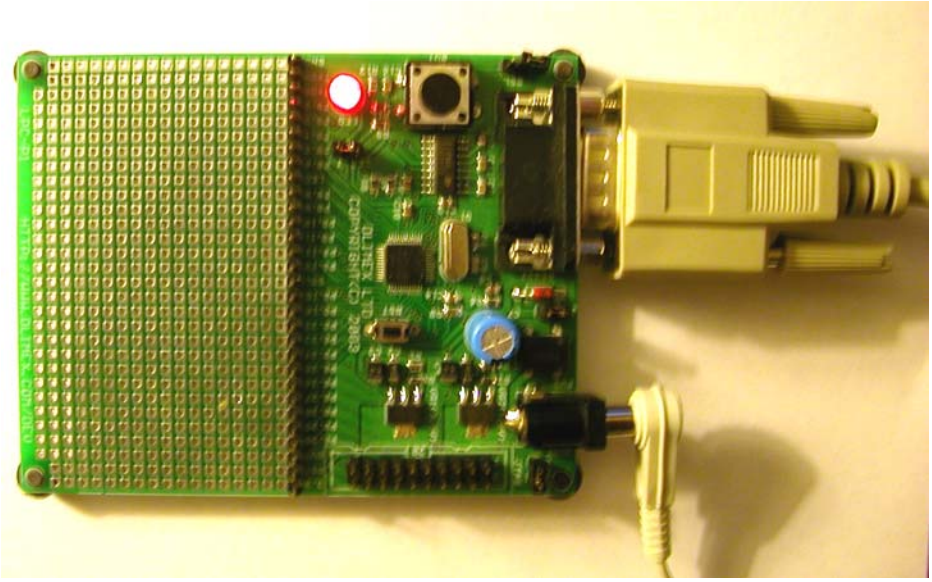


Remove the **BSL** (boot strap loader) jumper and hit the **RST** button.



Your application should start up and the LED will start blinking.

To prove that I am as honest as the sky is blue, here it is blinking away!

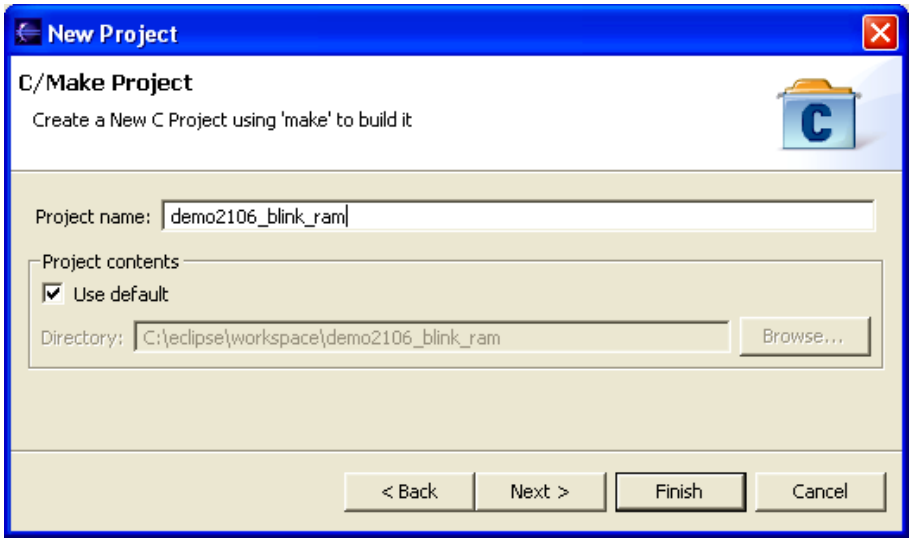


OK, I admit it; this photo has the reliability of a Bigfoot video!

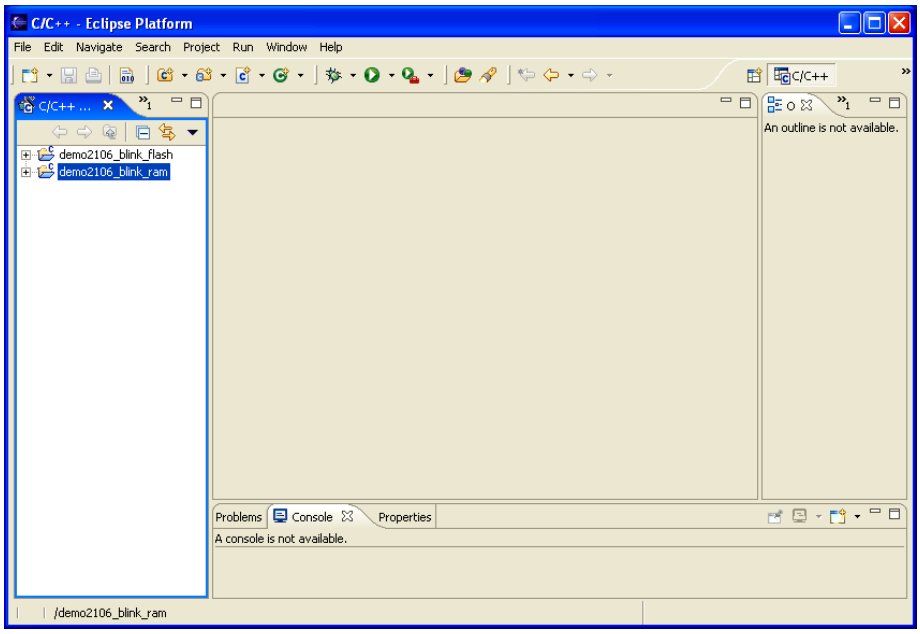
19 Create a New Project to Run the Code in RAM

Now we will create a new project that will run the blinker code in RAM. Only minor modifications to three files are required. We will show how to run the application using the Philips ISP flash utility. Later, we'll show how to use this very same RAM-based application with the Eclipse/CDT debugger and a Wiggler JTAG interface.

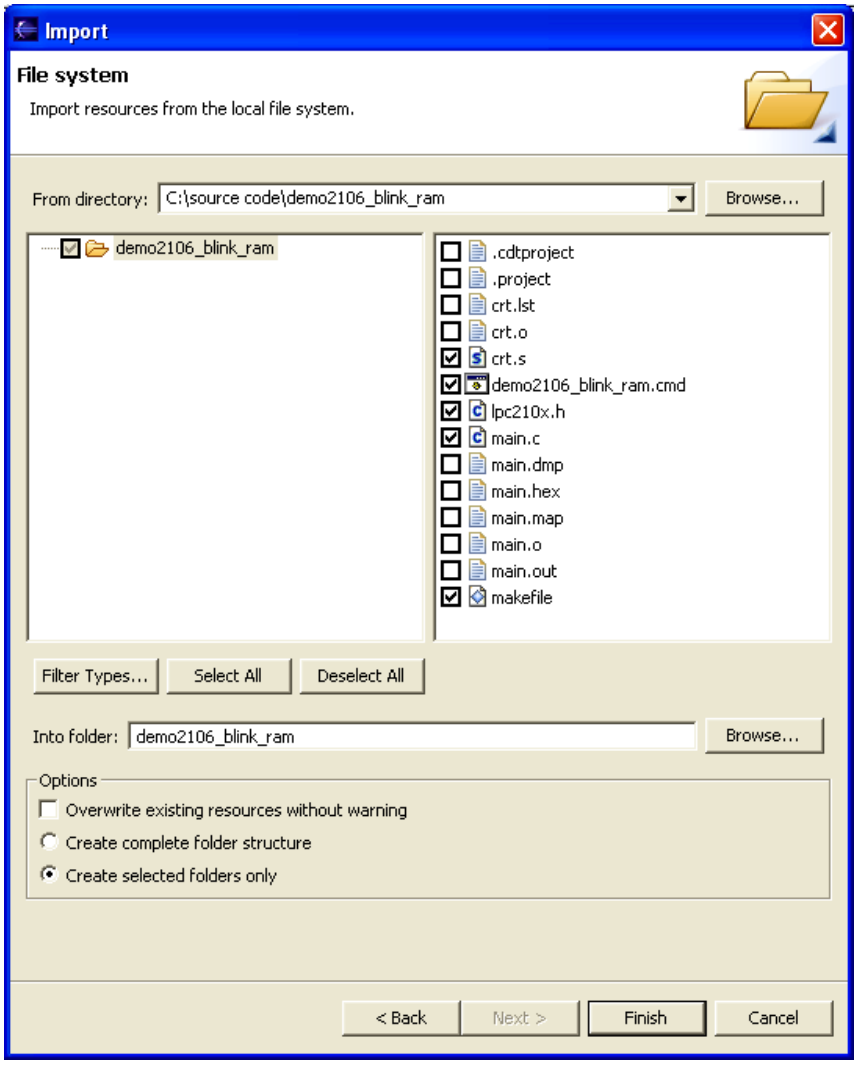
Using the techniques previously discussed, create a new project named **demo2106_blink_ram.**



Switch to the C/C++ Perspective and you will see that there are now two projects, although the new one contains no files.



Now using the “**File Import**” procedure described earlier, fetch the source files for the project **demo2106_flash_ram** included in the zip distribution for this tutorial.

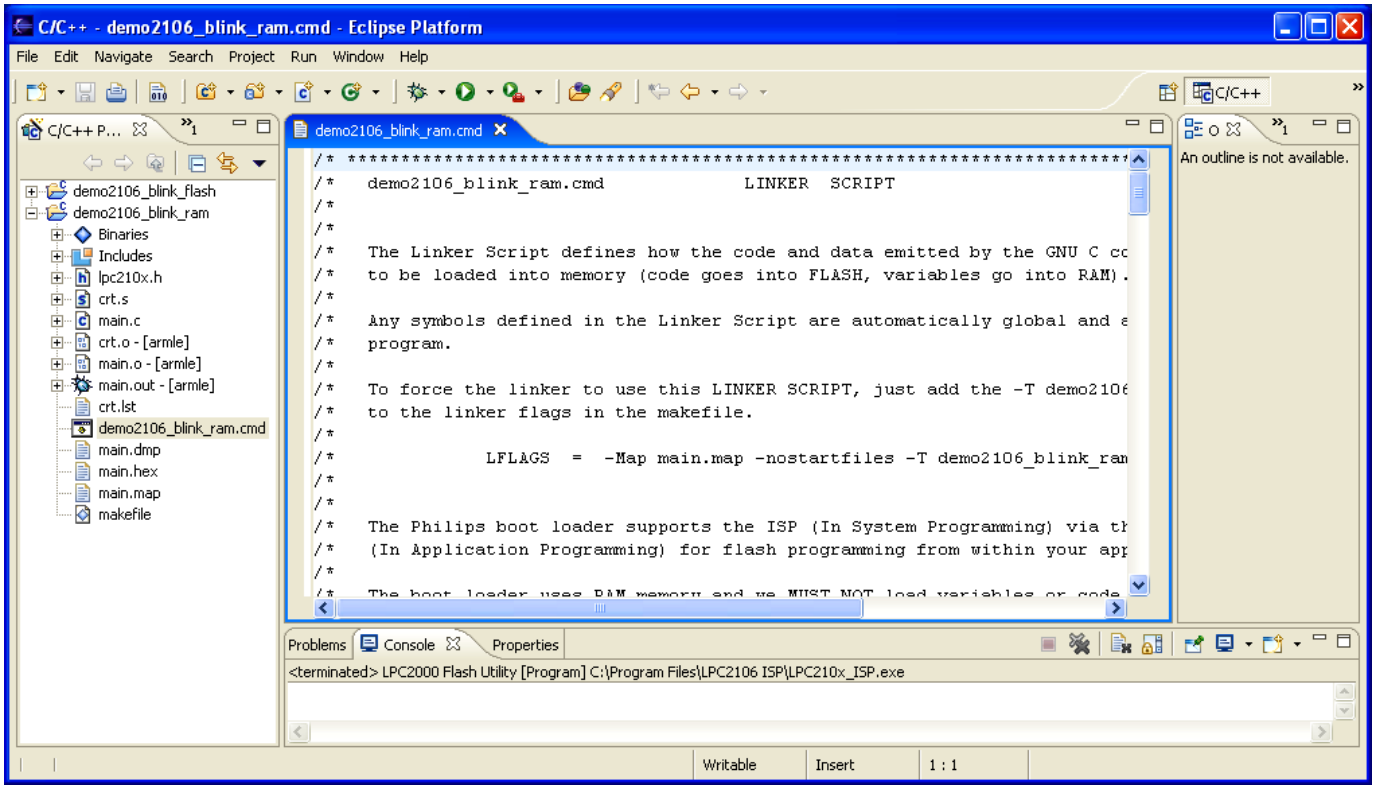


RAM,

The files we import are:

crt.s
demo2106_blink_ram.cmd
lpc210x.h
main.c
makefile.mak

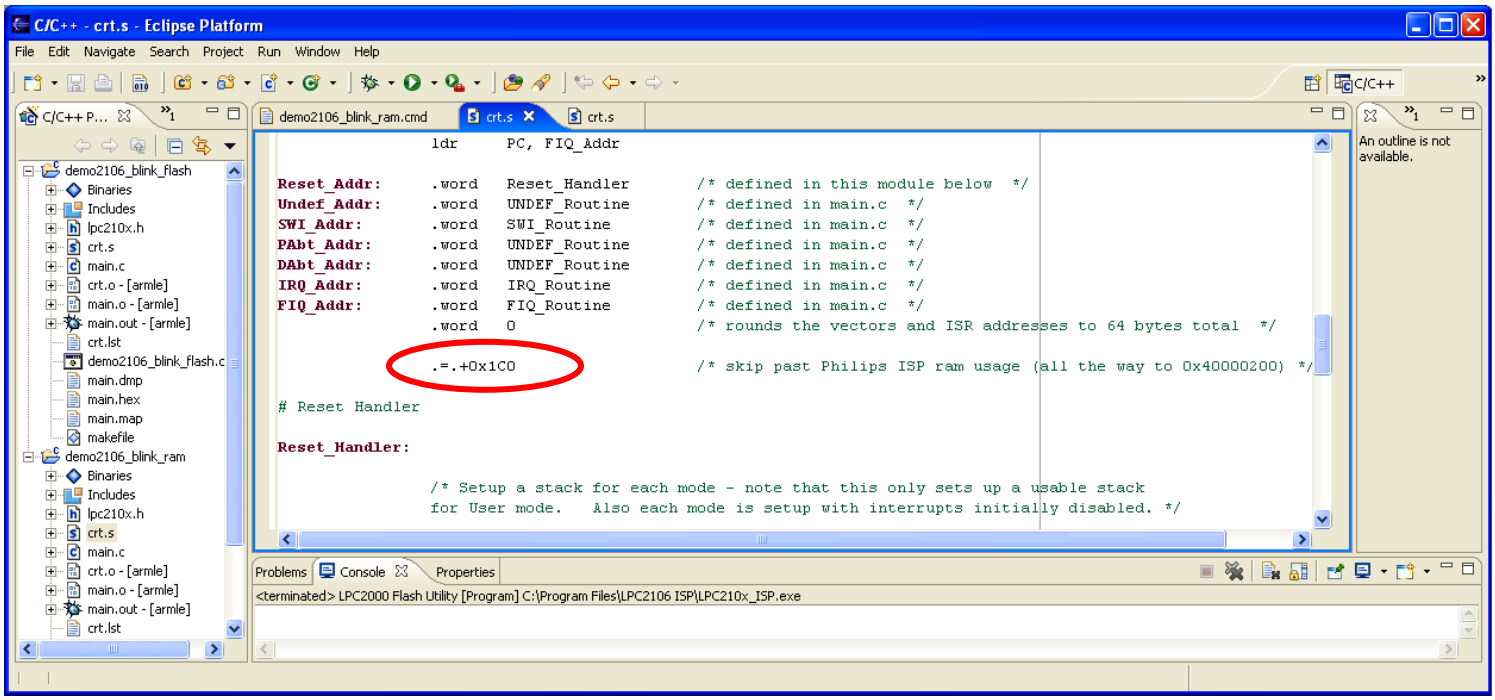
Now if you “Clean and Build” you should see a completed project with all the resultant files, as shown below.



20 Differences in the RAM Version

File CRT.S

In the startup assembler file, I used a simple trick to move the startup code away from the vectors to ensure that it doesn't encroach on the Philips ISP Flash Loader low RAM area.

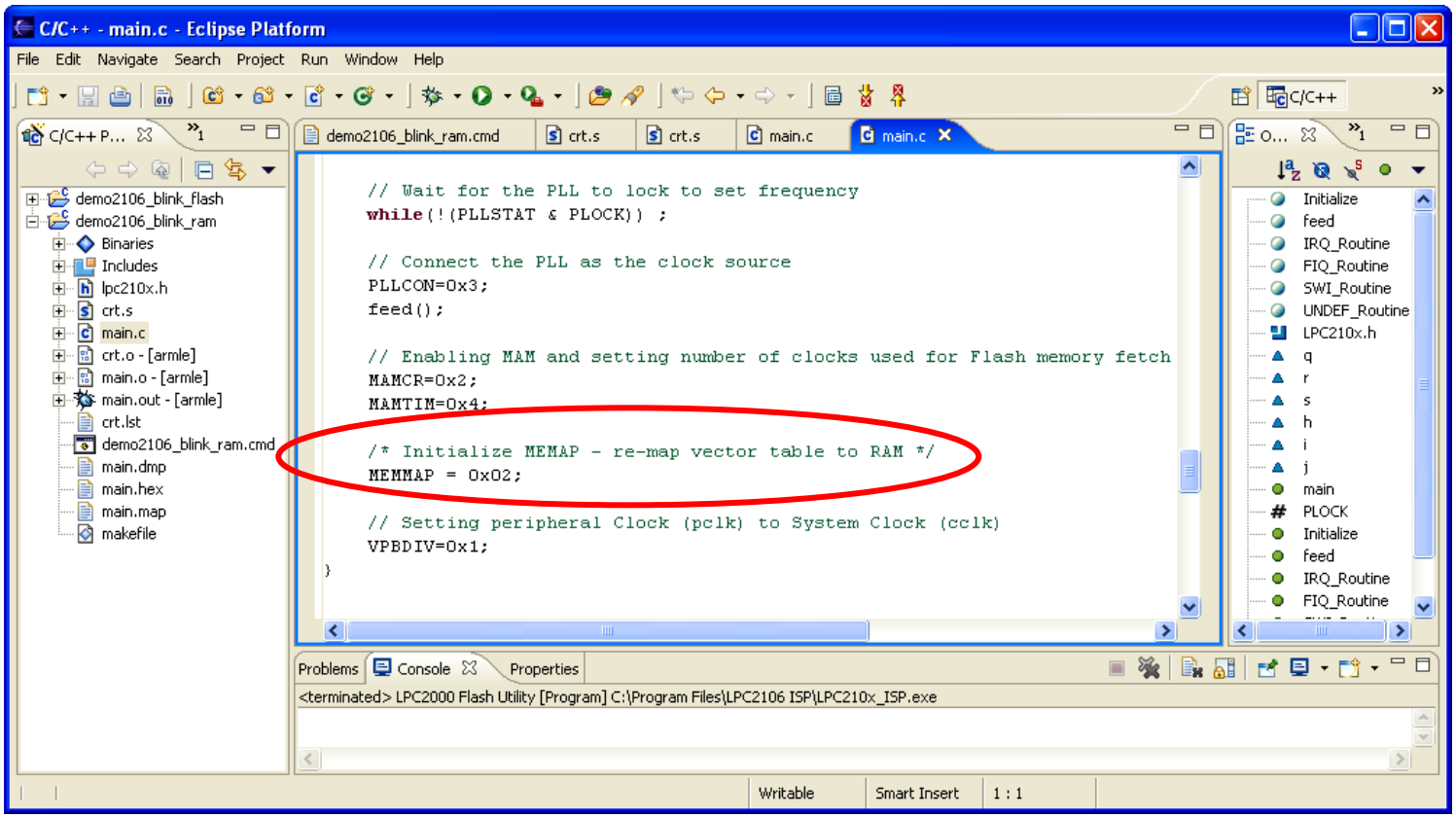


Remember that the entire project, code and variables, will be loaded into RAM starting at address 0x40000000. The location counter is advanced by the directive **.=.+0x1C0** to push

the Reset_Handler to address 0x40000200. This leaves a hole where the Philips ISP Flash Utility will use the low RAM. There are other ways to do this.

File MAIN.C

There is just one extra line of C code in the main program. It directs the LPC2106 to re-map the interrupt vectors to RAM at 0x40000000.



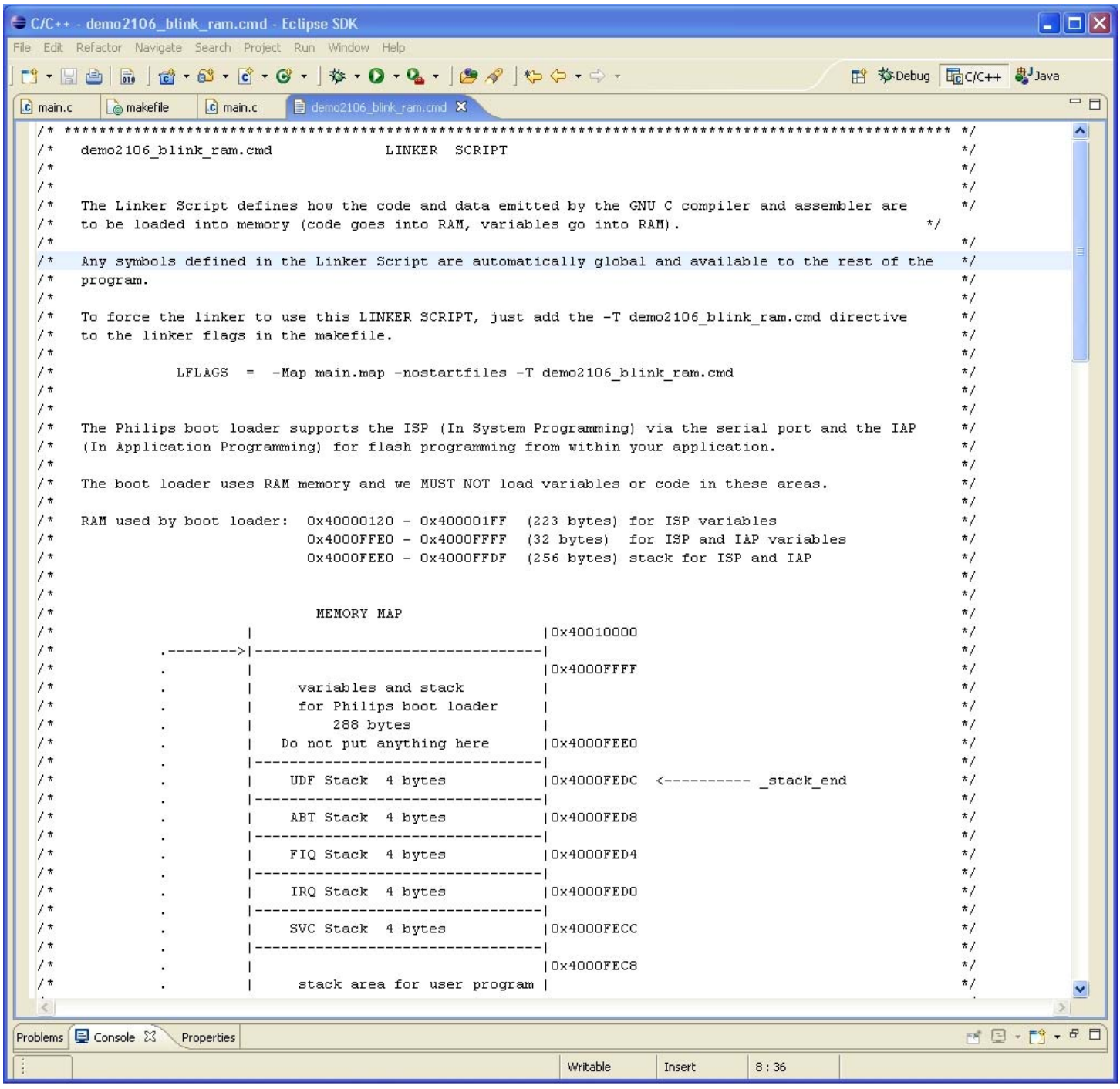
Since we are not using any interrupts in this example, this addition does not really matter. I've just added it for completeness; you should always do this when devising a project to run in RAM.

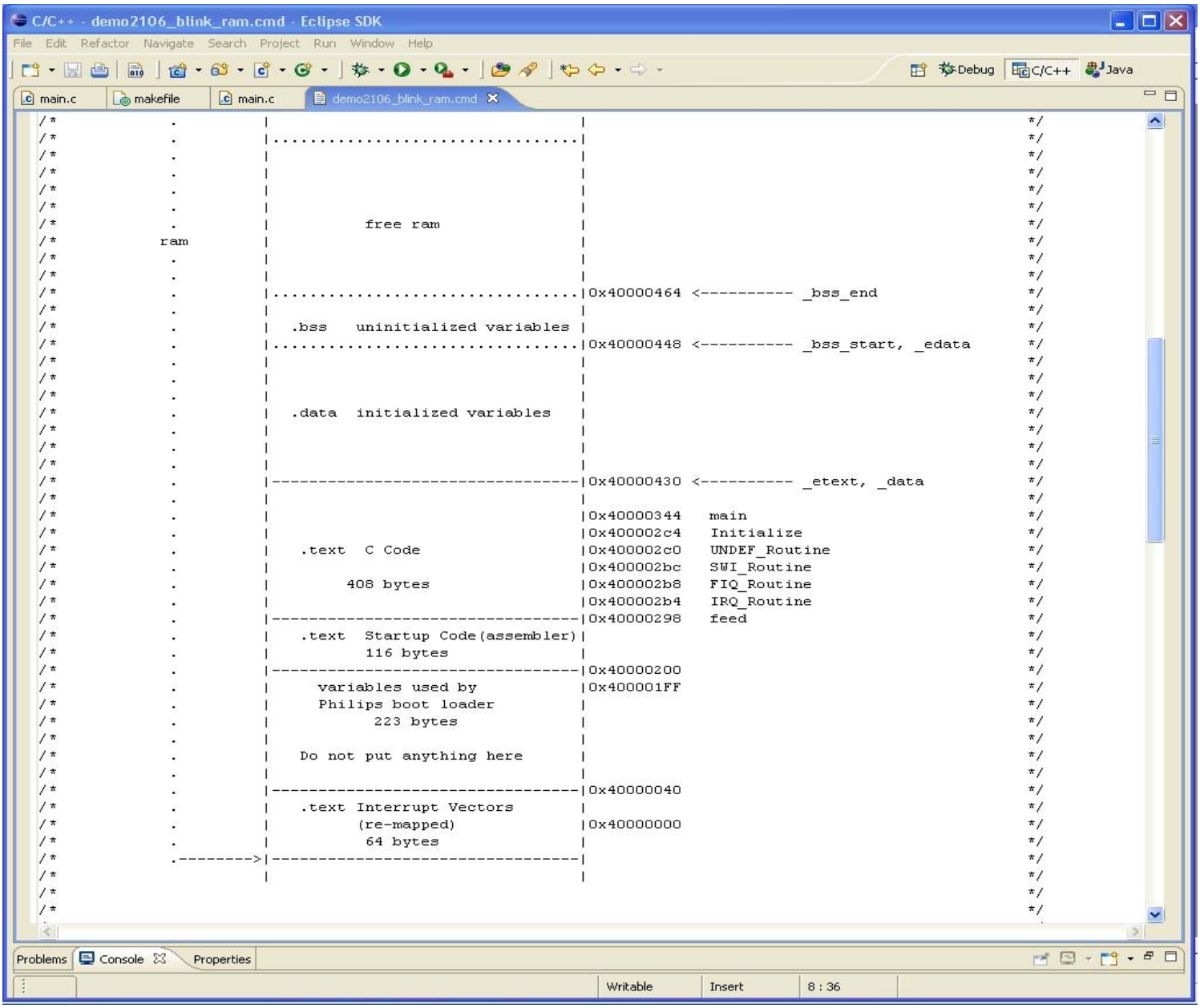
After you follow the next steps and get the application to execute out of RAM, you can run a little experiment and comment out the MEMMAP = 0x02; line. It will still run OK.

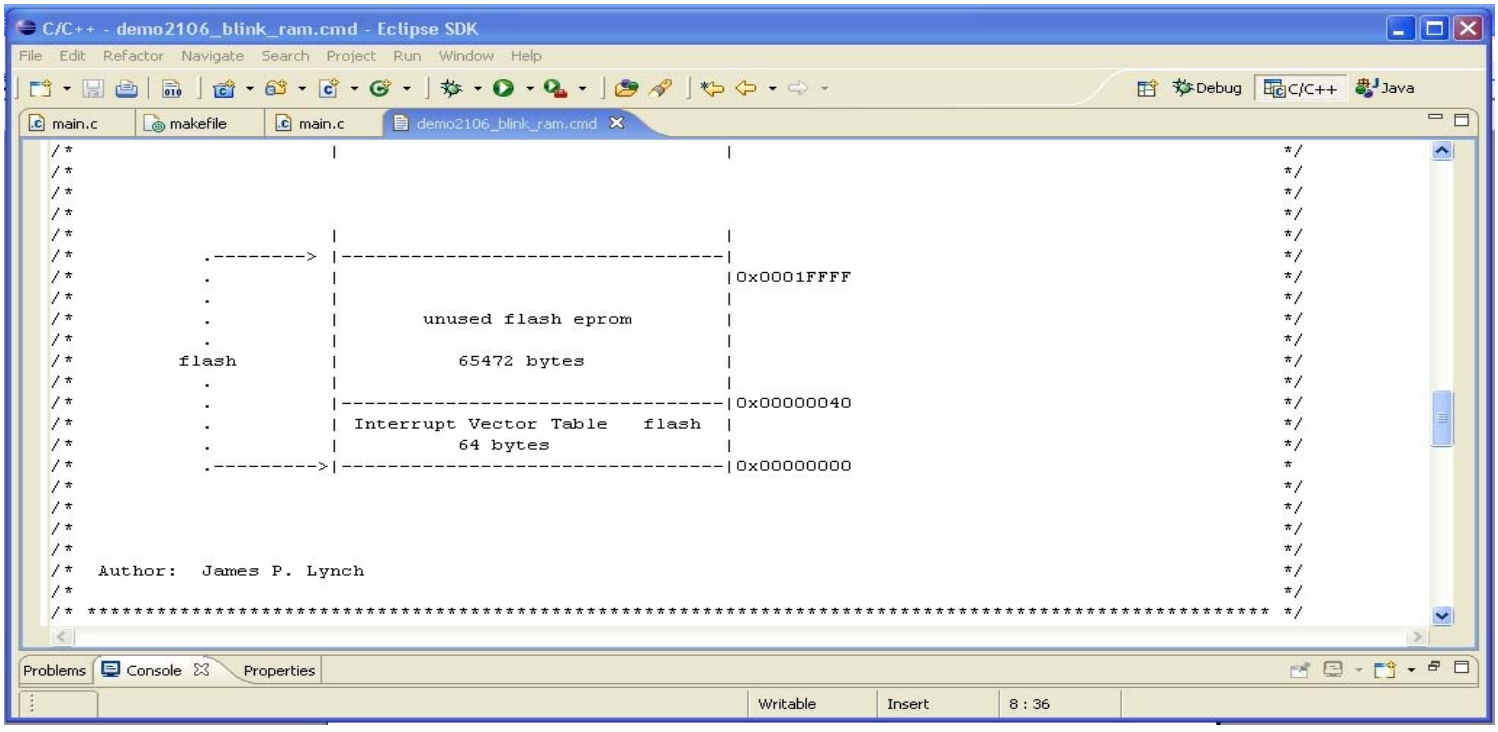
The reason for that is two-fold. First, we don't use interrupts in this example. Second, we use the Philips ISP Flash Loader to force the CPU to start at the address of Reset_Handler; which is at 0x40000200. This bypasses using the RESET vector at 0x4000000 to start the application.

File DEMO2106_BLINK_RAM.CMD

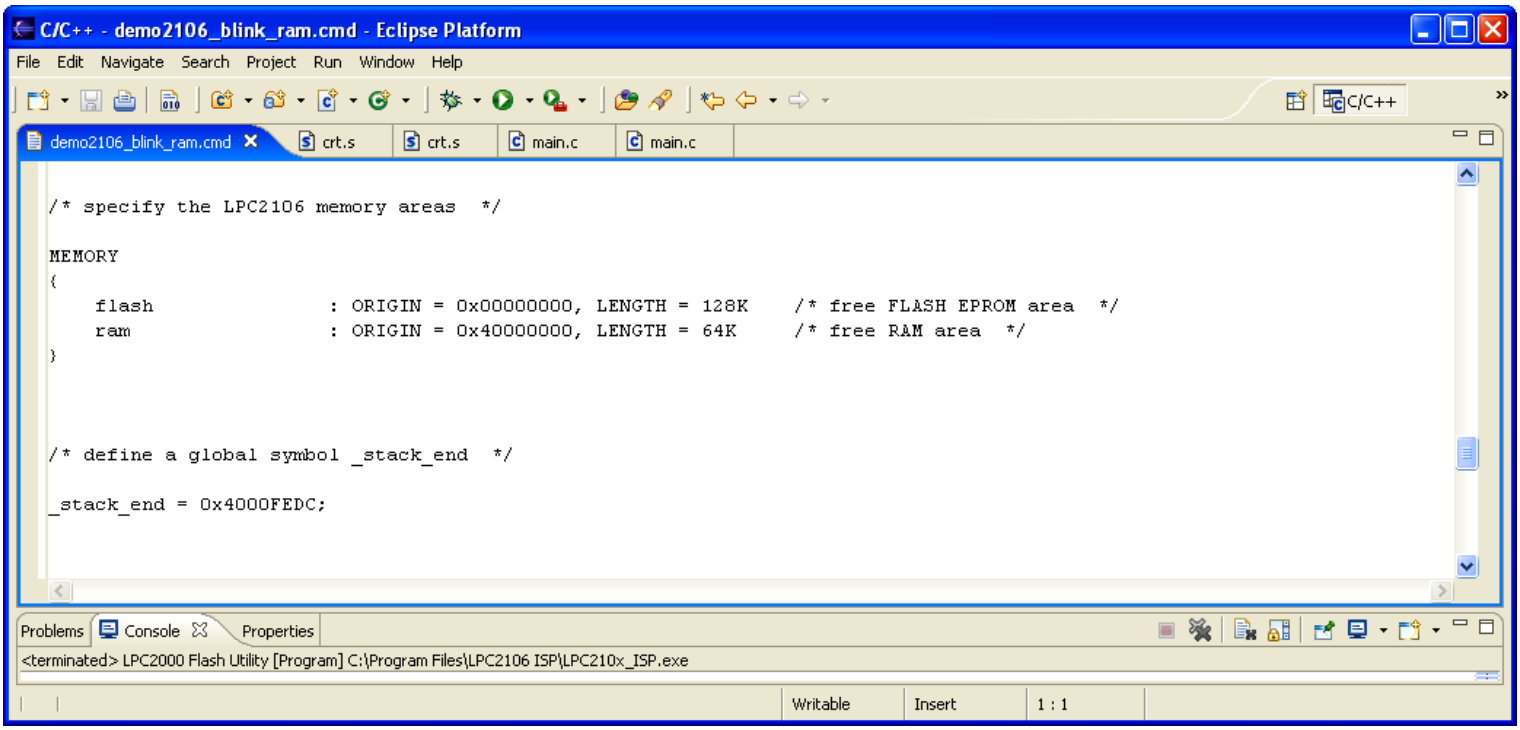
The entire project, both code and variables, is going to be loaded into RAM. Therefore, there are a few changes in the Linker Command Script file **demo2106_blink_ram.cmd**.




C/C++ - demo2106_blink_ram.cmd - Eclipse SDK
File Edit Refactor Navigate Search Project Run Window Help
Debug C/C++ Java
main.c makefile main.c demo2106_blink_ram.cmd
free ram
ram
0x40000464 <---------- _bss_end
.bss uninitialized variables
0x40000448 <---------- _bss_start, _edata
.data initialized variables
0x40000430 <---------- _etext, _data
0x40000344 main
0x400002c4 Initialize
.text C Code
0x400002c0 UNDEF_Routine
0x400002bc SWI_Routine
408 bytes
0x400002b8 FIQ_Routine
0x400002b4 IRQ_Routine
0x40000298 feed
.text Startup Code(assembler)
116 bytes
0x40000200
0x400001FF
variables used by
Philips boot loader
223 bytes
Do not put anything here
0x40000040
.text Interrupt Vectors
(re-mapped)
0x40000000
64 bytes
Problems Console Properties
Writable Insert 8 : 36

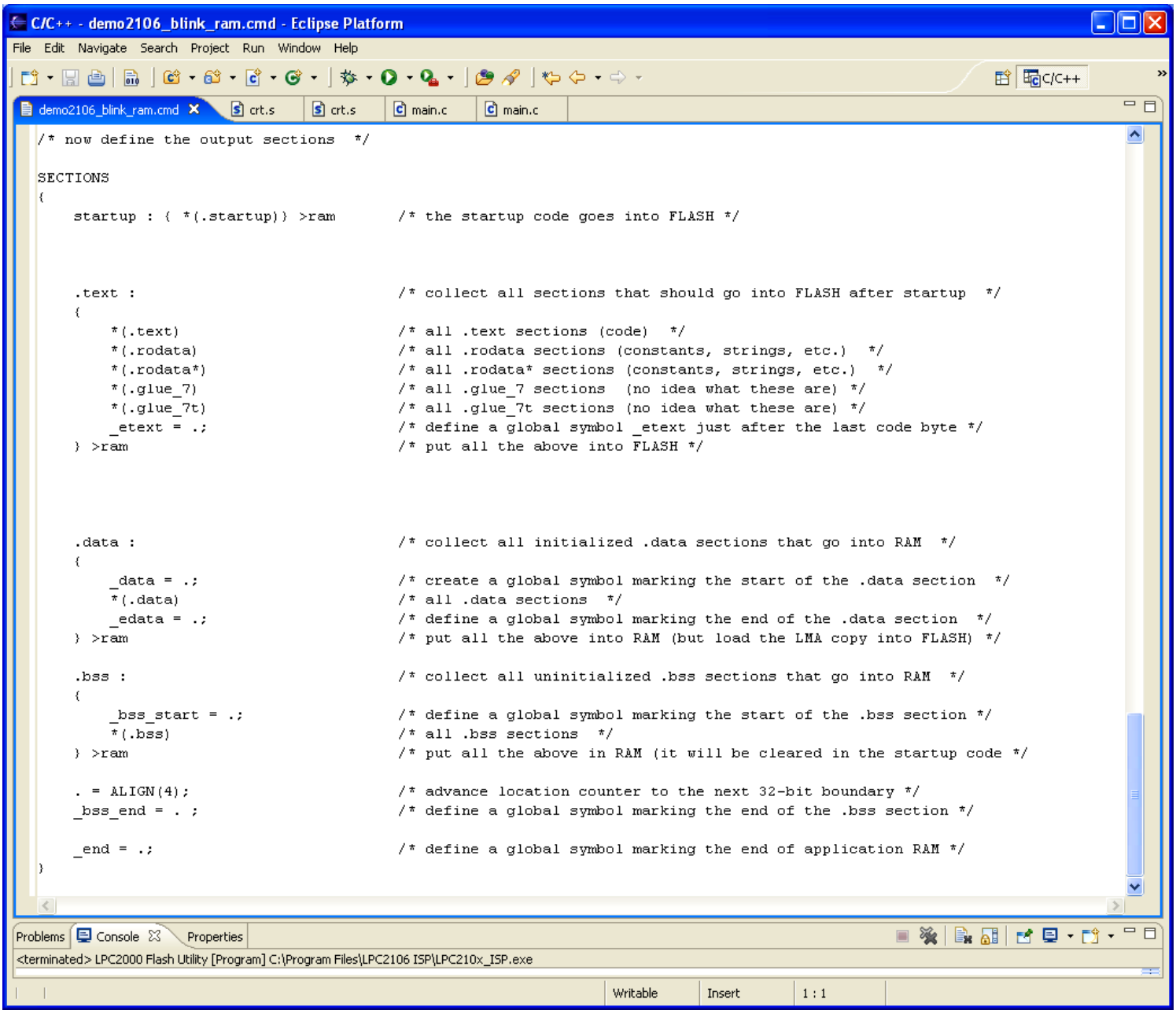

C/C++ - demo2106_blink_ram.cmd - Eclipse SDK
File Edit Refactor Navigate Search Project Run Window Help
Debug C/C++ Java
main.c makefile main.c demo2106_blink_ram.cmd
0x0001FFFF
unused flash eprom
flash
65472 bytes
0x00000040
Interrupt Vector Table flash
64 bytes
0x00000000
Author: James P. Lynch
Problems Console Properties
Writable Insert 8 : 36

I added quite a bit of annotation above to make it very clear how the memory (flash and ram) is organized.



Above I defined two memory areas for flash and RAM, consistent with the LPC2106 memory map. Of course, we're going to load everything (code and variables) into RAM!

Note that I also created a global symbol, **_stack_end**, that is used in the startup routine to build the various stacks. The address is positioned just after the stacks and variables used by the Philips ISP Flash Utility.



Above is the final part of the Linker Command Script. Notice that everything is loaded into **RAM**.

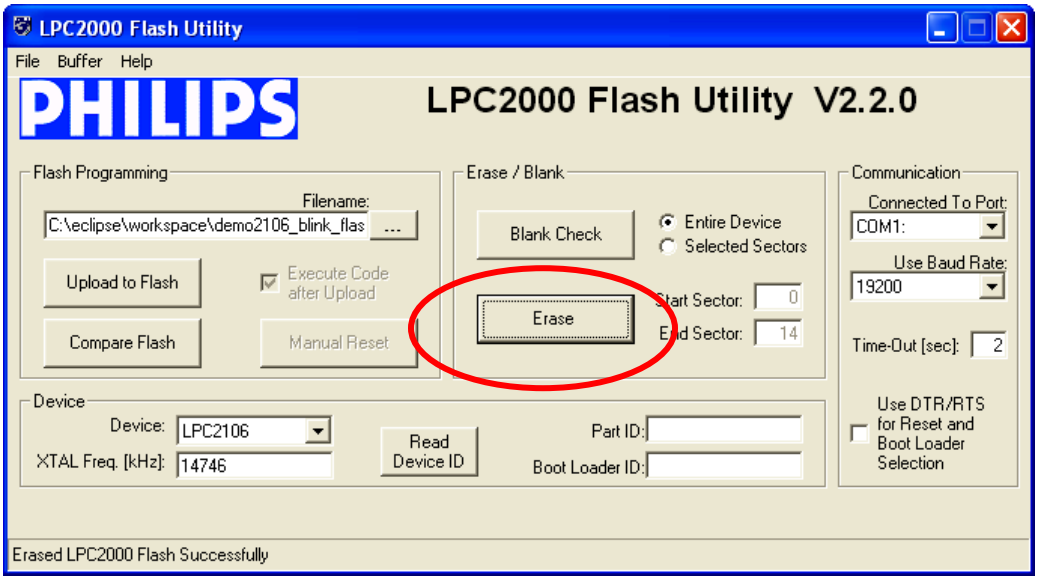
You might ask, “Do we still copy the **.data** section initializers?” I left the copy operation intact in file CRT.S but it now essentially copies over itself (wasteful). I wanted to keep things very similar. You could delete the **.data** initializer copy code in **crt.s** to save space.

You might also ask, “Do we still clear the **.bss** section?” The answer is absolutely yes, RAM memory powers on into an unknown state. We want all uninitialized variables to be zero ar start-up. Of course, stupid programmers rely on uninitialized variables to be zero at boot-up, this is how they get into trouble with uninitialized variables (not all compilers do this automatically).

At this point, if you haven’t cleaned and built the project, do it now.

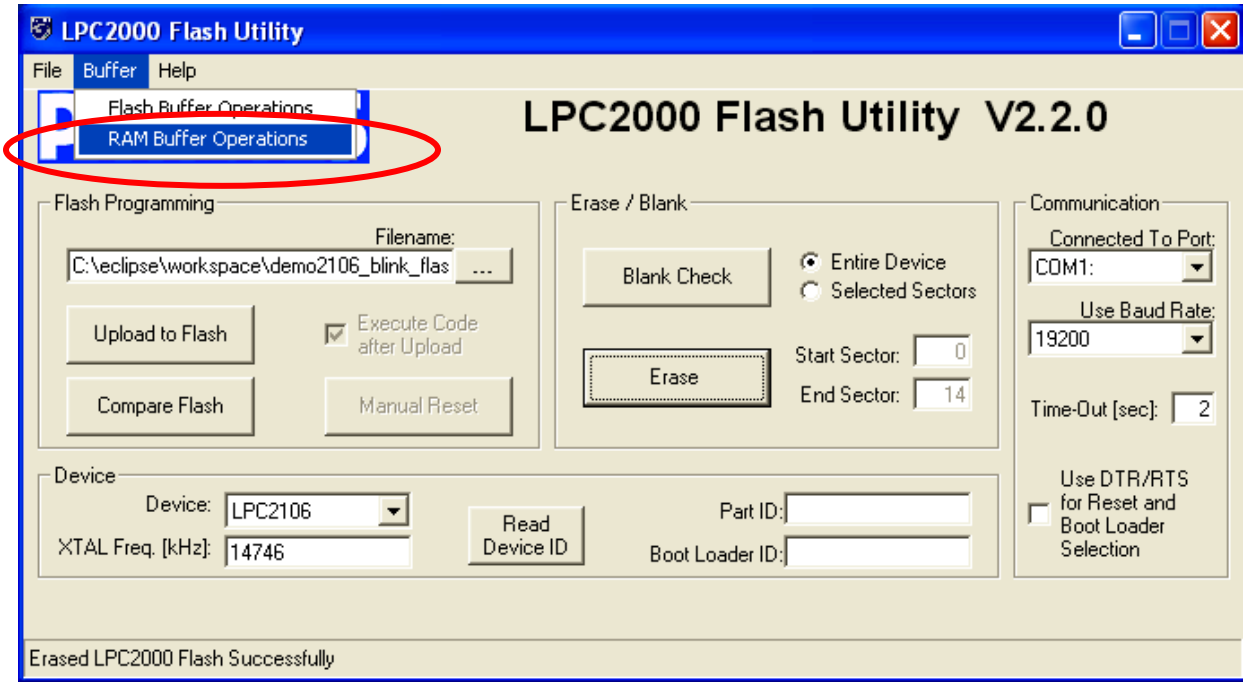
Make sure the BSL jumper is installed.

Now use the “External Tools” toolbar button to find the Philips ISP Flash Utility and start it. To make sure that we are not fooling ourselves, click on “Erase” to clear the flash memory.

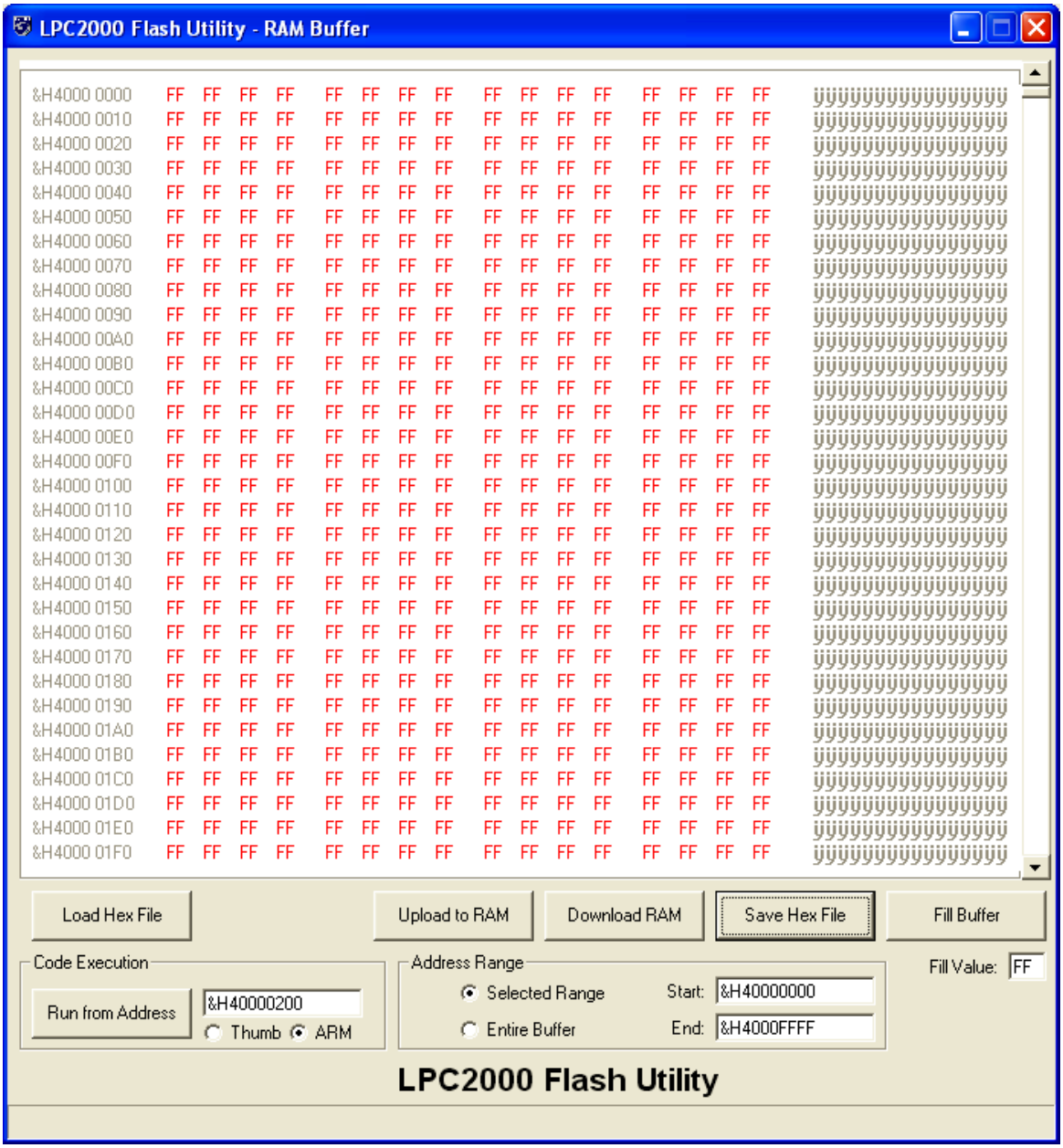


Now we can be sure that the blinking LED is not the Flash application running.

Click on “**Buffer – RAM Buffer Operations**.”

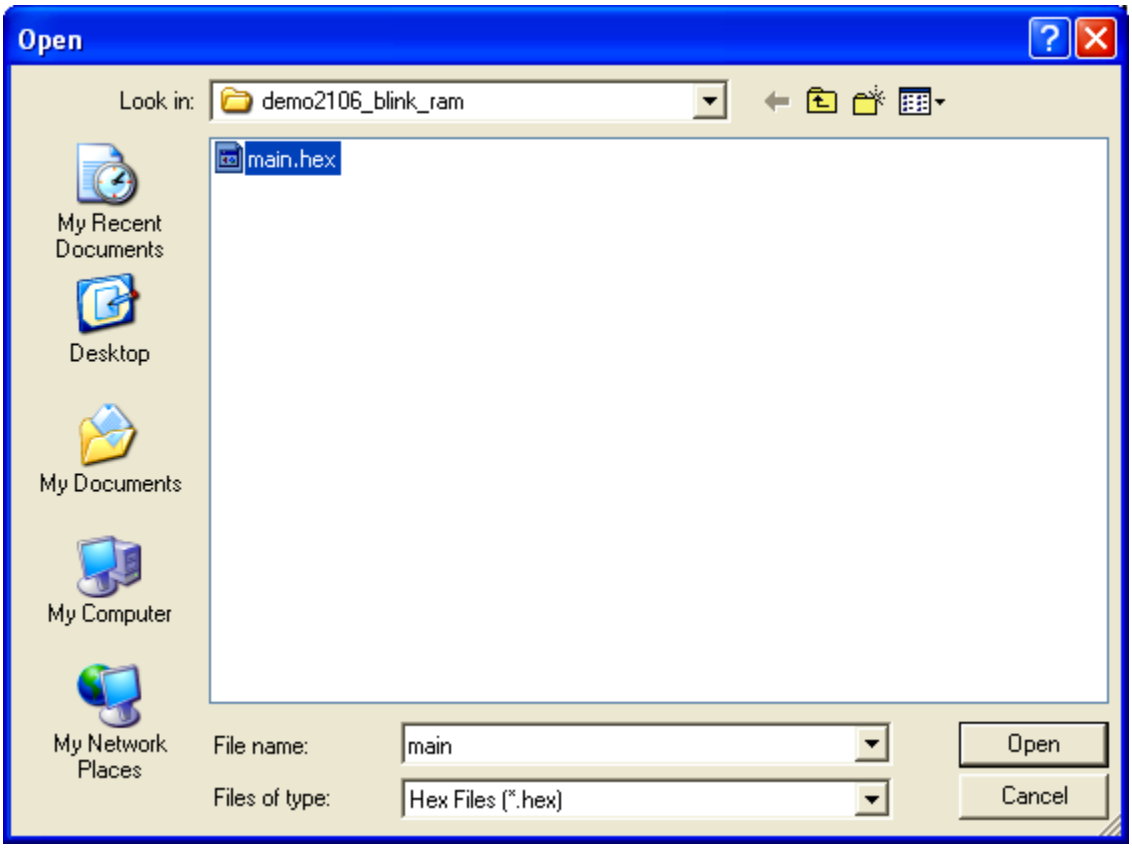


The RAM Buffer screen now appears. Click on “**Load Hex File**.” This is just an operation that fetches the hex file and puts it into the **Philips ISP Flash Utility**.



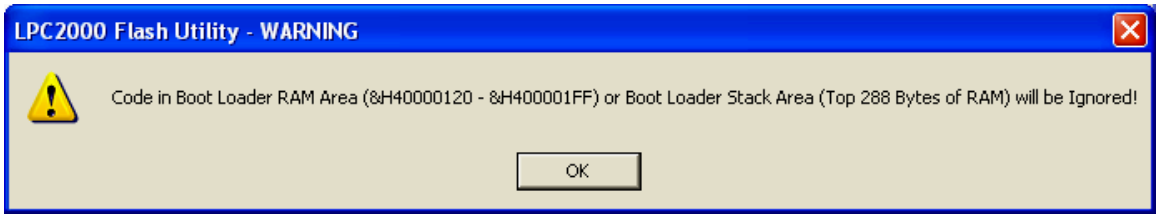
Notice that the button titled “Run from Address” has the value &H40000200 in it. This is thanks to the **ENTRY(Reset_Handler)** directive in the linker command script file. The Philips boot loader will simply load 0x40000200 into the PC register and let her rip!

When you click on the “Load Hex File” button, the following dialog will be presented.



Browse for the **main.hex** file in the project directory and click "**Open**".

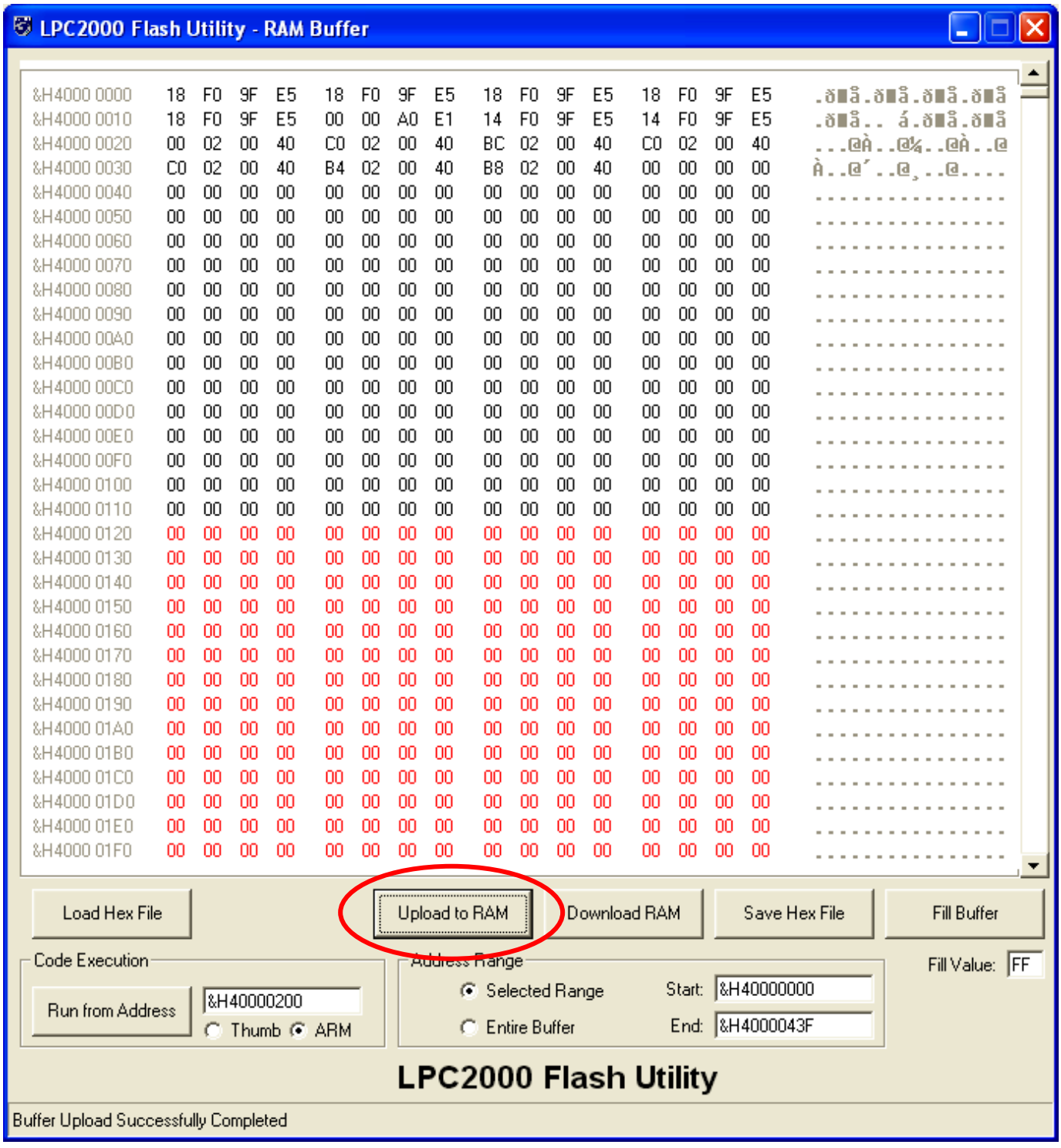
The following warning is presented. Since I advanced the location counter past the low RAM area used by Philips, it still thinks that there's code in there. If I had elected to make the interrupt vectors a separate section, I could have avoided this warning.



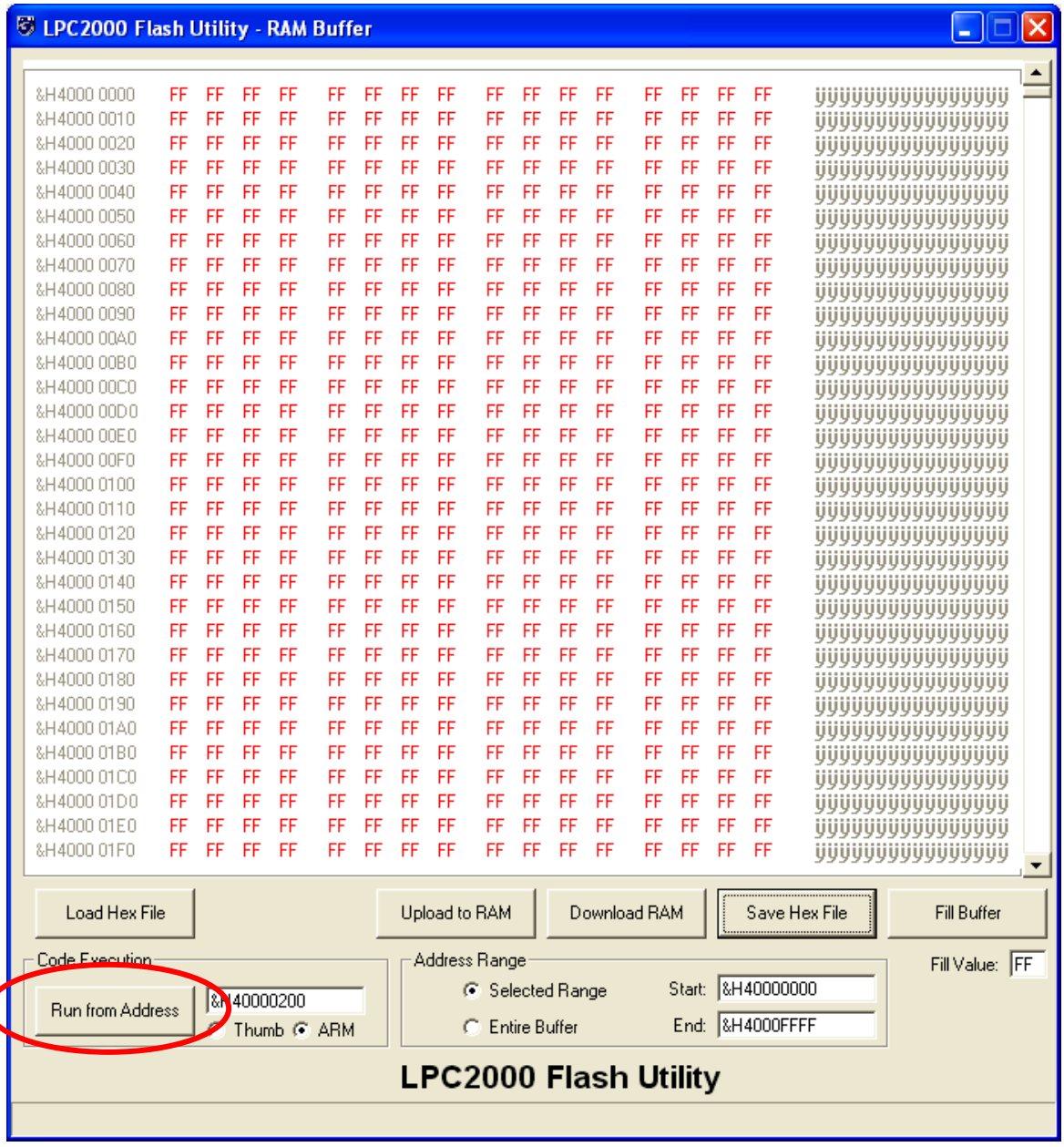
It will still execute OK, of course, since the hex file has no bytes defined for the area where we advanced the program counter past the Philips ISP low RAM usage.

Now click on the "**Upload to RAM**" button to load the hex file into the LPC2106 RAM memory.

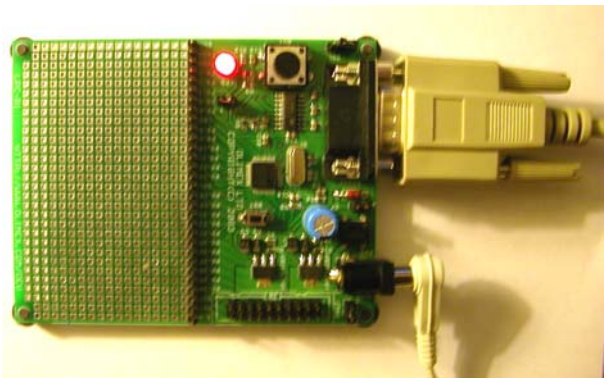
You will see a "progress bar" at the bottom of the screen and it will indicate that the operation has completed.


LPC2000 Flash Utility - RAM Buffer
&H4000 0000 18 F0 9F E5 18 F0 9F E5 18 F0 9F E5 18 F0 9F E5
&H4000 0010 18 F0 9F E5 00 00 A0 E1 14 F0 9F E5 14 F0 9F E5
&H4000 0020 00 02 00 40 C0 02 00 40 BC 02 00 40 C0 02 00 40
&H4000 0030 C0 02 00 40 B4 02 00 40 B8 02 00 40 00 00 00 00
&H4000 0040 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00
&H4000 0050 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00
&H4000 0060 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00
&H4000 0070 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00
&H4000 0080 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00
&H4000 0090 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00
&H4000 00A0 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00
&H4000 00B0 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00
&H4000 00C0 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00
&H4000 00D0 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00
&H4000 00E0 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00
&H4000 00F0 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00
&H4000 0100 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00
&H4000 0110 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00
&H4000 0120 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00
&H4000 0130 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00
&H4000 0140 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00
&H4000 0150 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00
&H4000 0160 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00
&H4000 0170 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00
&H4000 0180 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00
&H4000 0190 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00
&H4000 01A0 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00
&H4000 01B0 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00
&H4000 01C0 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00
&H4000 01D0 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00
&H4000 01E0 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00
&H4000 01F0 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00
Load Hex File
Upload to RAM
Download RAM
Save Hex File
Fill Buffer
Code Execution
Run from Address
&H40000200
Thumb
ARM
Address Range
Selected Range
Start:
&H40000000
Entire Buffer
End:
&H4000043F
Fill Value:
FF
LPC2000 Flash Utility
Buffer Upload Successfully Completed

You do **NOT** have to remove the BSL jumper. Click on the “Run from Address” button to execute the program.



Your application should blink, just like the Flash EPROM version did. Time for the Bigfoot picture!



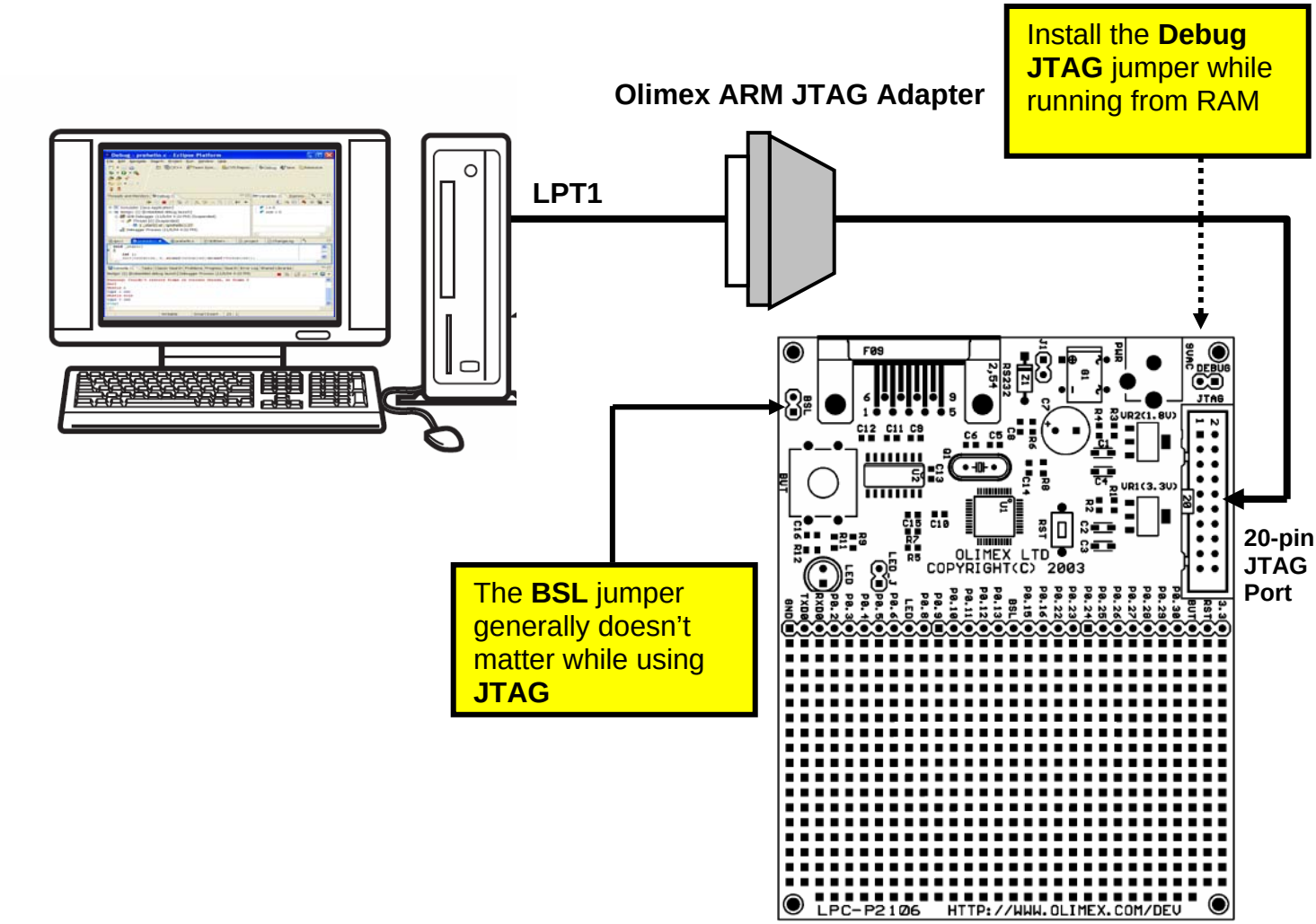
IT BLINKS!

21 Debug the RAM Project

The previous exercise, running the RAM project from the Flash Utility, was of academic interest but essentially of no practical value. Well, it is kind of cool that you can do that with a flash utility.

Eclipse/CDT interfaces seamlessly to the GDB debugger that is an integral part of the GNU tool chain. When you click on the "**Debug**" button, you will be able to watch the execution of your program graphically as it goes from breakpoint to breakpoint. You can park the cursor over a variable name and see its current value (assuming that execution has stopped, of course). You'll be able to look at structured variables, see the ARM registers and have the ability to modify variables and registers.

We will need the following hardware setup:



The **Olimex ARM JTAG Adapter** is a clone of the Macraigor **Wiggler** JTAG interface. It costs about $19.95 and all fits into a DB-25 shell. I bought a straight-through printer cable from my local computer retailer and fitted it from the LPT1 printer port to the ARM JTAG **Wiggler**. The **Wiggler** was then fitted to the 20-pin JTAG header on the Olimex **LPC-P2106** board.

The red stripe on the ribbon cable is pin 1 and should be nearest the power plug.

The **Debug JTAG** jumper should be fitted. It doesn't matter if the **BSL** jumper is installed or not. Make all these connections with the power off.

A. Blunt Talk About the Wiggler

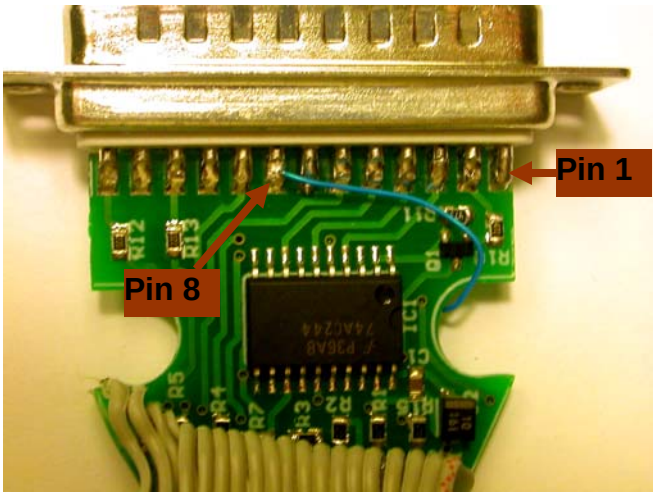
Let's talk bluntly about the **Wiggler**. The **Wiggler** is one of many products from the Canadian company Macraigor. It connects the parallel port of your PC to the 20-pin JTAG header on the Olimex **LPC-P2106** board. It is just a simple level shifter and a transistor. Macraigor charges $150 for it; the Olimex clone is about $19.

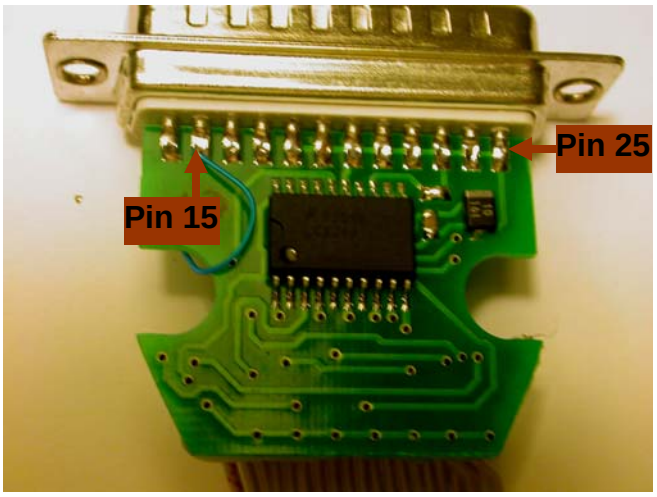
There are several schematic diagrams on the web for the **Wiggler**; notably Leon Heller has one on the LPC2000 message board on Yahoo. You could build your own but I doubt you'd save that much money after paying the shipping from Digikey and the gas to drive to Radio Shack. The Olimex version is a fair deal.

Obviously the Macraigor Company is not happy about all these clones running about, so recently they slipped an impediment into the works. The latest version of **OCDremote**; their free JTAG server for the **Wiggler** and other products, is expecting a connection (short circuit) between **pins 8 and 15** of the LPT1 printer port. This has made a lot of people fail.

Olimex has revised their design and modified their stock of **Wigglers** to make this connection, but there are large numbers of the device out there that don't have this modification (like my Olimex **Wiggler**).

Use an ohmmeter on the 25-pin printer connector on the **Wiggler** to see if these two pins are connected. If not, you can easily disassemble the Olimex **Wiggler** and tack-solder a jumper to do the job. Again, **you must connect pin 8 to pin 15**.





I used that 30 gauge Radio Shack blue Teflon coated hookup wire and a microscope to do the soldering above. If you have a good magnifier; the DB-25 pins on the wiggler have the pin numbers embossed in the white plastic above and below the rows of pins.

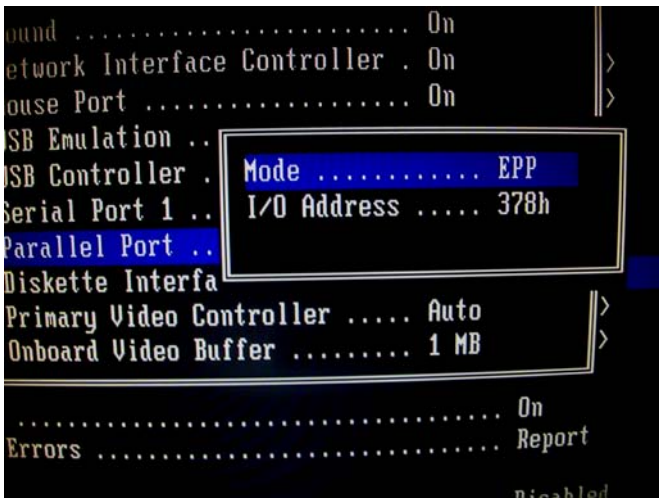
We're not quite finished with our **Wiggler** suffering. There's the final issue of the PC Printer port mode. Most modern PCs, like my new Dell, have the Printer Port defaulted to "**ECP**" mode.

The **Wiggler** will not work with the printer port configured for **ECP** mode.

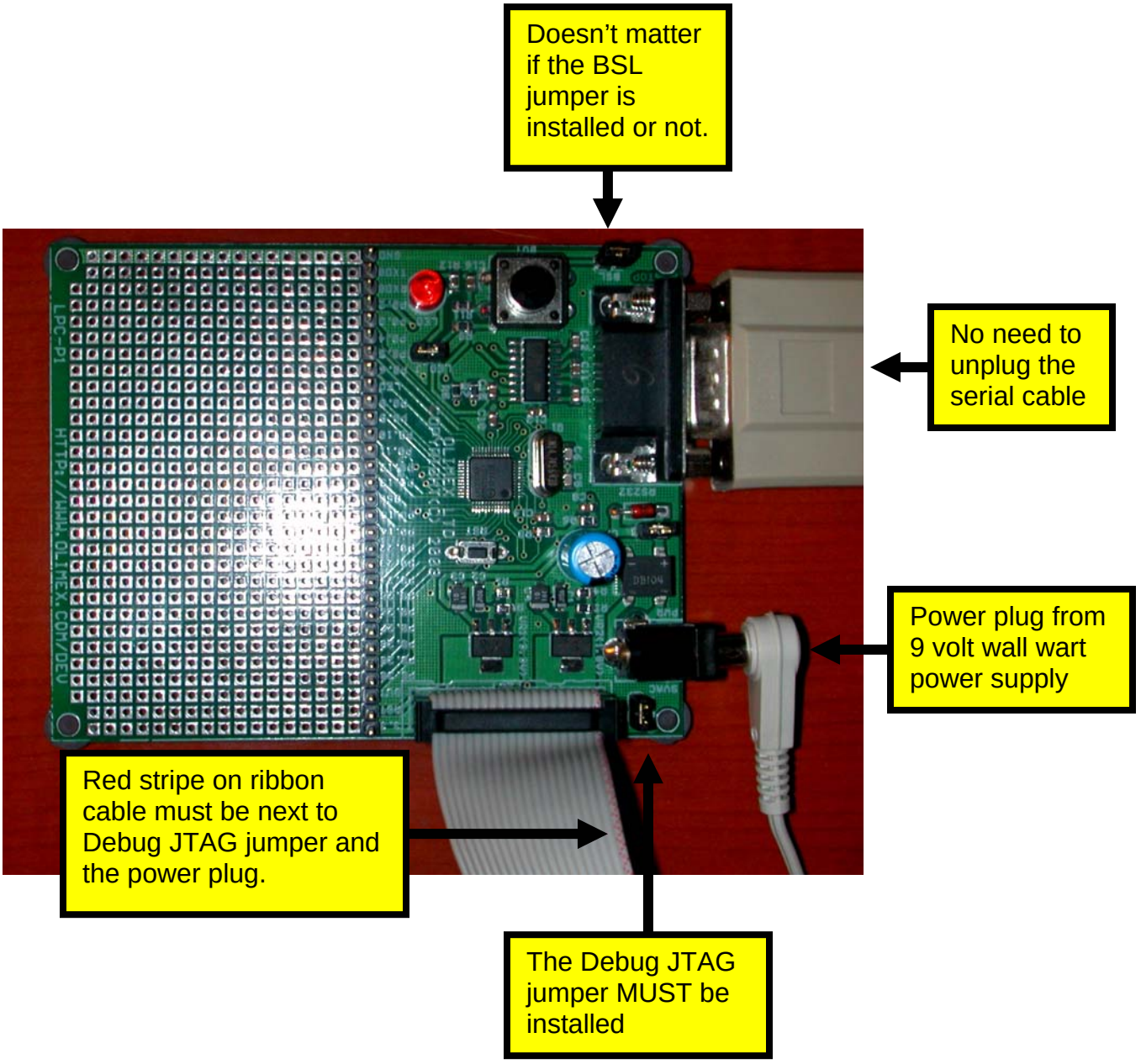
The Macraigor web site has a FAQ with the following citation:

> **What mode must my parallel port be in?**
>
> **As far as the parallel port is concerned, a Wiggler is a simple uni-directional device. It will work with the parallel port in any mode EXCEPT "ECP". It will NOT work in ECP mode at all.**
>
> **The Raven works best with a parallel port in EPP mode. It may work in ECP mode. If the parallel port is in an older mode, such as uni-directional, AT, or compatible, the Raven will work but slower.**
>
> **Remember, the mode is set in the CMOS bios of your computer.**

On my Dell Dimension Desktop PC, the CMOS setup can be entered if you hit the **F2** key as the machine boots up. By maneuvering around the CMOS setup, you can find the Parallel Port setup and see what mode it is set up as. If it's **ECP** mode, change it to **EPP** mode, as I did in the screen photograph below. Save the CMOS setup and exit. My printer is a USB device, so this action didn't effect my printer operation.



Let’s review the hardware setup one more time.



Power up the Olimex LPC-P2106 board and press the **RST** button for good luck!

B. Final Preparations Before Starting Eclipse Debugger

Before we start the **Eclipse** Graphical Debugger, I should mention that debuggers absolutely hate compiler optimization. This one is no different. We have been compiling with **–O3** and you will find some strange things happening when you single-step at that optimization level.

Just to be sure, let's turn off optimization. Go to the makefile and change the setting to **–O0** and rebuild!

File: **makefile.mak**

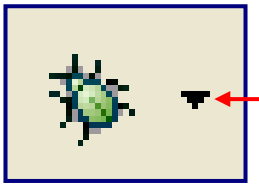
```
NAME    = demo2106_blink_ram

CC       = arm-elf-gcc
LD       = arm-elf-ld -v
AR       = arm-elf-ar
AS       = arm-elf-as
CP       = arm-elf-objcopy
OD       = arm-elf-objdump

CFLAGS   = -I./ -c -fno-common -O0 -g
AFLAGS   = -ahls -mapcs-32 -o crt.o
LFLAGS   =  -Map main.map -Tdemo2106_blink_ram.cmd
CPFLAGS  = -O ihex
ODFLAGS  = -x --syms

all: test
```

Turn off compiler optimization by setting compiler flag to:

-O0 - no optimization

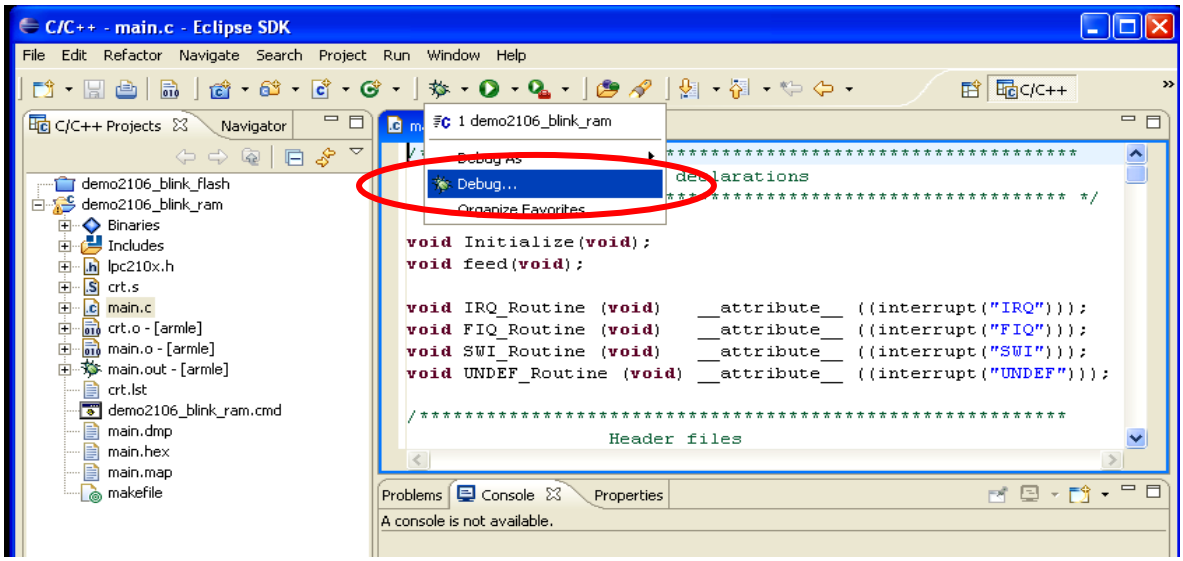
C. Create a Debug Launch Configuration

The first order of business is to set up a "**debug launch configuration**." The quickest way to get to the "**debug launch configuration**" screen is to click on the "insect" button (insect – bug – get it?). Specifically, click on the down arrowhead to bring up the debug pull-down menu.



Click on down arrowhead to get the pull-down menu

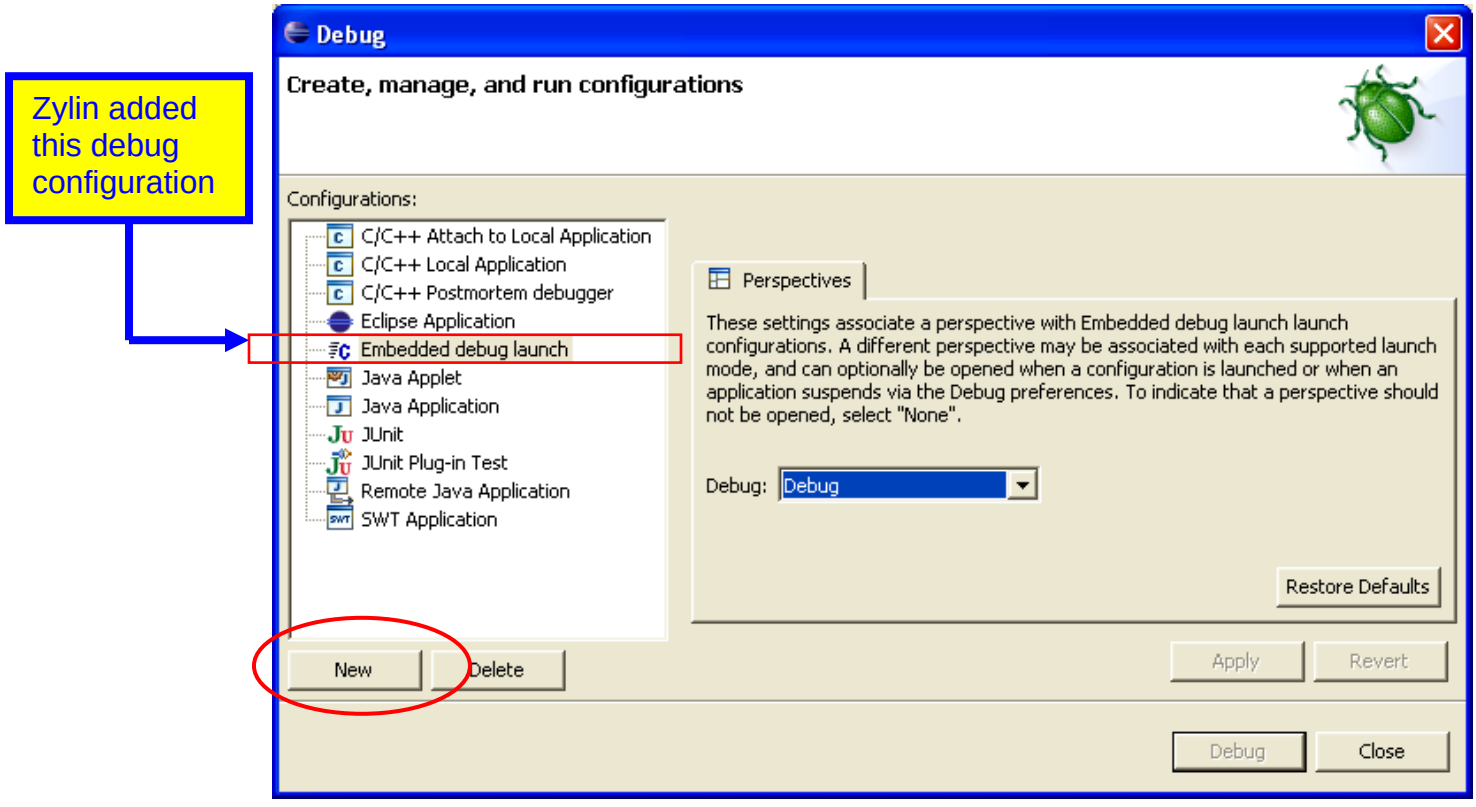
Click on the “**Debug …**” selection in the debug pull-down list to bring up the Debug configuration screen.



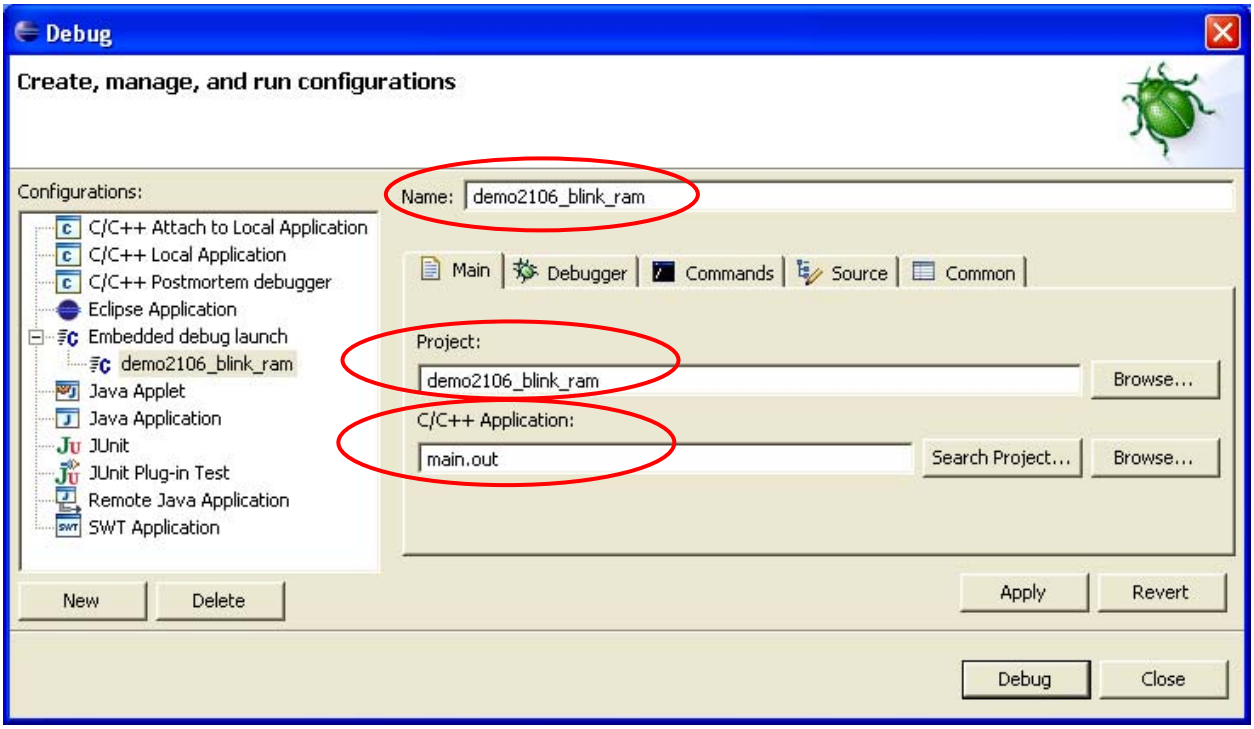
In the “Debug Launch Configuration” screen below, you can see the Zylin modification. Note that one of the possible debug configuration types is now “**Embedded debug launch.**”

You will tend to create a separate “**Embedded debug launch**” configuration for every project you create; it’s very convenient for people who have multiple projects going on at the same time.

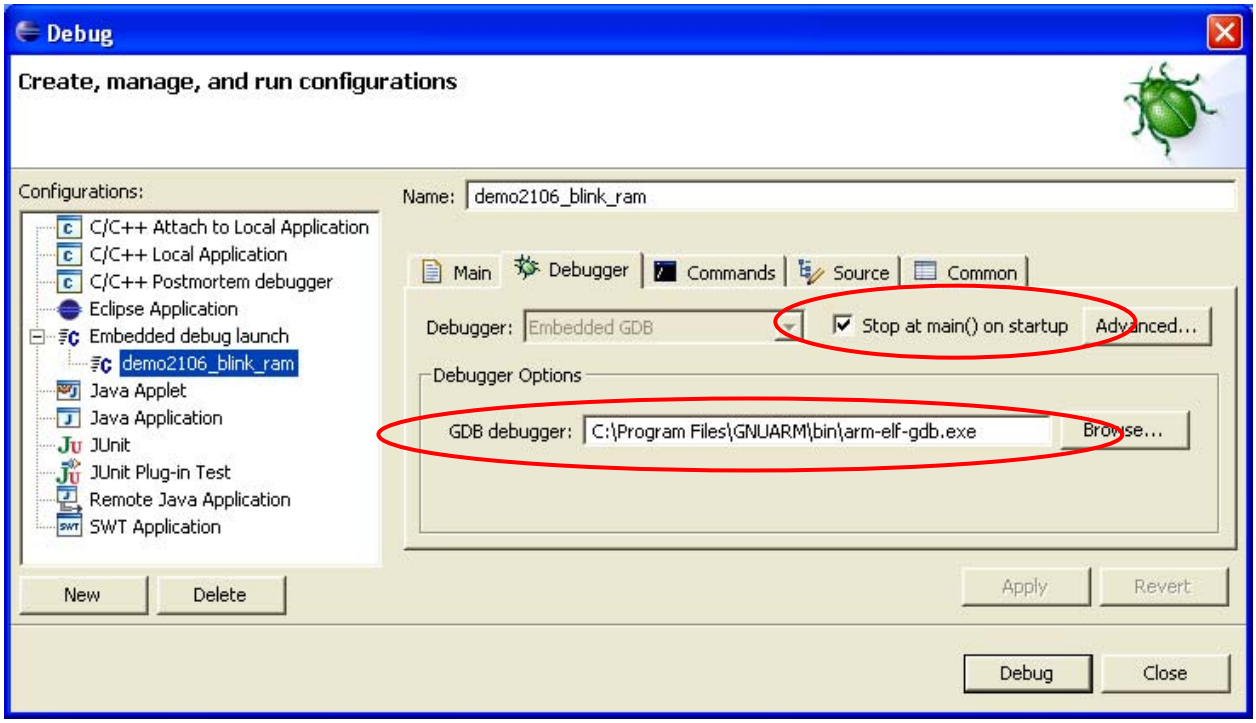
Click on the Zylin “**Embedded debug launch**” configuration and then “**New**” to get started.



In the “**Main**” tab, set the name to anything you like and the project to “**demo2106_blink_ram**.” I was, of course, lazy and made the debug configuration name the same as the project. Set the C/C++ Application to “**main.out**.” Main.out is an arm-elf format file that has the executable and debug information within the file.

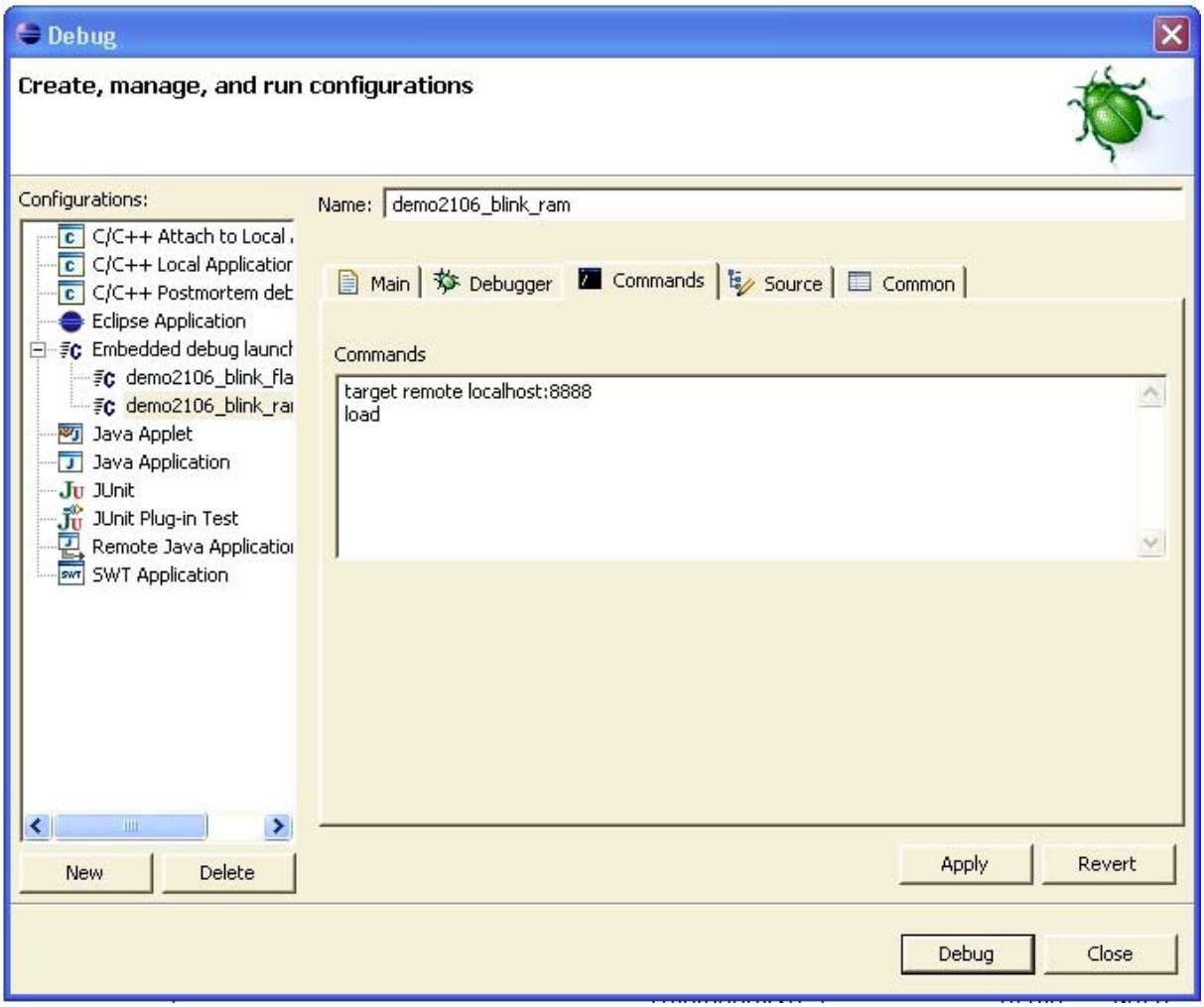


Under the “**Debugger**” tab, use the “**browse**” button to set the “GDB debugger” text window to “**c:\program files\GNUARM\bin\arm-elf-gdb.exe**” and check the box that instructs the debugger to stop at main() on startup.



Under the “**commands**” tab, enter the following two GDB commands to run at startup:

target remote localhost:8888
load



The “**target remote**” command specifies that the protocol used to talk to the application is “GDB Remote Serial” protocol with the serial device being a internet socket called **localhost:8888** (the default specification for the Macraigor **OCDremote** driver).

Target Remote supports the GDB “**load**” command; the specific download file (**main.out**) was specified above in the “main” tab. In this case, the “**load**” command will download the executable code into RAM and the Eclipse/GDB debugger will use the symbol information contained within the “**main.out**” file to locate all statements and variables.

When we debug FLASH programs, we can’t use the “**load**” command since the GDB debugger cannot program FLASH memory. In this case, we will use the Philips Flash Utility to burn the executable into FLASH and substitute the GDB command “**symbol-file main.out**” to provide the debugger with the statement locations and symbol information. There is more on this later in the tutorial.

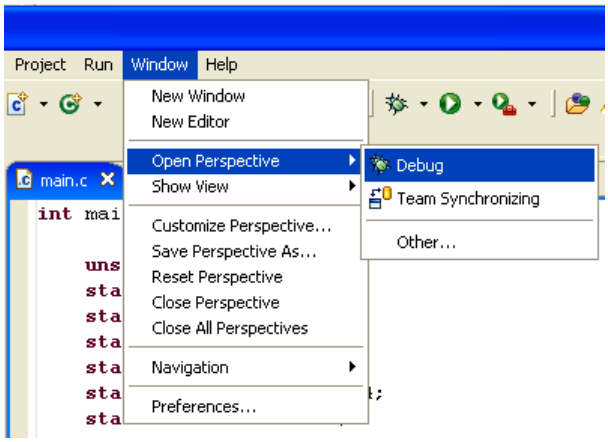
The “**source**” tab can be left at its default settings.

Likewise, the “common” tab can be left at its default setting. Click on “**apply**” and then “**Close**” to complete specification of the debug launch configuration.

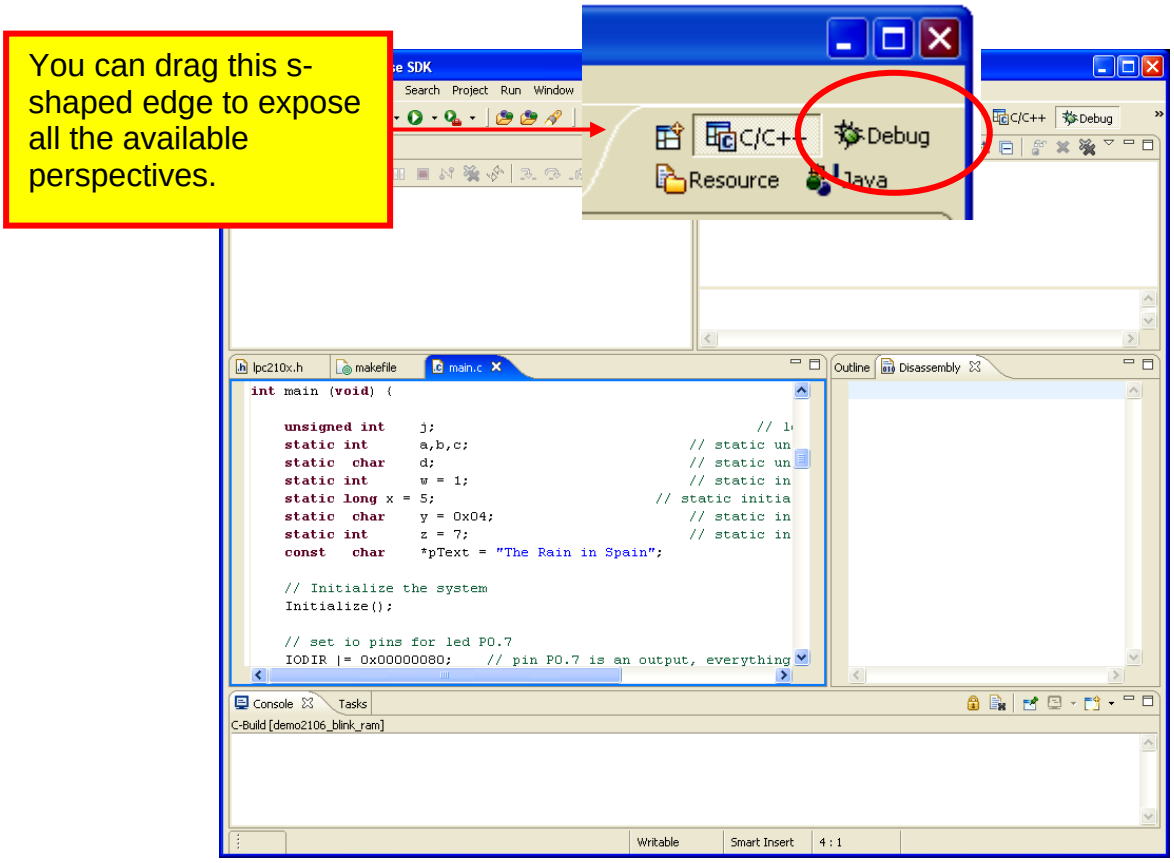
D. Switch to Debug Perspective

What you see on the screen when using Eclipse is called a “perspective” and up to now, we have been using the “**C/C++**” perspective. Once the application has been built, we must switch to the “**Debug**” perspective to debug it.

One way is to change the perspective in the “**Window**” pull-down menu as shown below.



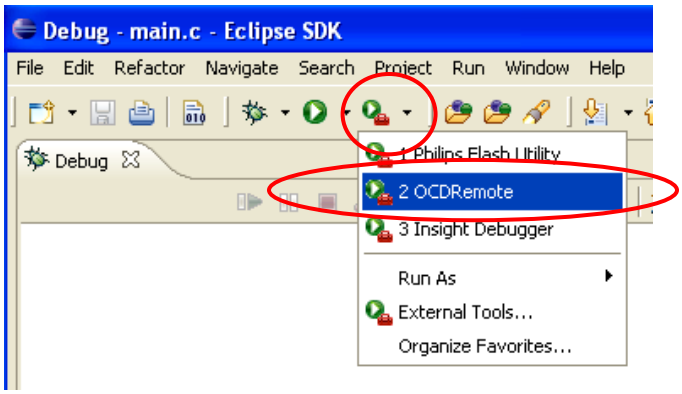
It’s also convenient to click on the “**Debug Perspective**” button on the upper right of the Eclipse screen. Below is the “**Debug**” perspective.



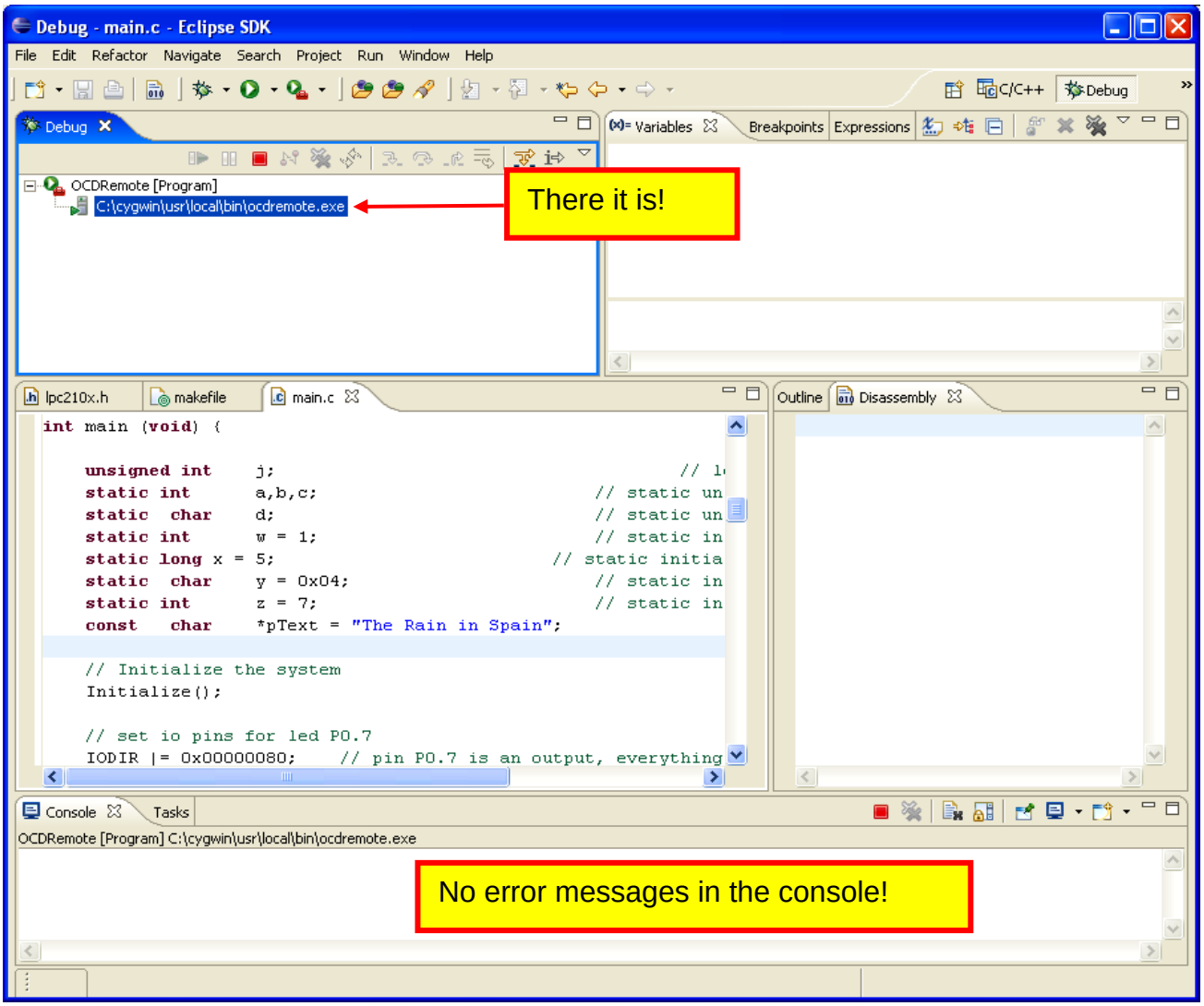
E. Start the OCDRemote utility

The Macraigor **OCDRemote** utility must be started **before** the Debugger is launched.

Remember that we set up the **OCDRemote** as an External Tool. It's easily started by clicking on the pull-down arrow of the External Tool button. Note the little red toolbox on that button.



The well-known problem of the Wiggler/**OCDRemote** combination is that it doesn't always start. Below is an example of where it does start properly.

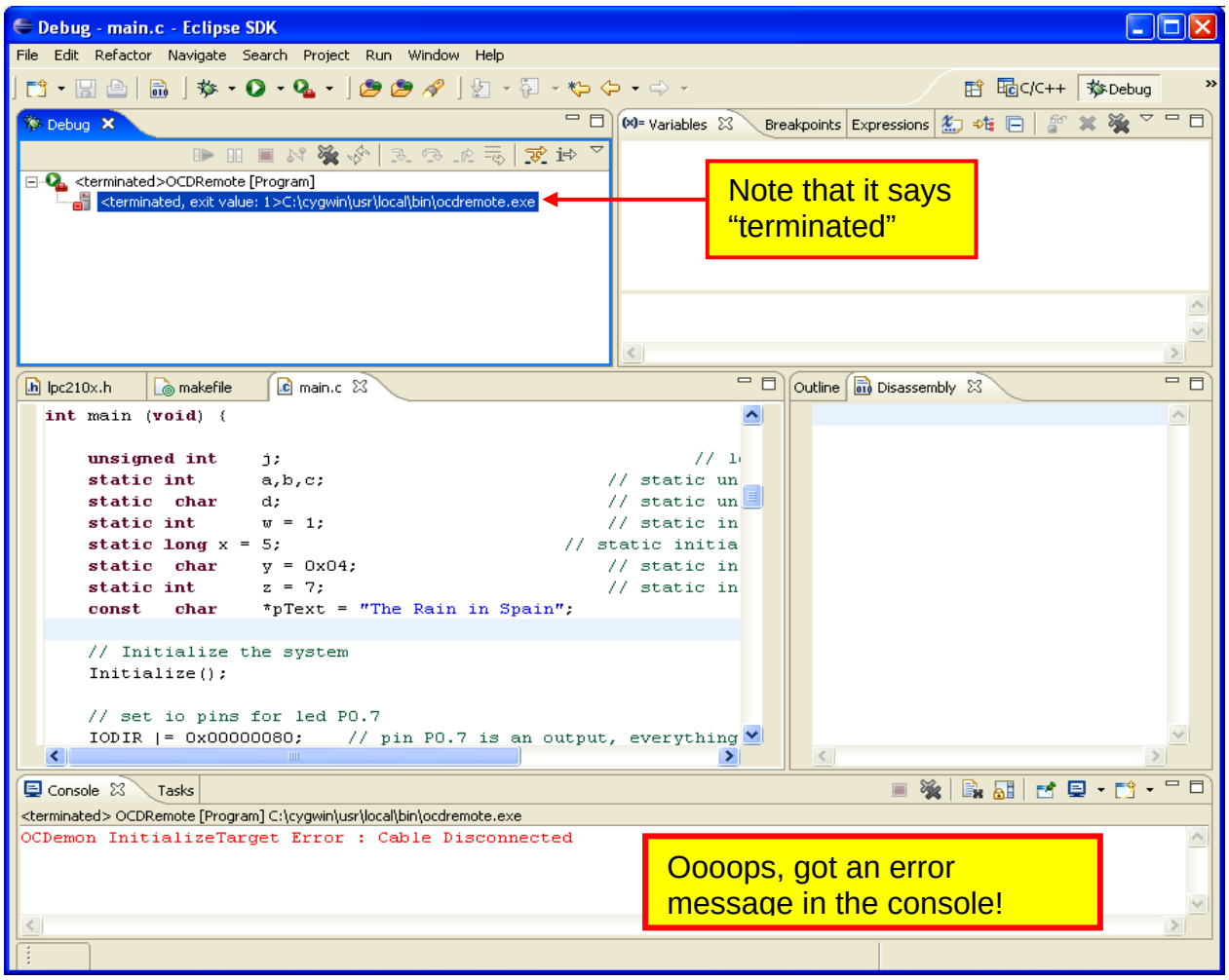


When everything works, the GDB Debugger communicates using the GDB Serial Protocol to an internet socket called **localhost:8888**, we specified this in our Embedded Debug Launch Configuration (the “command” tab).

The Macraigor **OCDRemote** DLL intercepts the GDB Serial Protocol via the internet socket and converts it into JTAG signals on the **LPT1** printer port connector. The Wiggler device merely translates the JTAG signals to 3.3 volts for use with the Philips LPC2106 microprocessor.

The GDB “**load**” command, shown above, downloads the executable into RAM.

Here is an example of **OCDRemote** failing.



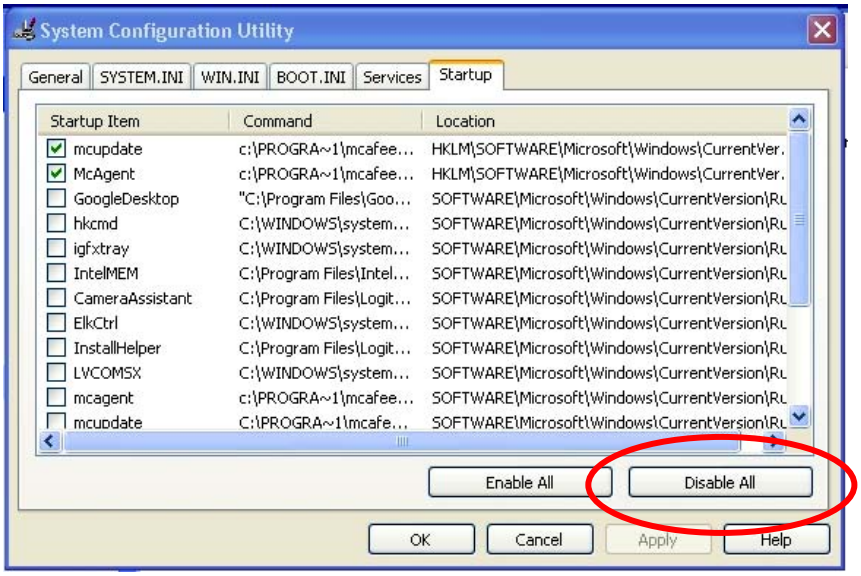
If you have trouble getting **OCDremote** to start; try these remedies:

- You may have accidentally started multiple copies of **OCDremote**. Bring up the Windows Task Manager (**ctrl-alt-del**) and search the list of running tasks. If there are multiples of **ocdremote.exe**, terminate all of them and start over.

- Keep trying; I’ve clicked it ten times before it started (this is simply Voodoo).

- Make sure your computer is not running cpu-intensive applications in the background, such as internet telephone applications (my beloved **SKYPE** for example). The **OCDRemote**/wiggler system does "bit-banging" on the **LPT1** printer port which is fairly low in the Windows priority order.

  For Windows XP users, here is a simple way to get rid of all those background programs. Click "**Start – Help and Support – Use Tools… - System Configuration Utility – Open System Configuration Utility – Startup Tab**"



  Click on "**Disable All**". Windows will ask you to re-boot and the PC will restart with none of the start-up programs running. Use the same procedure to reverse this action.

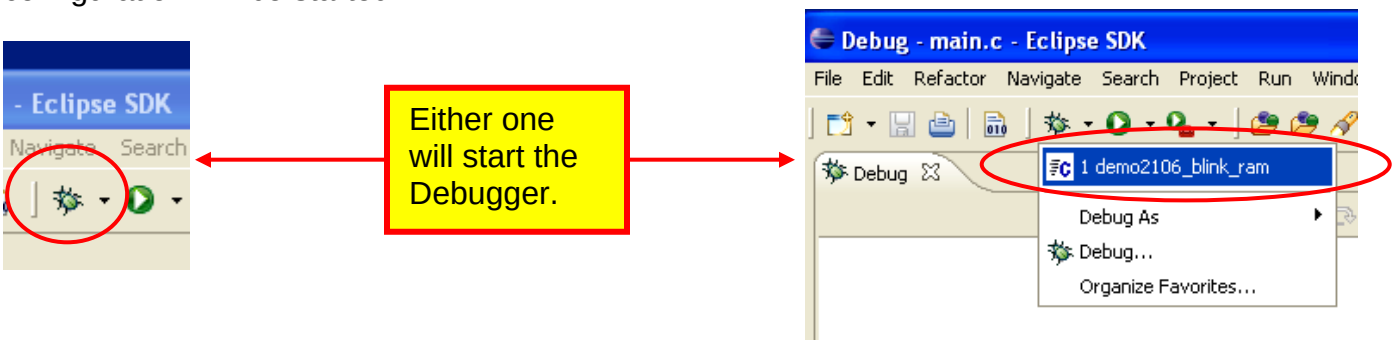
- Try a lower speed (JTAG clock rate). The slowest speed is **8** (4 kHz) whilst the fastest speed is **1** (380 kHz).

- Go to bed; let it win tonight.

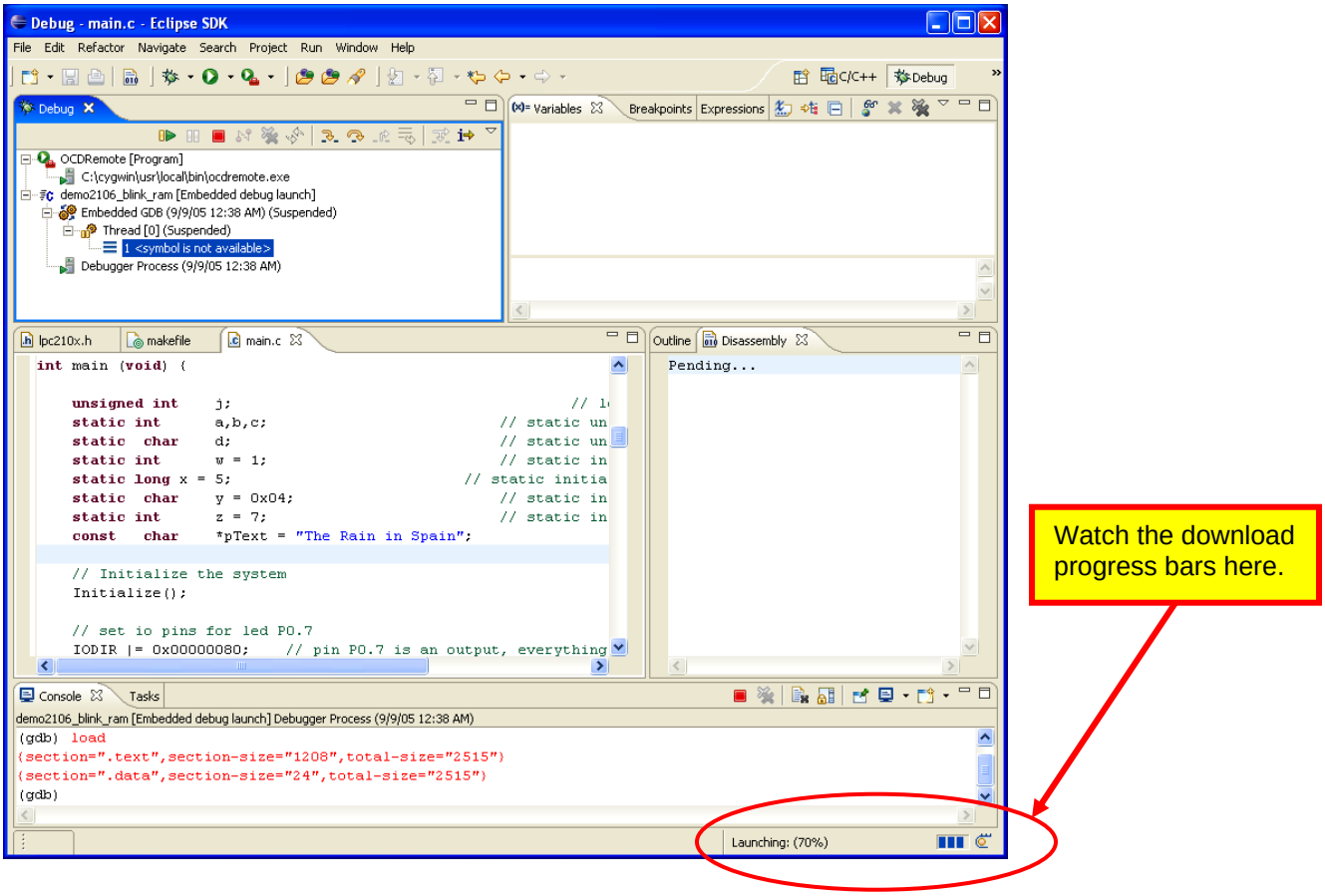
F. Start the Debugger

Our “Debug Configuration” has been defined and we’ve switched to the Debug perspective. We started the **OCDRemote** utility and verified that it’s working.

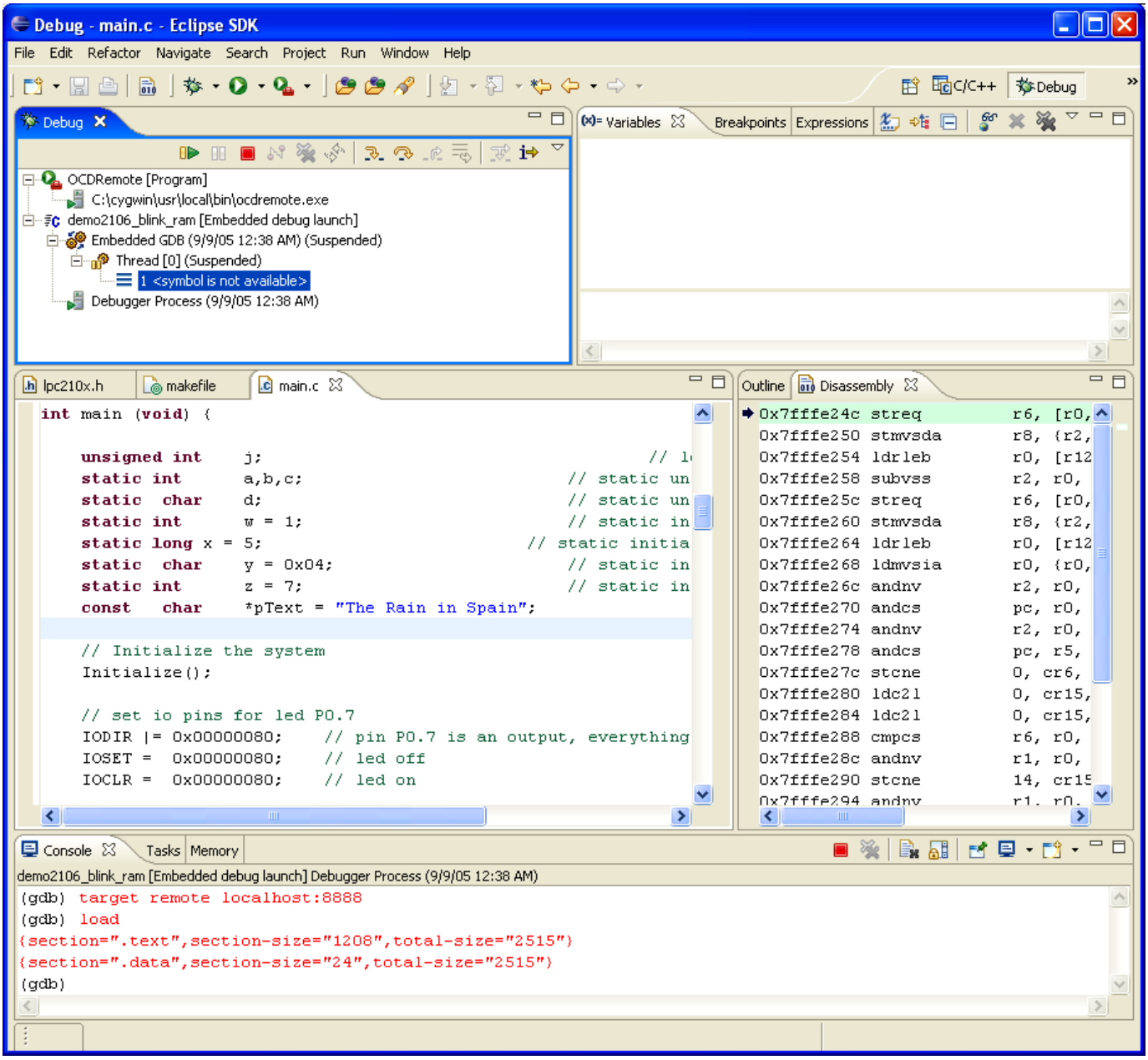
Now is the time to start the debugger. Since the “Embedded Debug Launch” configuration “**demo2106_blink_ram**” was the last configuration accessed above, clicking on the “Bug” button will suffice. If you’re not sure, use the pull-down” arrow to see exactly what configuration will be started.



The Debugger will start up and execute the two commands specified earlier. It will connect to the target via JTAG and start a download of the application. You can watch the progress bars at the lower right of the screen.



When downloading completes, the Debugger is in “idle” mode with the executable code loaded into RAM.



You can see above in the “console” view that the debugger executed our two commands specified in the launch configuration earlier. It followed that with the download of the **.text** and **.data** sections.

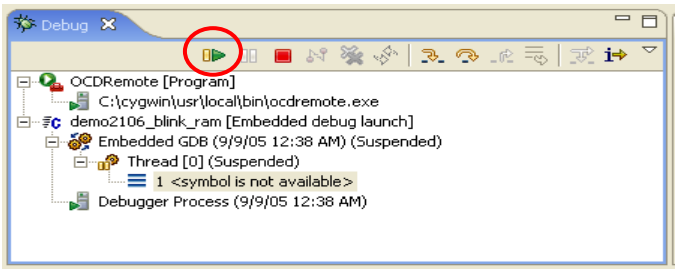
The downloading can be a little slow. You may want to experiment with a faster speed setting for the Olimex wiggler.

The debugger is “idle”, waiting for you to issue a command.

G. Run to Main

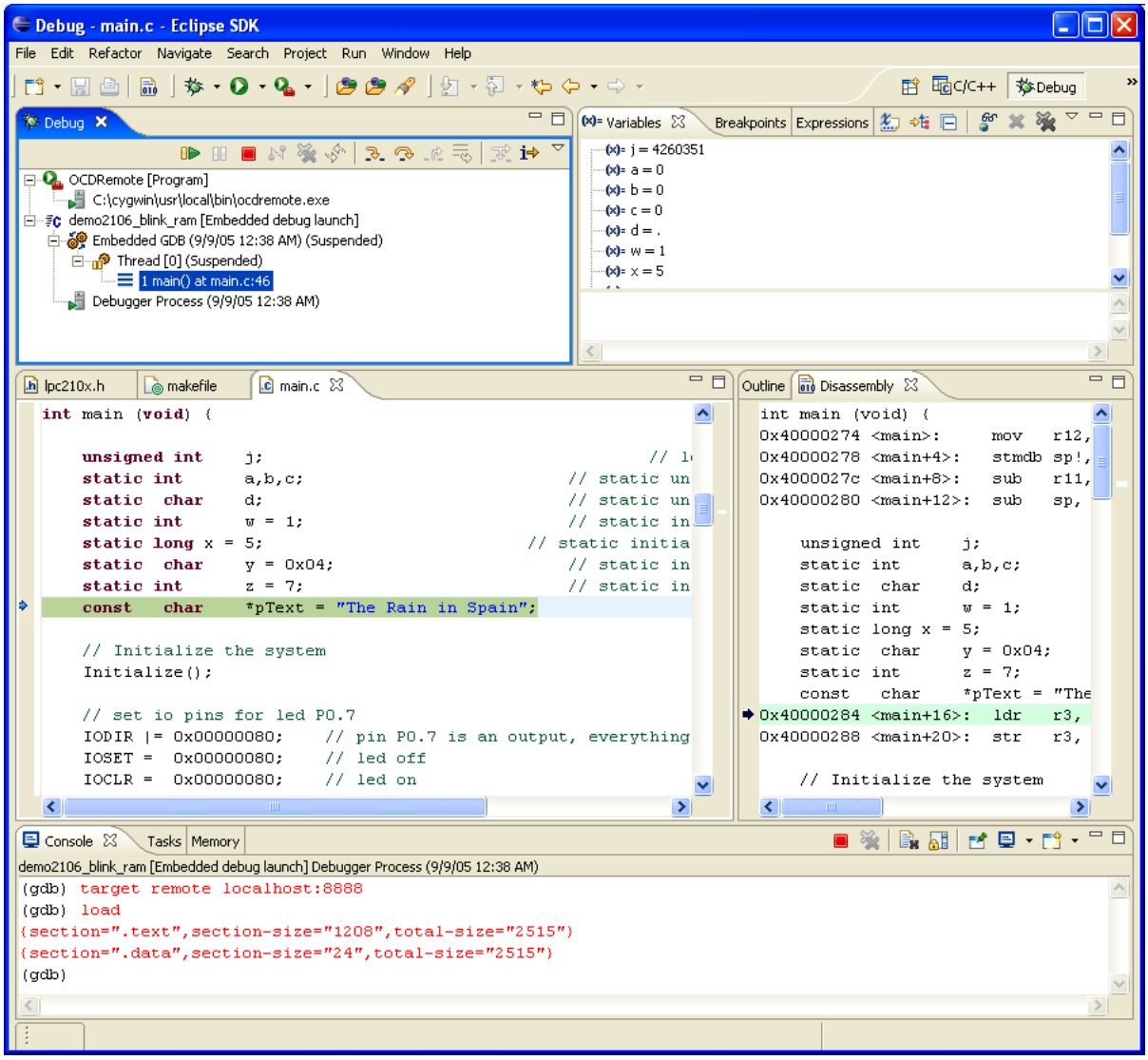
The first move is to start the application. It will stop at the main() program; we specified this earlier in our launch configuration setup.

In the Debug view, click on the green arrow to start execution of the application..



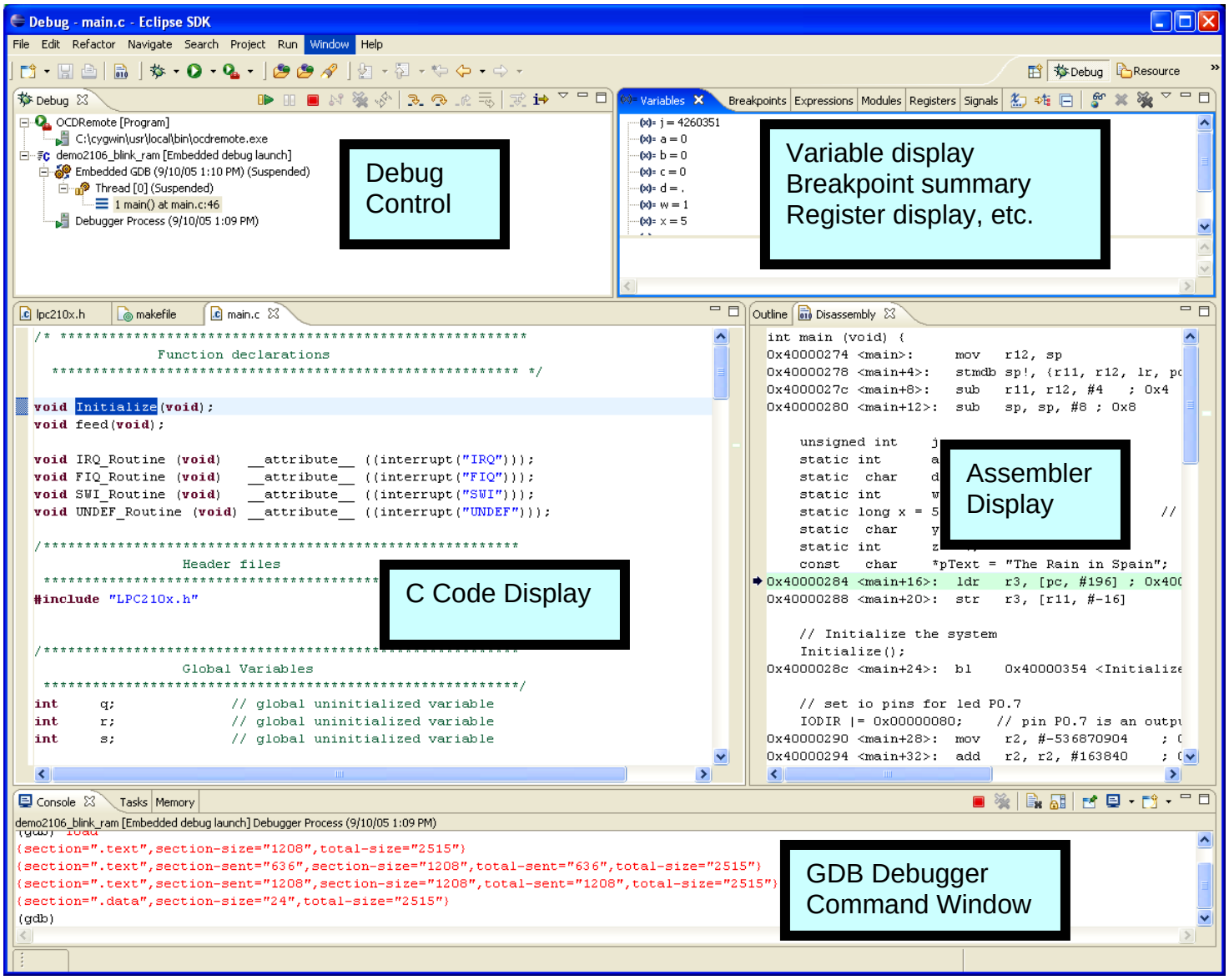
The application will start, run all of our ARM initialization code and stop at the start of **main()**. Note that in the Debug view, the **Thread[0]** is suspended at line 46 of main. With embedded cross development, we only have one execution thread. Code targeted for the PC platform can have multiple threads of execution.

Run to Main() stopped here



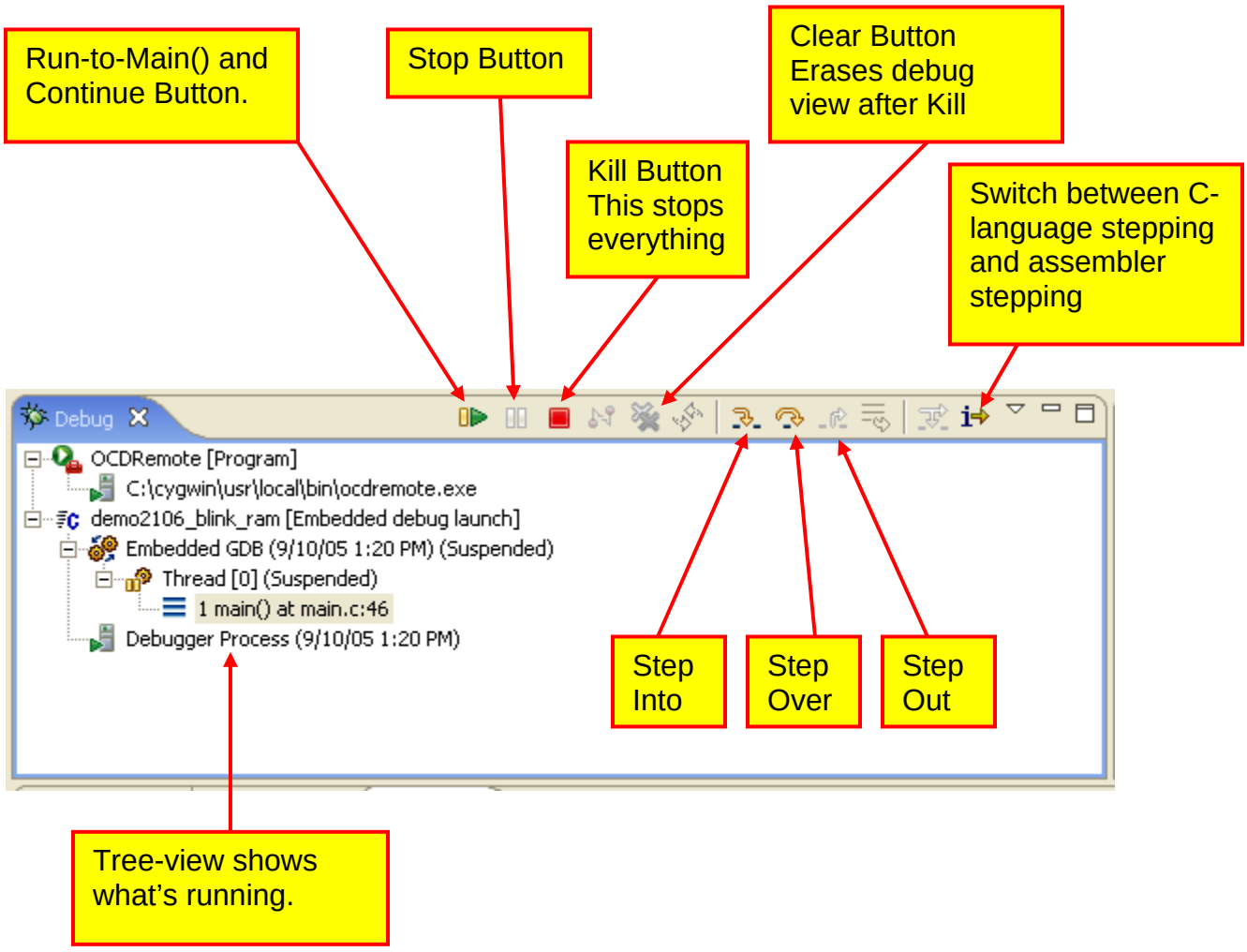
H. Components of the DEBUG Perspective

Before operating the Eclipse debugger, let's review the components of the Debug perspective.



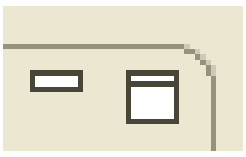
I. Debug Control

The Debug view should be on display at all times. It has the **Run**, **Stop** and **Step** buttons. The tree-structured display shows what is running; in this case it's the **OCDRemote** utility and our application, shown as **Thread[0]**.



Notes: When you resume execution by clicking on the **Run/Continue** button, many of the buttons are "grayed out." Click on "**Thread[0]**" to highlight it and the buttons will re-appear. This is due to the possibility of multiple threads running simultaneously and you must choose which thread to pause or step. In our ARM development system, we only have one thread.

All of these views, such as the Debug Control view above, can be maximized to full-screen, minimized or returned to multi-pane by the "maximize" and "minimize" buttons at the upper right corner.

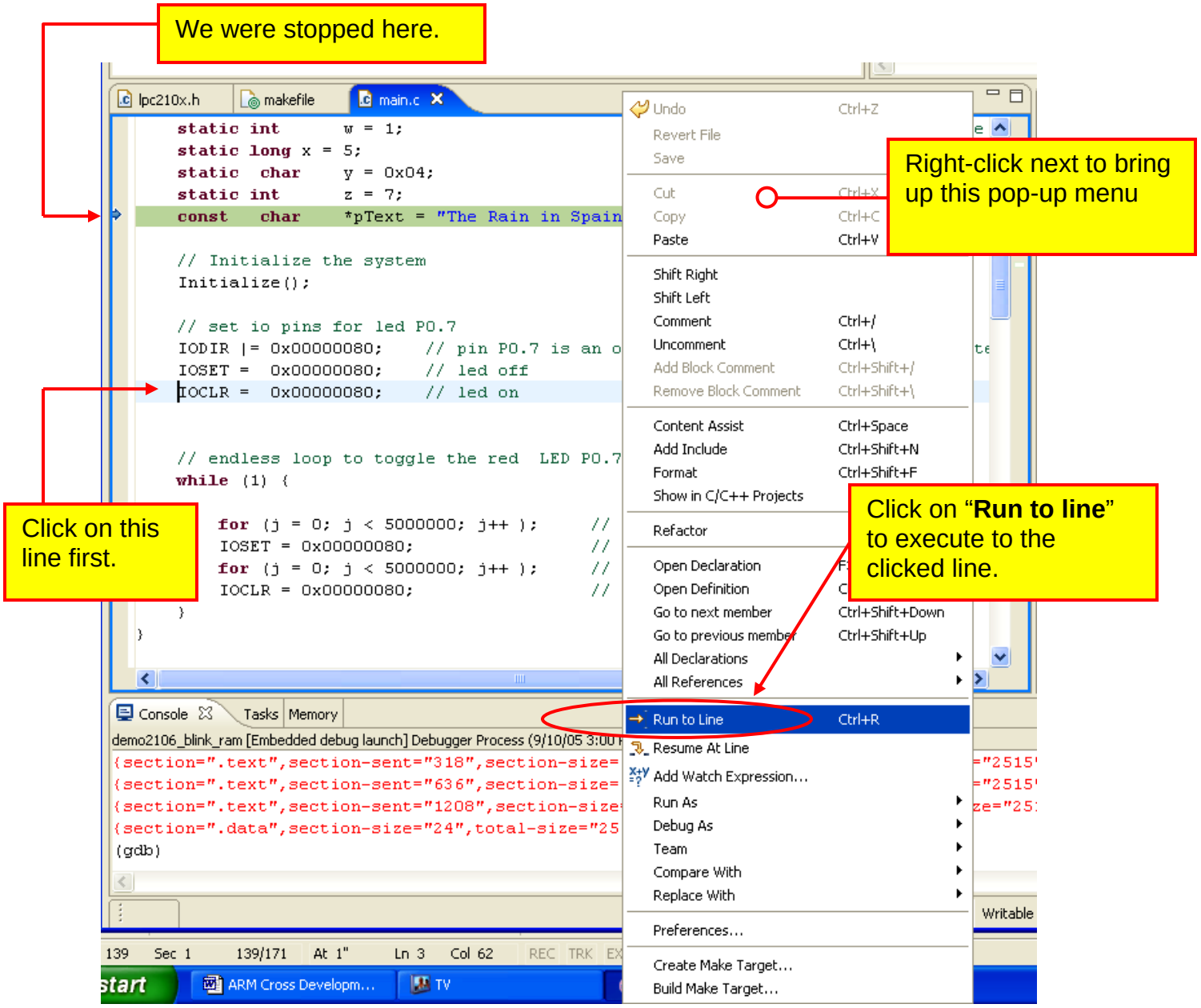


J. Run and Stop with the Right-Click Menu

The easiest method of running is to employ the right-click menu. In the example below, the blue arrowhead cursor indicates where the program is currently stopped.

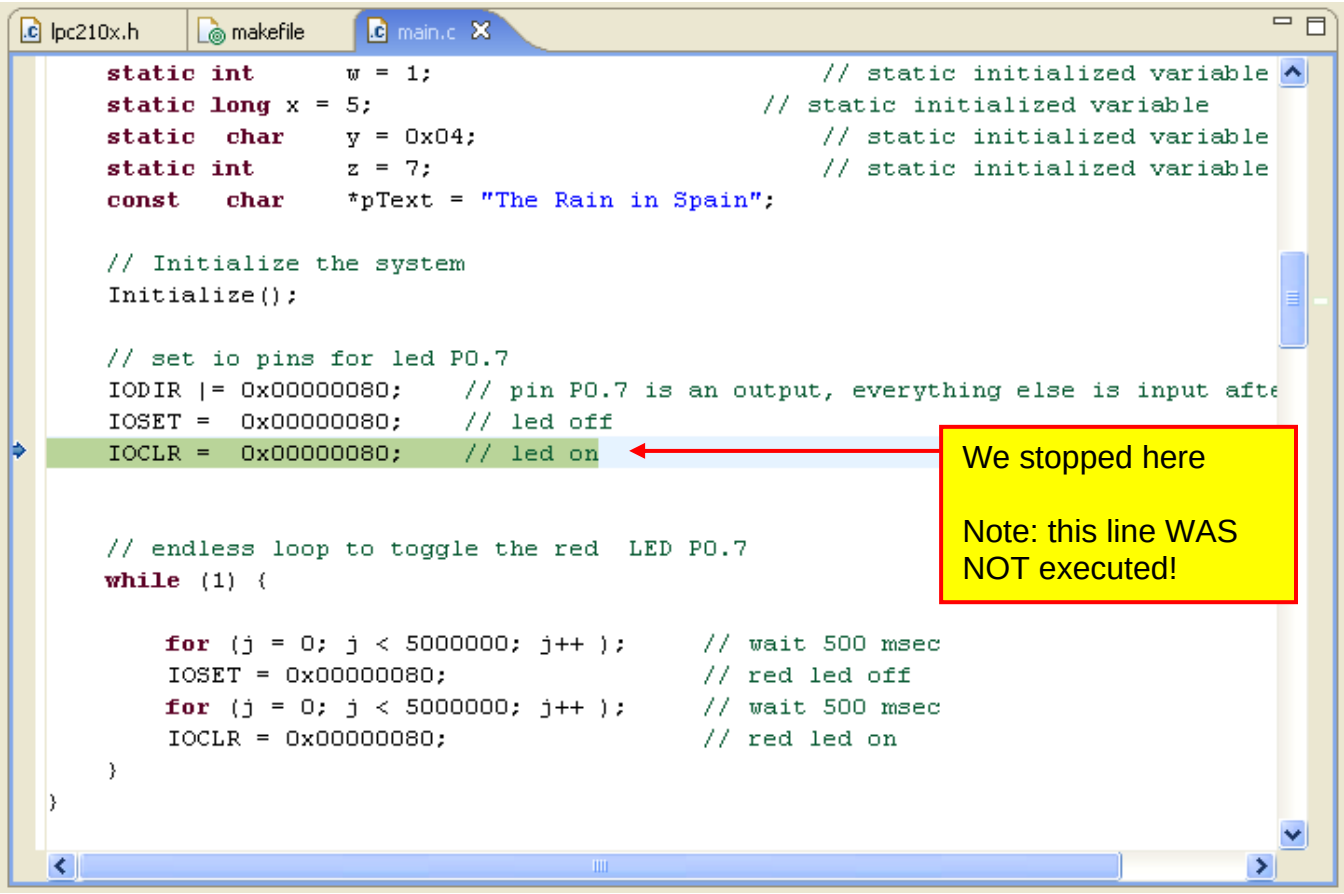
To go to the **IOCLR = 0x00000080;** statement several lines away, click on the line where you want to go (this should highlight the line and place the cursor there).

Now **right click** on that line. Notice that the rather large pop-up menu has a "**Run to Line**" option.



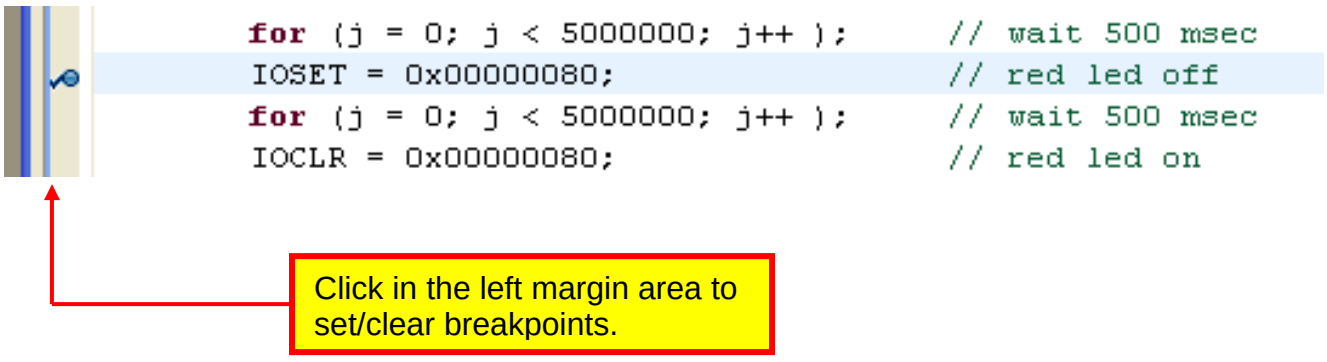
When you click on the "**Run to line**" choice, the program will execute to the line the cursor resides on and then stop (N.B. it will not execute the line).

You can right-click the "**Resume at Line**" choice to continue execution from that point. If there are no other breakpoints set, then the Blink application will start blinking continuously.



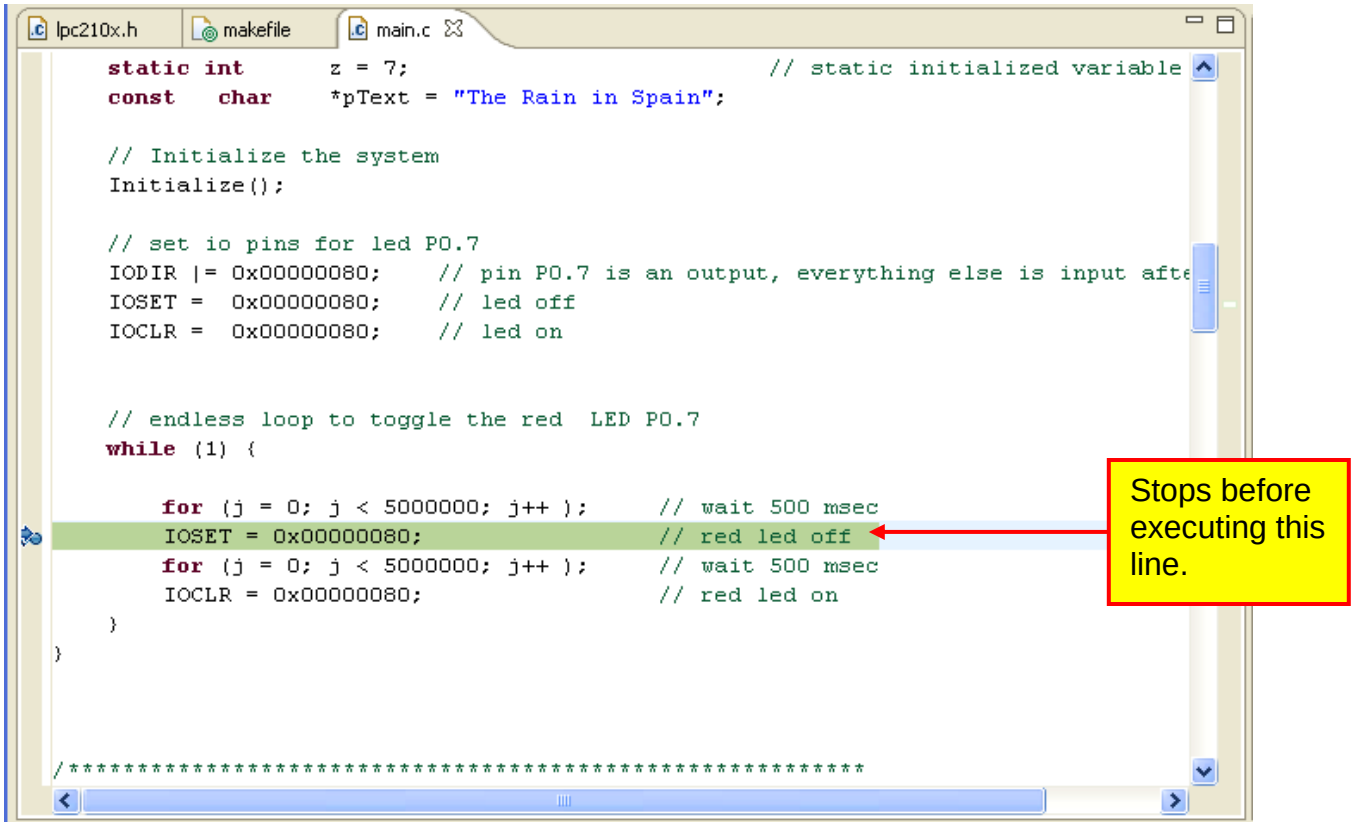
K. Setting a Breakpoint

Setting a breakpoint is very simple; just double-click on the far left edge of the line. Double-clicking on the same spot will remove it.



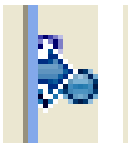
Now click on the “**Run/Continue**” button in the Debug view. 

Assuming that this is the only breakpoint set, the program will execute to the breakpoint line and stop.

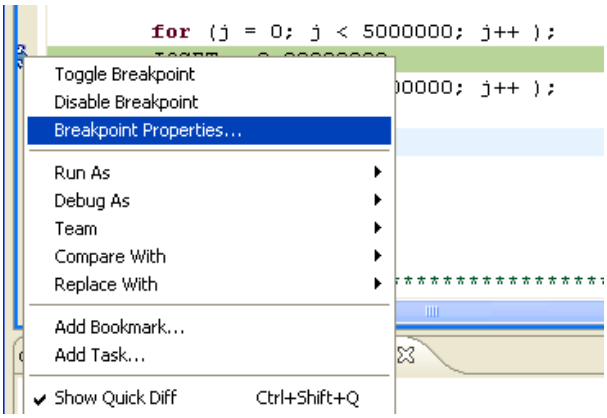


Since this is a RAM application and breakpoints are “software” breakpoints, there can be a nearly unlimited number of breakpoints set.

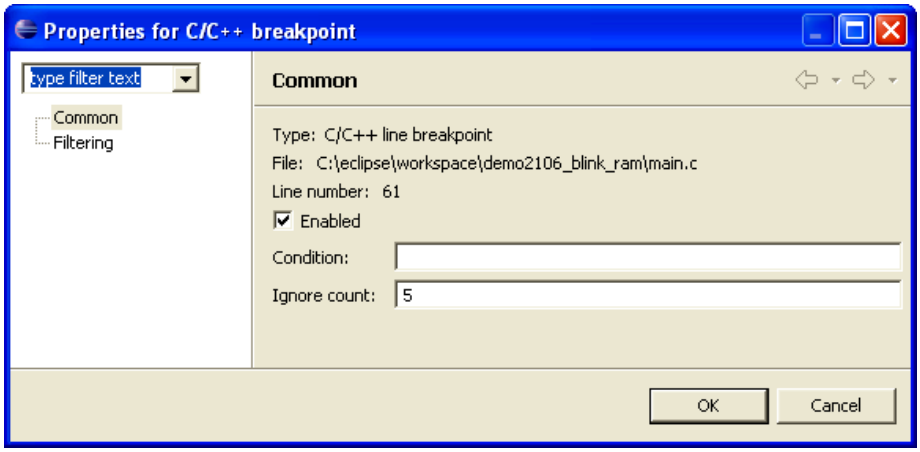
The breakpoints can be more complex. For example, to ignore the breakpoint 5 times and then stop, right-click on the breakpoint on the far left.

 symbol

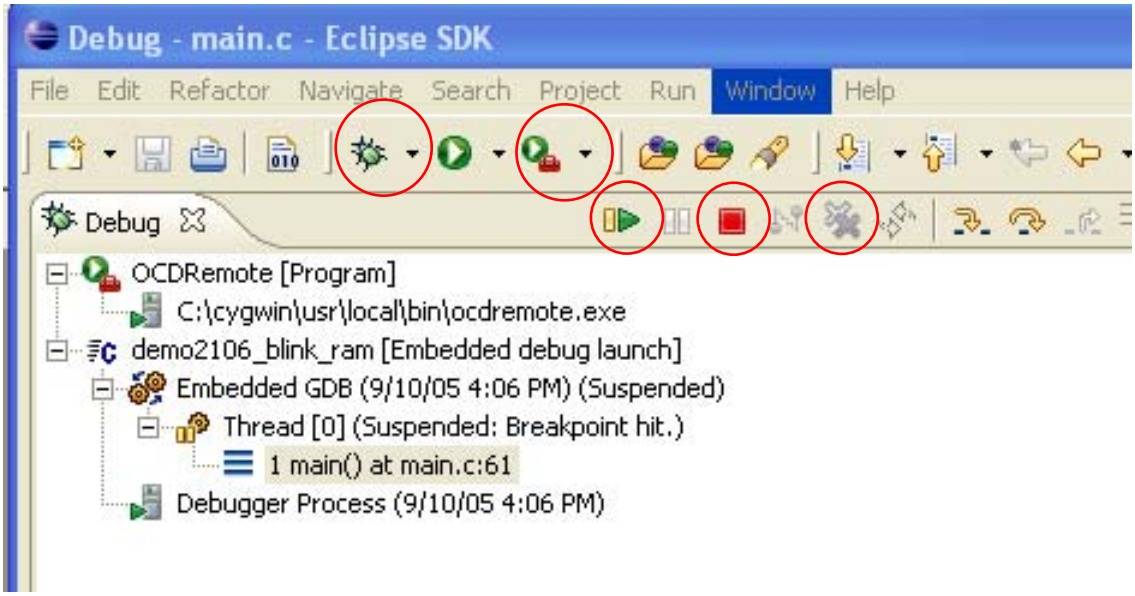
This brings up the pop-up menu below and click on “**Breakpoint Properties …**”.



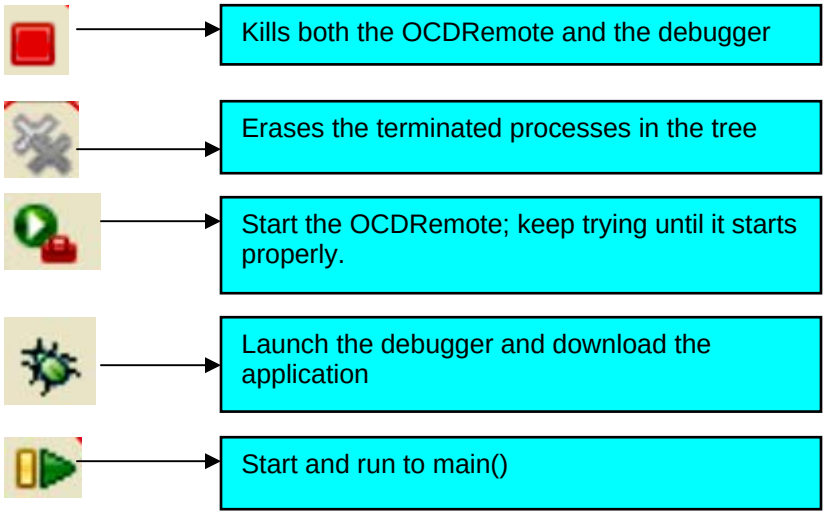
In the “**Properties for C/C++ breakpoint**” window, set the **Ignore Count** to 5. This means that the debugger will ignore the first five times it encounters the breakpoint and then stop.



To test this setup, we must terminate and re-launch the debugger.



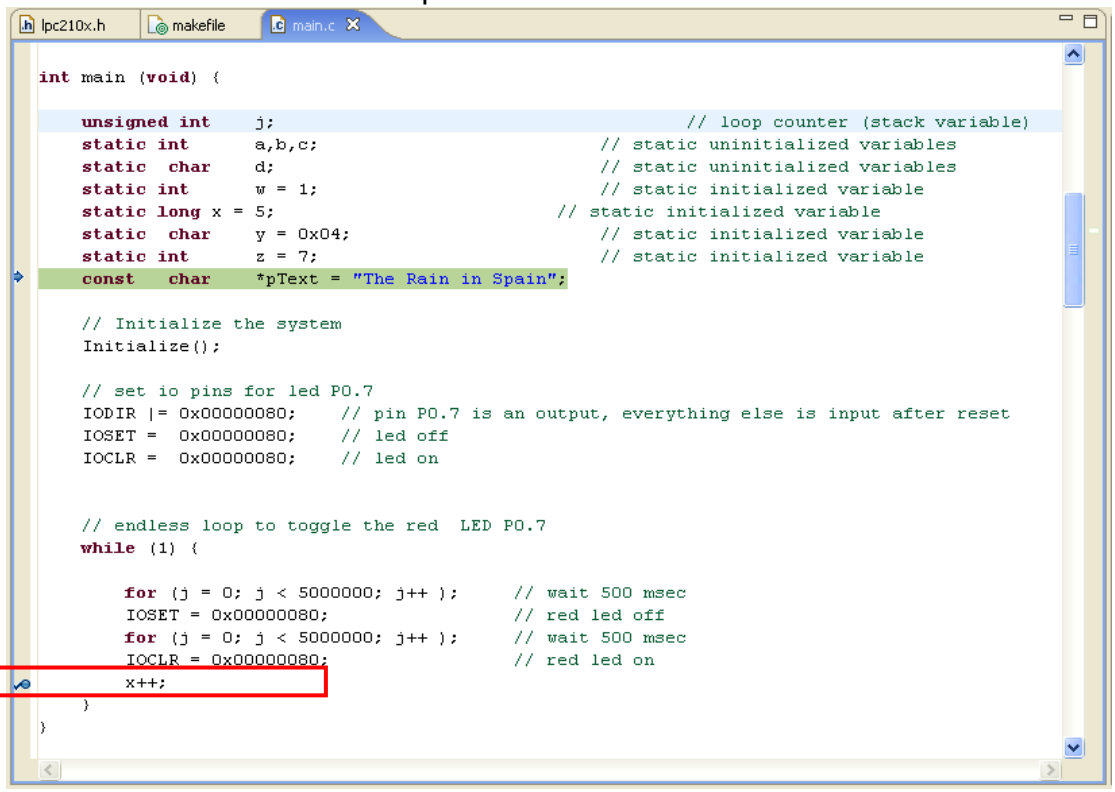
Get used to this sequence:



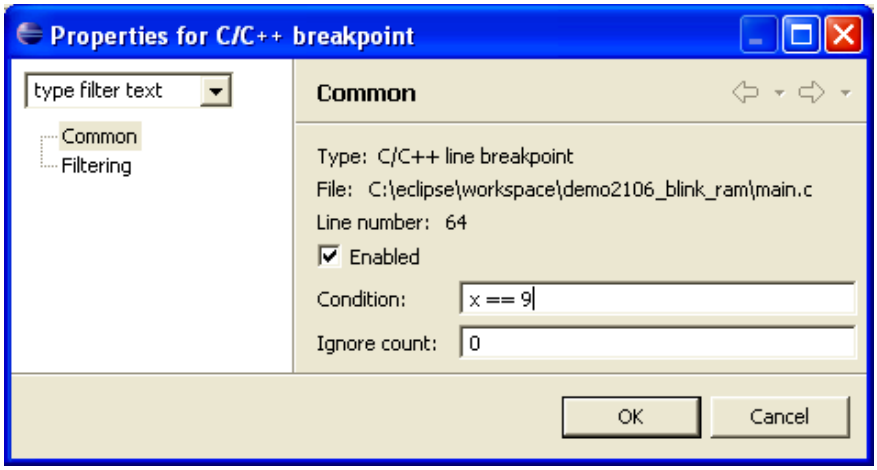
Now when you hit the **Run/Continue** button again, the program will blink 5 times and stop. Don't expect this feature to run in real-time. Each time the breakpoint is encountered the debugger will automatically continue until the "ignore" count is reached. This involves quite a bit of debugger communication at a very slow baud rate.

In addition to specifying a "ignore" count, the breakpoint can be made **conditional** on an expression. The general idea is that you set a breakpoint and then specify a conditional expression that must be met before the debugger will stop on the specified source line.

In this example, a line has been added to the blink loop that increments a variable "x". Double-click on that line to set a breakpoint.



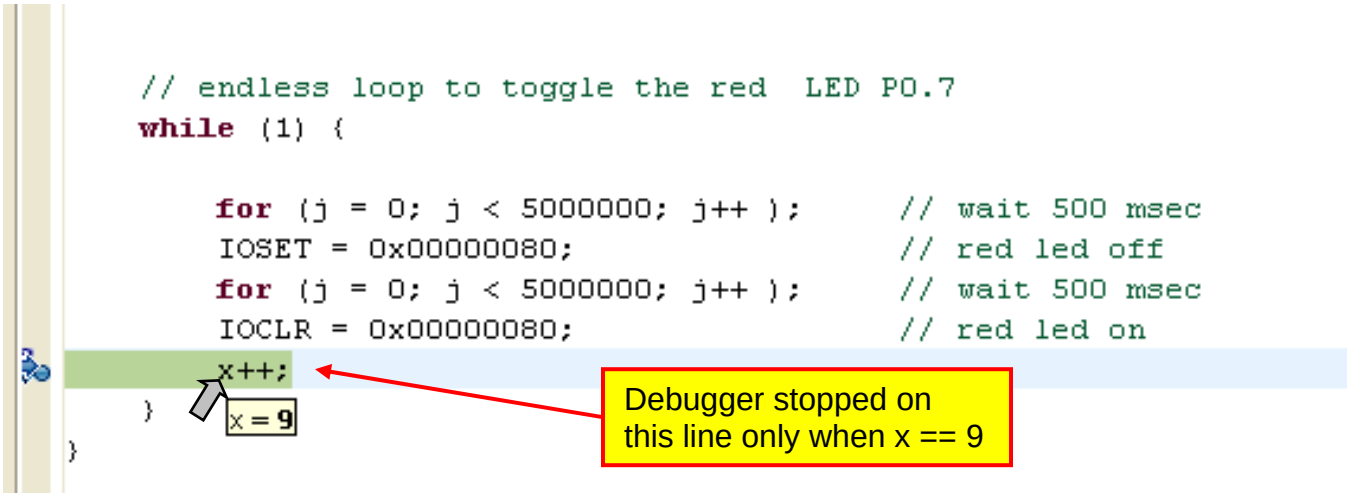
Right click on the breakpoint symbol and select "**Breakpoint Properties**". In the Breakpoint Properties window, set the condition text box to "**x == 9**".



A nice feature of Eclipse debugging is that you can edit the source file within the debugger and rebuild the application without leaving the debugger. Of course, you need to **kill the OCDRemote and the Debugger and restart the download** after the build; as specified

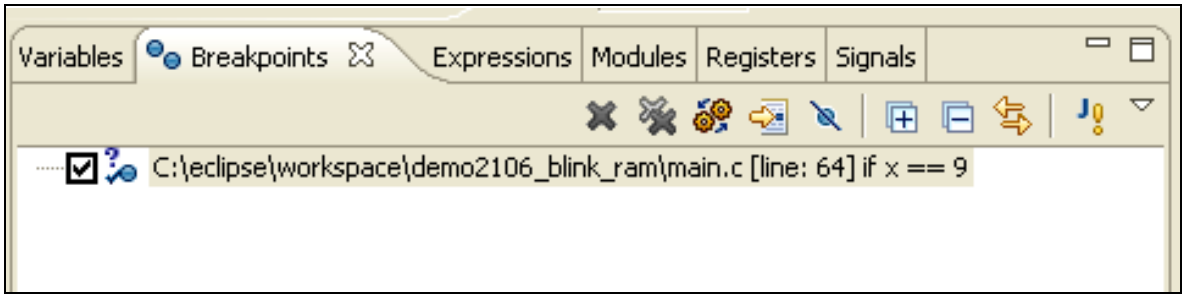
above. This is necessary for this release of **CDT** because the "**Restart**" button appears inoperative. The advantage is that you don't have to change the Eclipse perspective – just stay in the Debug perspective.

Start the application and it will stop on the breakpoint line (this will take a long time, 9 seconds on my Dell computer). If you park the cursor over the variable x after the program has suspended on the breakpoint, it will display that the current value is 9.



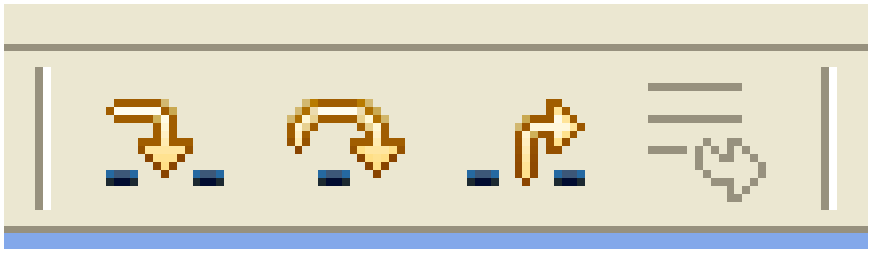
If you specify that it should break when x == 50000, you will essentially wait forever. The way this works, the debugger breaks on the selected source line every pass through that source line and then queries via JTAG for the current value of the variable x. When x==50000, the debugger will stop. Obviously, that requires a lot of serial communication at a very slow baud rate. Still, you may find some use for this feature.

In the Breakpoint Summary view, shown directly below, you can see all the breakpoints you have created and the right-click menu lets you change the properties, remove or disable any of the breakpoints, etc. The example below shows one conditional breakpoint that will stop on source line 64 only if the variable **x** is equal to 9.



L. Single Stepping

Single-stepping is the single most useful feature in any debugging environment. The debug view has three buttons to support this.



Step Into Step Over Step Out Of

Step Into

If the cursor is at a function call, this will step **into** the function. It will stop at the first instruction inside the function.

If cursor is on any other line, this will execute one instruction.

Step Over

If the cursor is at a function call, this will step **over** the function. It will execute the entire function and stop on the next instruction after the function call.

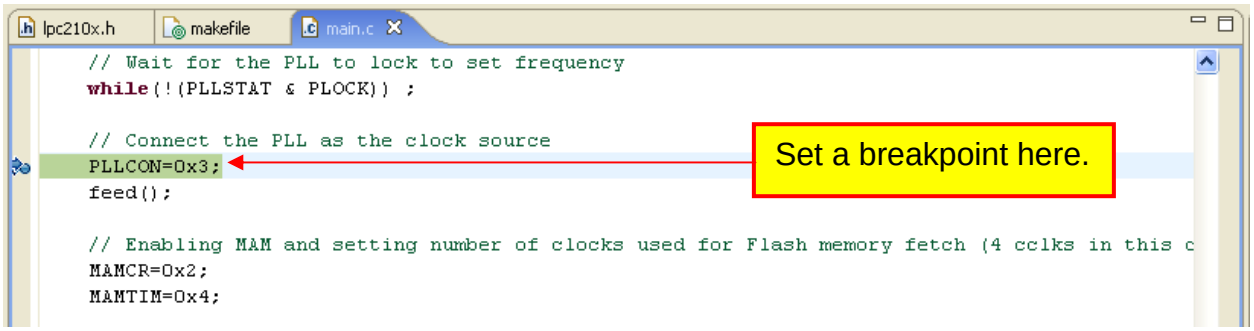
If cursor is on any other line, this will execute one instruction

Step Out Of

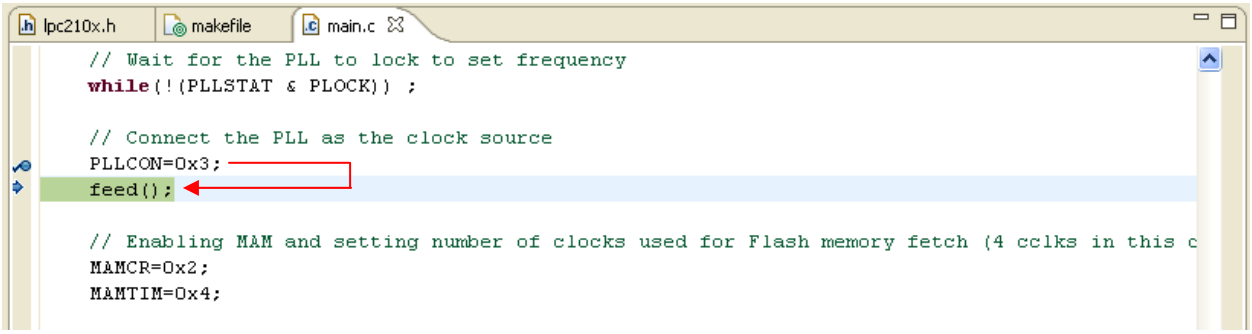
If the cursor is within a function, this will execute the remaining instructions in the function and stop on the next instruction after the function call.

This button will be “grayed-out” if cursor is not within a function.

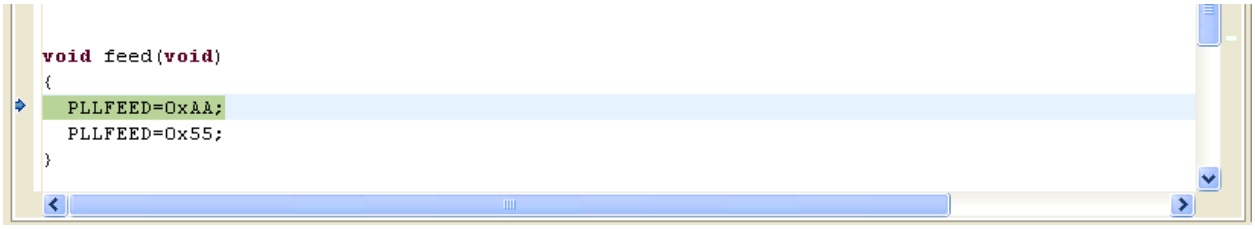
As a simple example, restart the debugger and set a breakpoint on a line in the **Initialize()** function. Hit the **Start** button to go to that breakpoint.



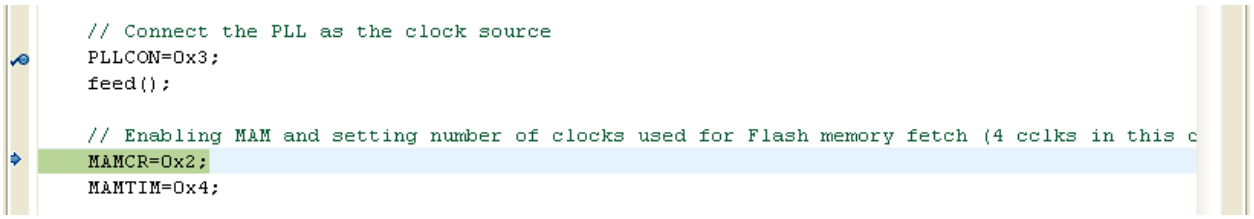
Click the "**Step Over**" button  The debugger will execute one instruction.



Click the "**Step Into**" button  The debugger will enter the feed() function.



Notice that the "**Step Out Of**" button is illuminated. Click the "**Step Out Of**" button The debugger will execute the remaining instructions in feed() and return to just after the function call.

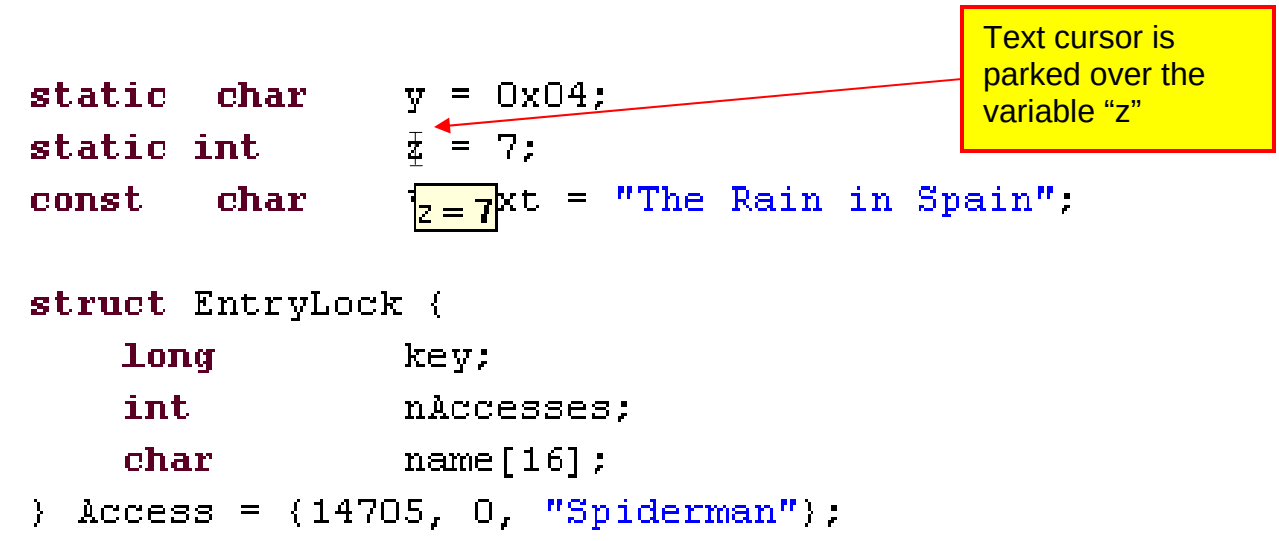


M. Inspecting and Modifying Variables

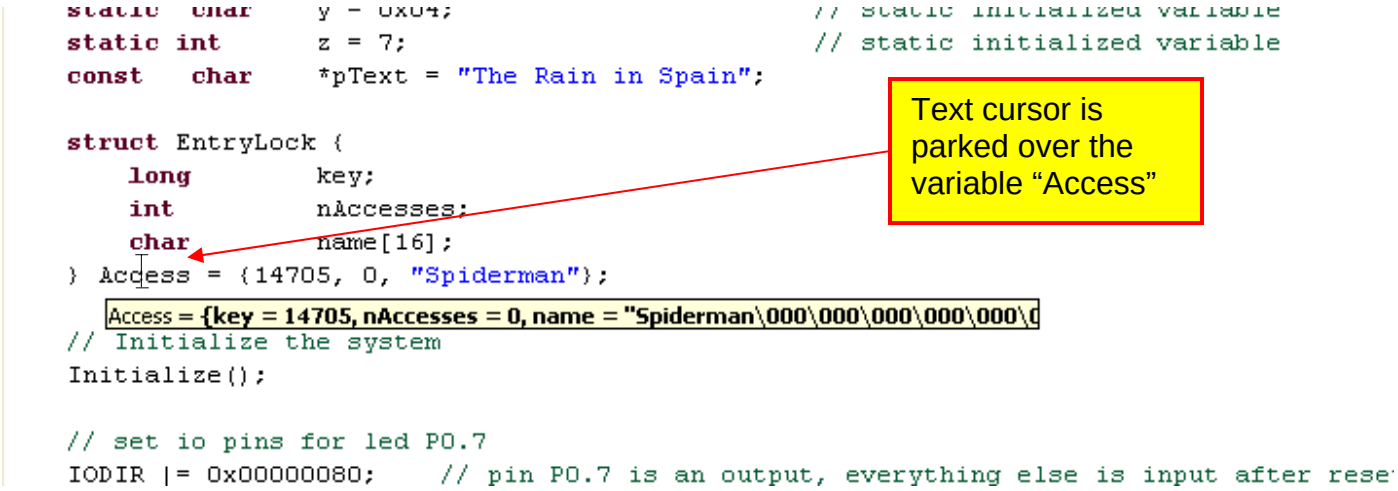
Before proceeding on this topic, let's add a couple of structured variables to the simple blinker test program. After rebuilding the application and re-launching the debugger, we can inspect variables once a breakpoint has been encountered.

```
/* ********************************************************
                Function declarations
  ******************************************************** */

void Initialize(void);
void feed(void);

void IRQ_Routine (void)   __attribute__ ((interrupt("IRQ")));
void FIQ_Routine (void)   __attribute__ ((interrupt("FIQ")));
void SWI_Routine (void)   __attribute__ ((interrupt("SWI")));
void UNDEF_Routine (void) __attribute__ ((interrupt("UNDEF")));

/*********************************************************
                  Header files
 *********************************************************/
#include "LPC210x.h"


/*********************************************************
                  Global Variables
 *********************************************************/
int     q;              // global uninitialized variable
int     r;              // global uninitialized variable
int     s;              // global uninitialized variable

short   h = 2;          // global initialized variable
short   i = 3;          // global initialized variable
char    j = 6;          // global initialized variable

struct comms {
    int     nbytes;
    char*   pBuf;
    char    buffer[32];
} channel = {5, &channel.buffer[0], {"Faster than a speeding bullet"}};

/*********************************************************
                      MAIN
*********************************************************/

int main (void) {

    unsigned int    j;                              // loop counter (stack variable)
    static int      a,b,c;                          // static uninitialized variables
    static  char    d;                              // static uninitialized variables
    static int      w = 1;                          // static initialized variable
    static long     x = 5;                          // static initialized variable
    static  char    y = 0x04;                       // static initialized variable
    static int      z = 7;                          // static initialized variable
    const   char    *pText = "The Rain in Spain";

    struct EntryLock {
        long        key;
        int         nAccesses;
        char        name[16];
    } Access = {14705, 0, "Spiderman"};

    // Initialize the system
    Initialize();

    // set io pins for led P0.7
    IODIR |= 0x00000080;    // pin P0.7 is an output, everything else is input after reset
    IOSET =  0x00000080;    // led off
    IOCLR =  0x00000080;    // led on

    // endless loop to toggle the red  LED P0.7
    while (1) {

        for (j = 0; j < 5000000; j++ );     // wait 500 msec
        IOSET = 0x00000080;                 // red led off
        for (j = 0; j < 5000000; j++ );     // wait 500 msec
        IOCLR = 0x00000080;                 // red led on
        x = x + 1;
    }
}
```

The simple way to inspect variables is to just park the cursor over the variable name in the source window; the current value will pop up in a tiny text box. Execution must be stopped for this to work; either by breakpoint or pause.

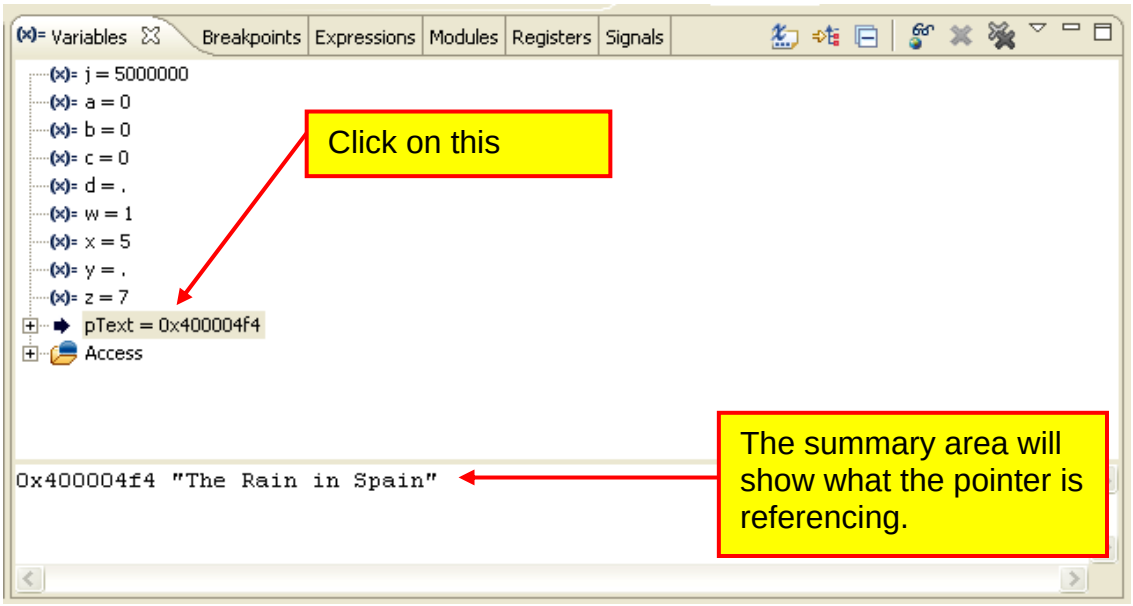


For a structured variable, parking the cursor over the variable name will show the values of all the internal component parts.

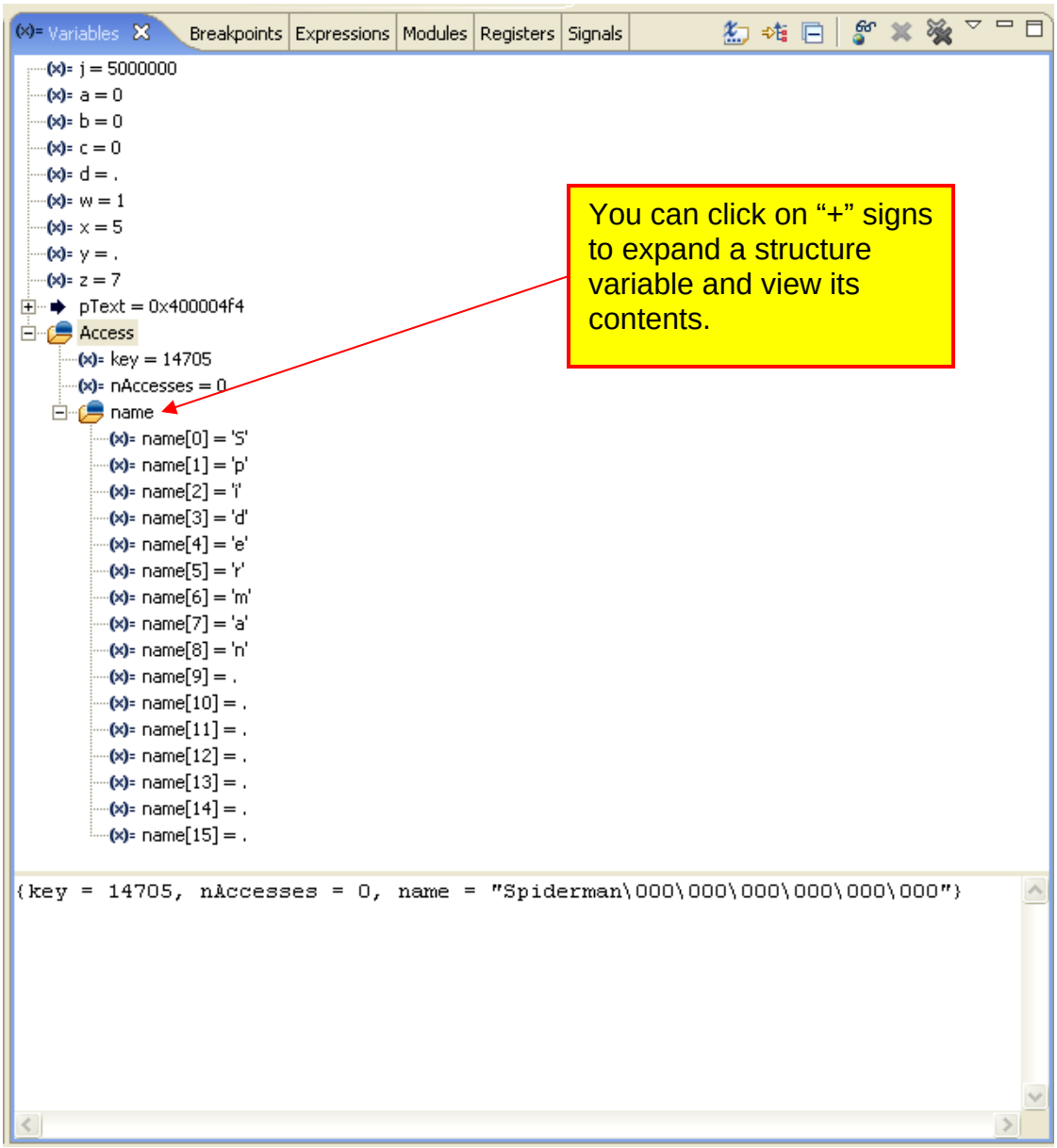


Another way to look at the local variables is to inspect the “**Variables**” view. This will automatically display all automatic variables in the current stack frame. It can also display any global variables that you choose. For simple scalar variables, the value is printed next to the variable name.

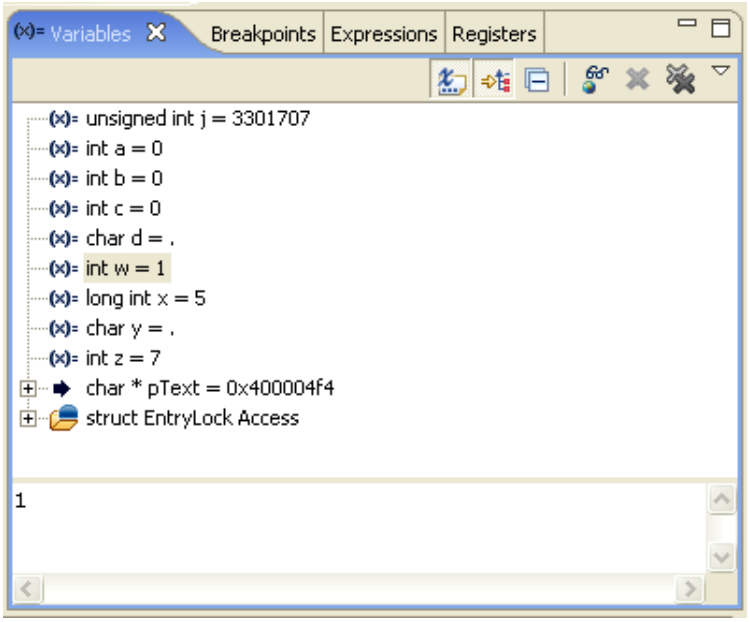
If you click on a variable, its value appears in the summary area at the bottom. This is handy for a structured variable or a pointer; wherein the debugger will expand the variable in the summary area.



The Variables view can also expand structures. Just click on any “+” signs you see to expand the structure and view its contents.



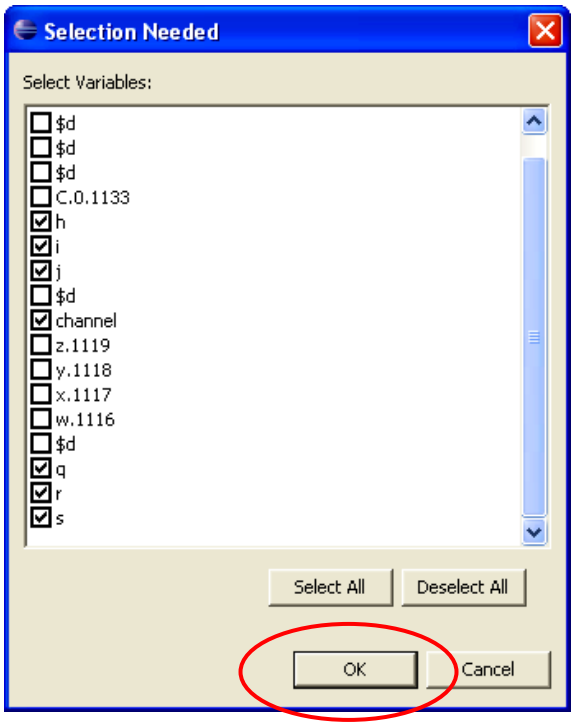
If you click on the “Show Type Names” button,  each variable name will be displayed with its type, as shown below.



Global variables have to be individually selected for display within the “Variables” view.

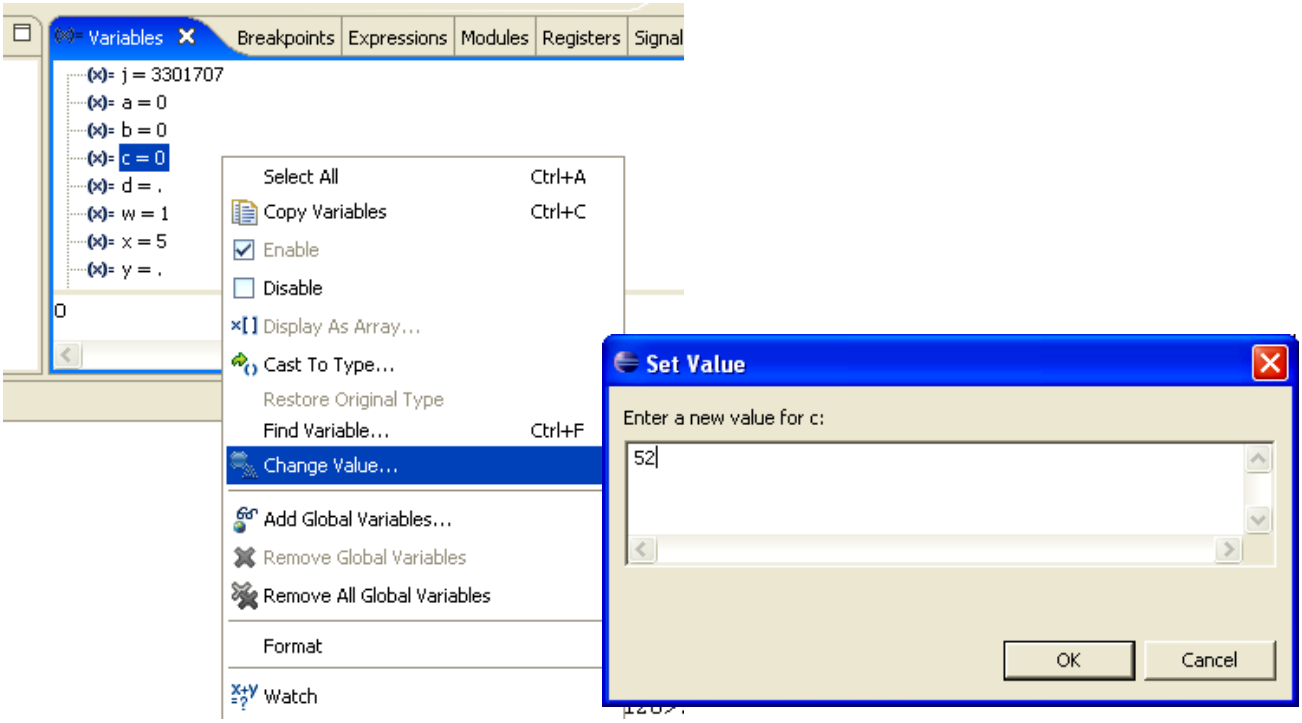
Use the “Add Global Variables” button  to open the selection dialog.

Check the variables you want to display and then click “**OK**” add them to the **Variables** view,

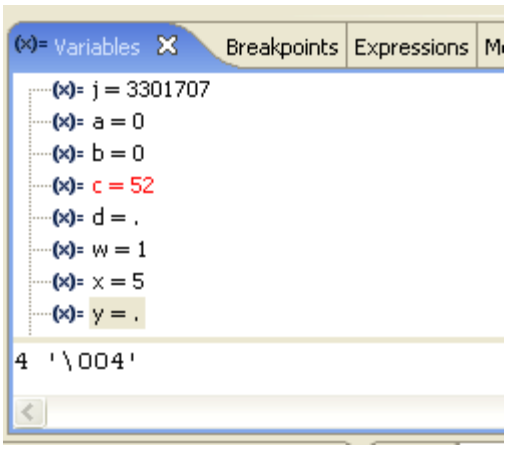


Note: not sure what the extra variables are. Might be a CDT bug?

You can easily change the value of a variable at any time. Assuming that the debugger has stopped, click on the variable you wish to change and right click. In the right-click menu, select "**Change Value…**" and enter the new value into the pop-up window as shown below. In this example, we change the variable "c" to 52.



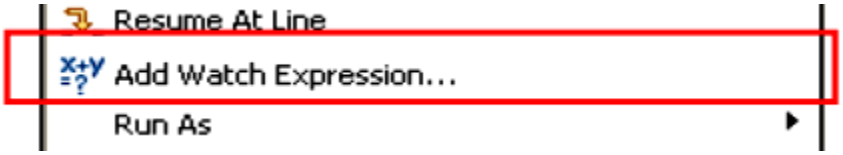
Now the "**Variables**" view should show the new value for the variable "c". Note that it has been colored red to indicate that it has been changed.



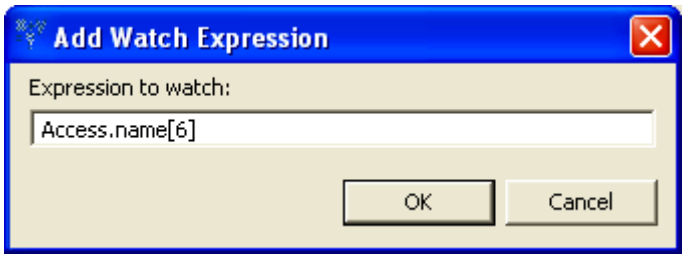
N. Watch Expressions

The “Expressions” view can display the results of expressions (any legal C Language expression). Since it can pick any local or global variable, it forms the basis of a customizable variable display; showing only the information you want.

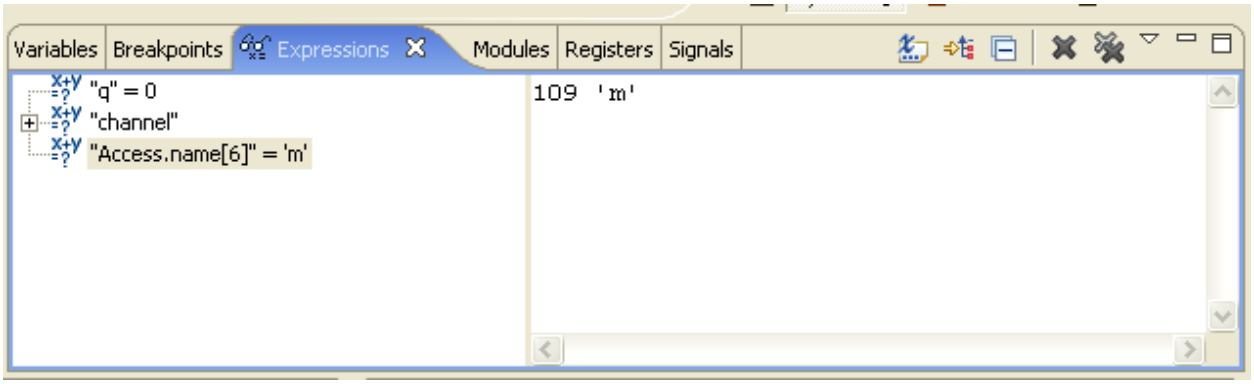
For example, to display the 6th character of the name in the structured variable “**Access**”, bring up the right-click menu and select “**Add Watch Expression…**”.



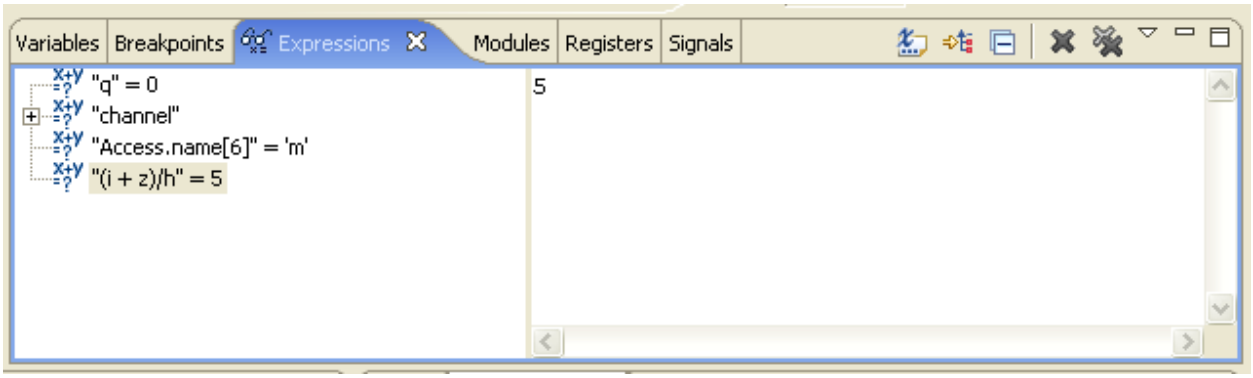
Enter the fully qualified name of the 6th character of the name[] array.



Note that it now appears in the “Expressions” view.



You can type in very complicated expressions. Here we defined the expression (i + z)/h

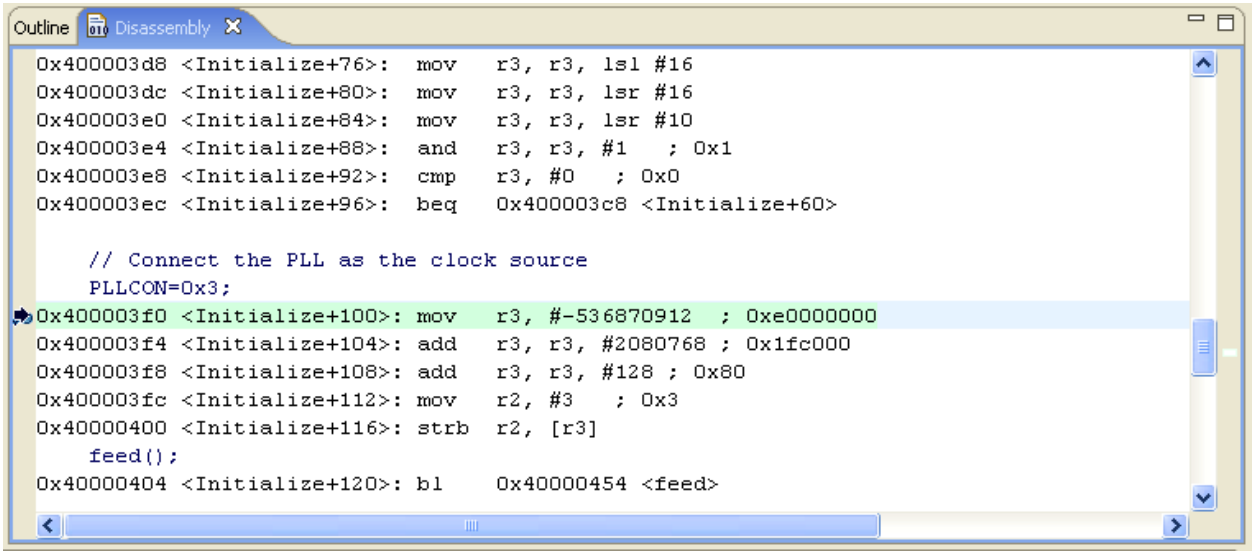


O. Assembly Language Debugging

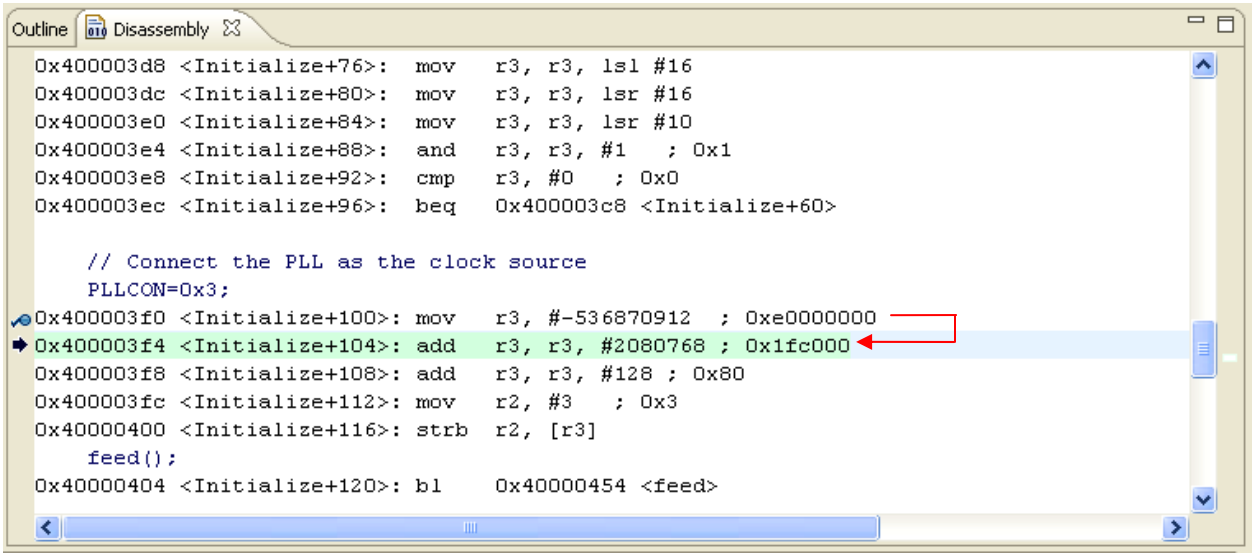
The Debug perspective includes an Assembly Language view.

If you click on the Instruction Stepping Mode toggle button in the Debug view,  the assembly language window becomes active and the single-step buttons apply to the assembler window. The single-step buttons will advance the program by a single assembler instruction. Note that the “Disassembly” tab lights up when the assembler view has control.

Note that the debugger is currently stopped at the assembler line at address 0x400003f0.



If we click the “**Step Over**” button in the Debug view, the debugger will execute one assembler line.

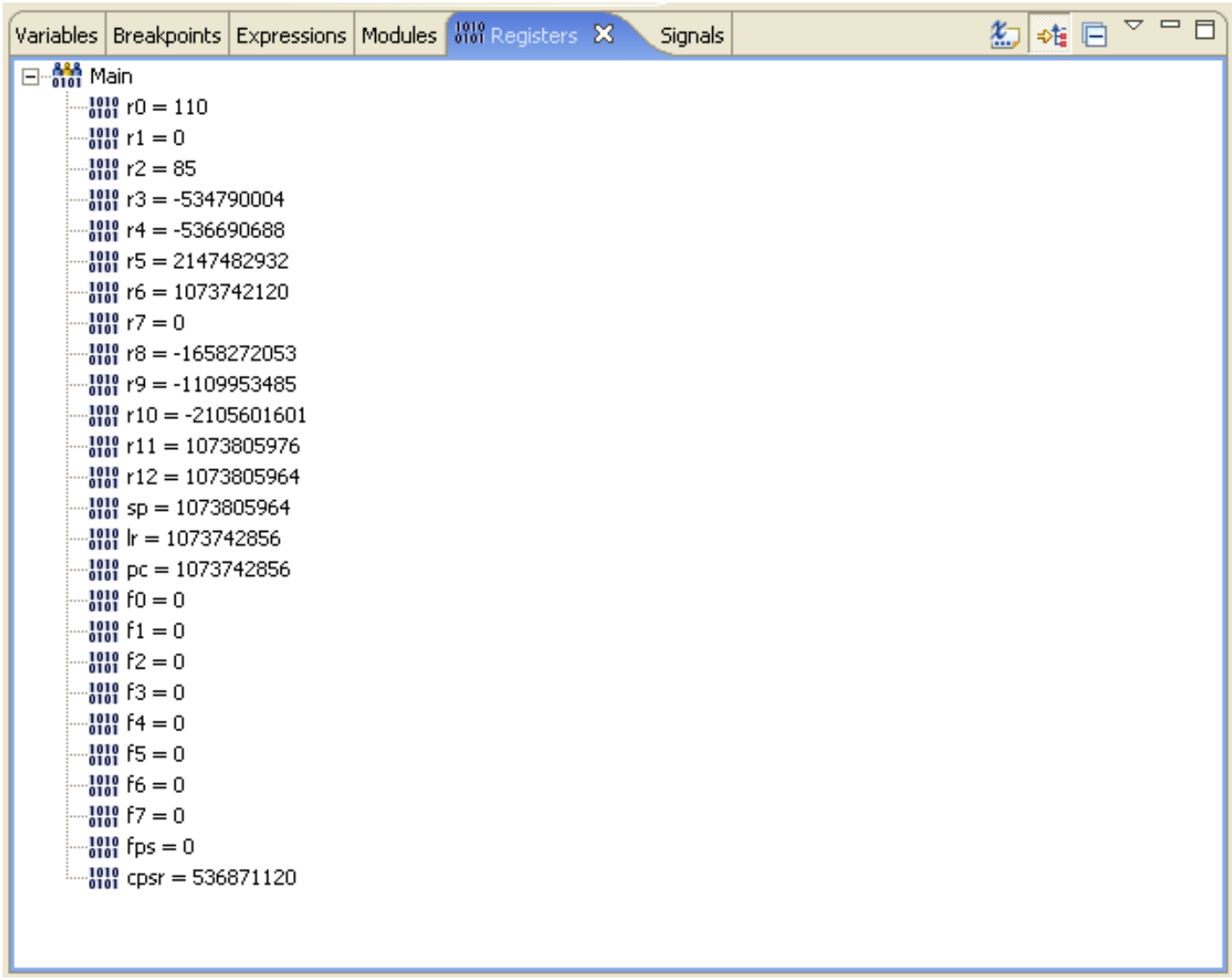


The “**Step Into**” and “**Step Out Of**” buttons work in the same was as for C code.

P. Inspecting Registers

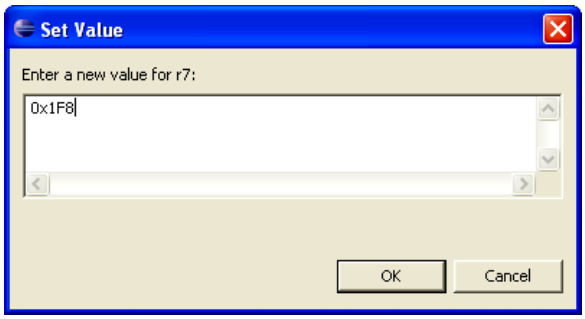
Unfortunately, parking the cursor over a register name (R3 e.g.) does not pop up its current value. For that, you can refer to the “Registers” view.

Click on the “**+**” symbol next to Main and the registers will appear. The Philips LPC2106 doesn’t have any floating point registers so registers F0 through FPS are not applicable.

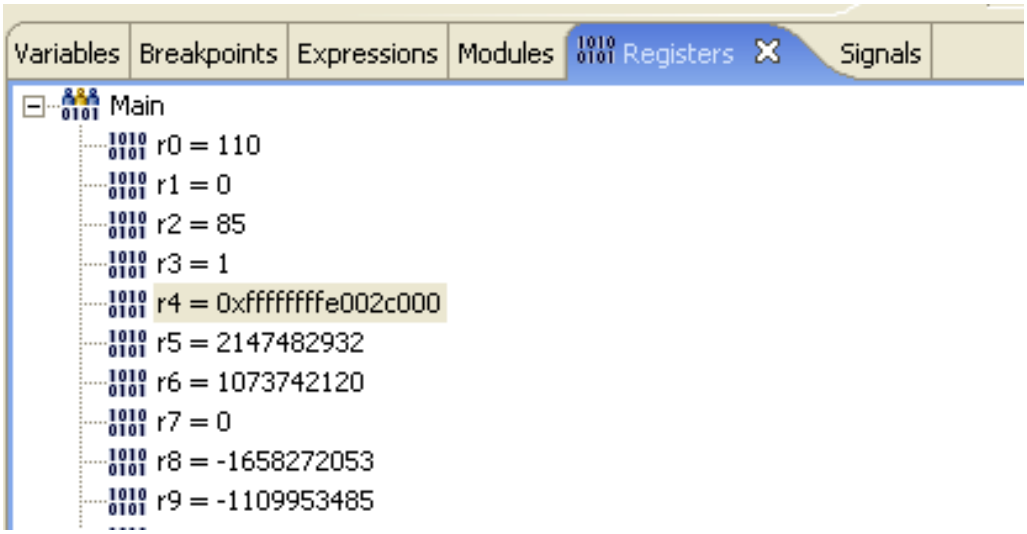


If you don’t like a particular register’s numeric format, you can click to highlight it and then bring up the right-click menu.

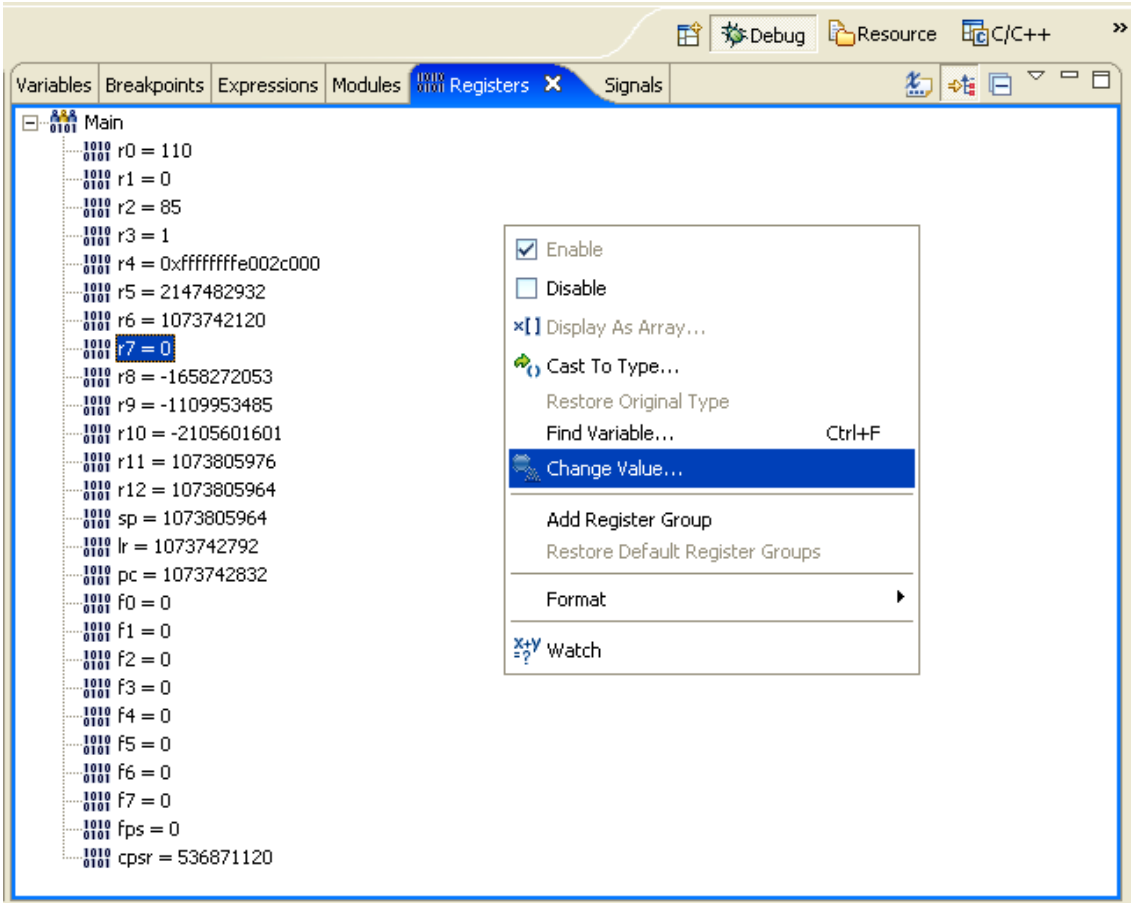
The “**Format**” option permits you to change the numeric format to hexadecimal, for example.



Now the register display shows r4 in hexadecimal format.



Of course, the right click menu lets you change the value of any register. For example, to change **r7** from **zero** to **0x1F8**, just select the register, right-click and select "**Change Value…**"

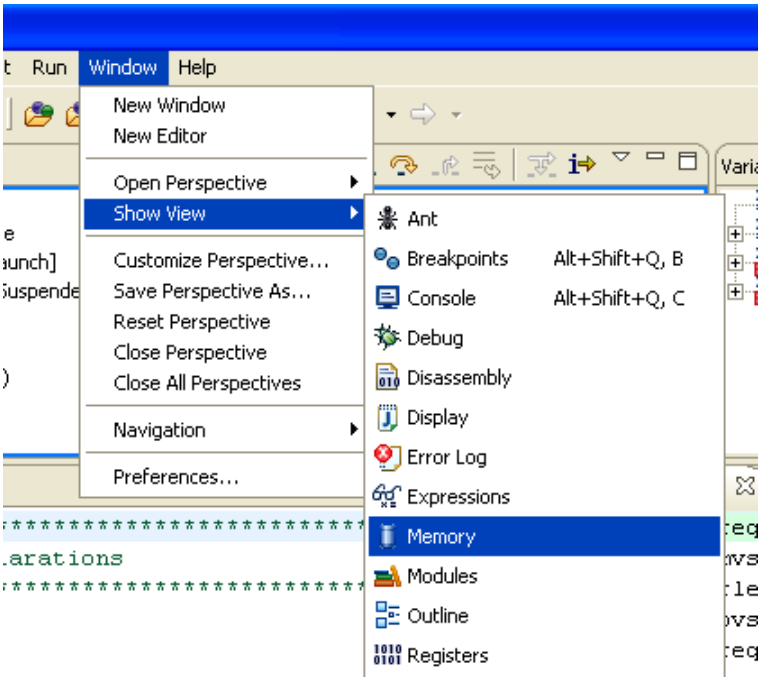


Now the value for **r7** has been changed to **0x1F8**.

It goes without saying that you had better use this feature with great care! Make sure you know what you are doing before tampering with the ARM registers.

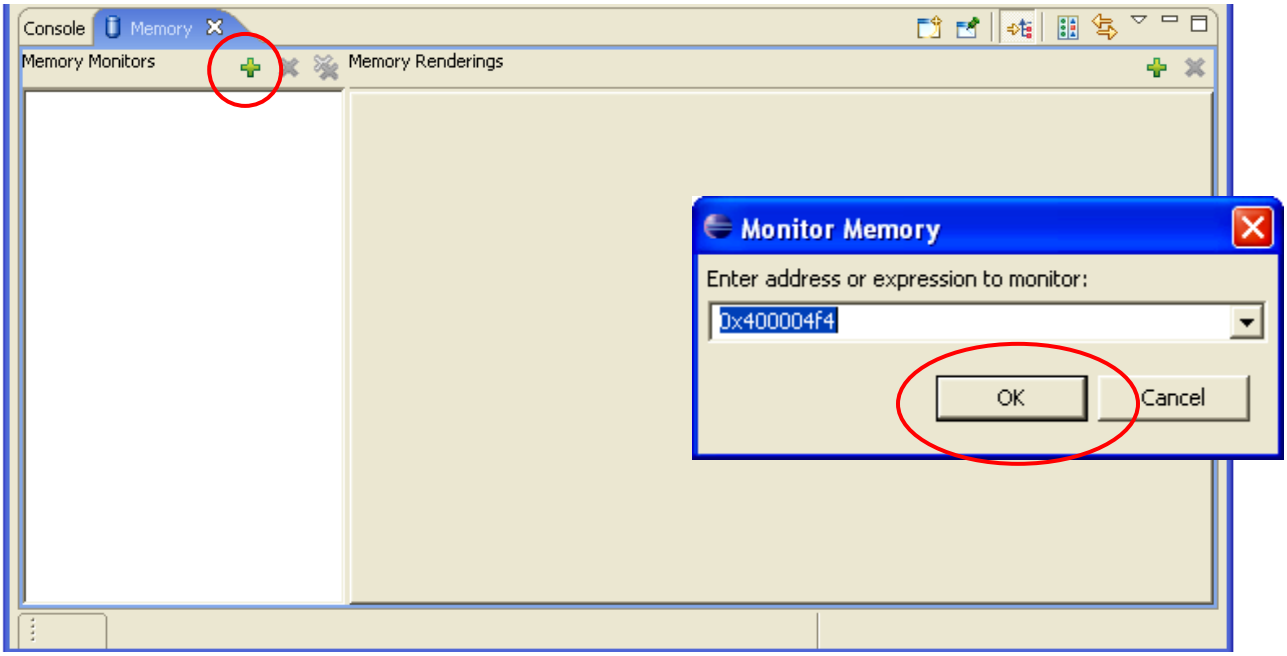
Q. Inspecting Memory

Viewing memory is a bit complex in Eclipse. First, the memory view is not part of the default debug launch configuration. You can add it by clicking "**Window – Show View – Memory**" as shown below.



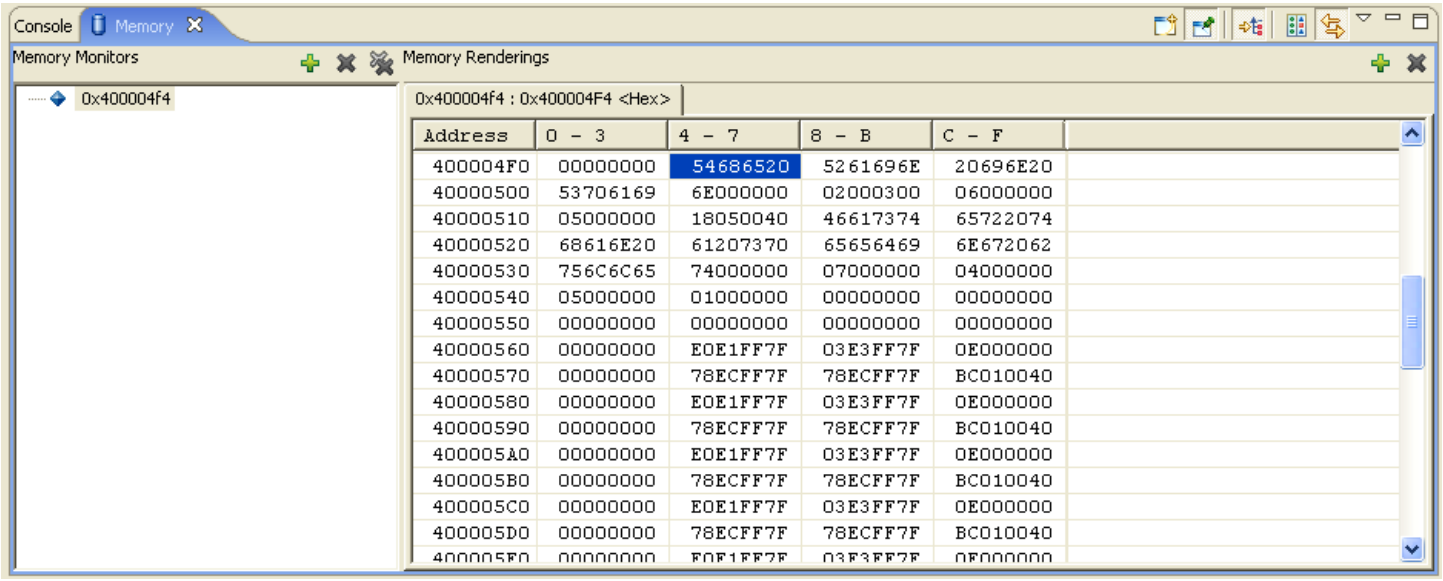
The memory view appears in the "**Console**" view at the bottom of the Debug perspective. At this point, nothing has been defined. Memory is displayed as one or more "**memory monitors**". To create a memory monitor, click on the "**+**" symbol.

Enter the address **0x400004f4** (address of the string “The Rain in Spain”) in the dialog box.



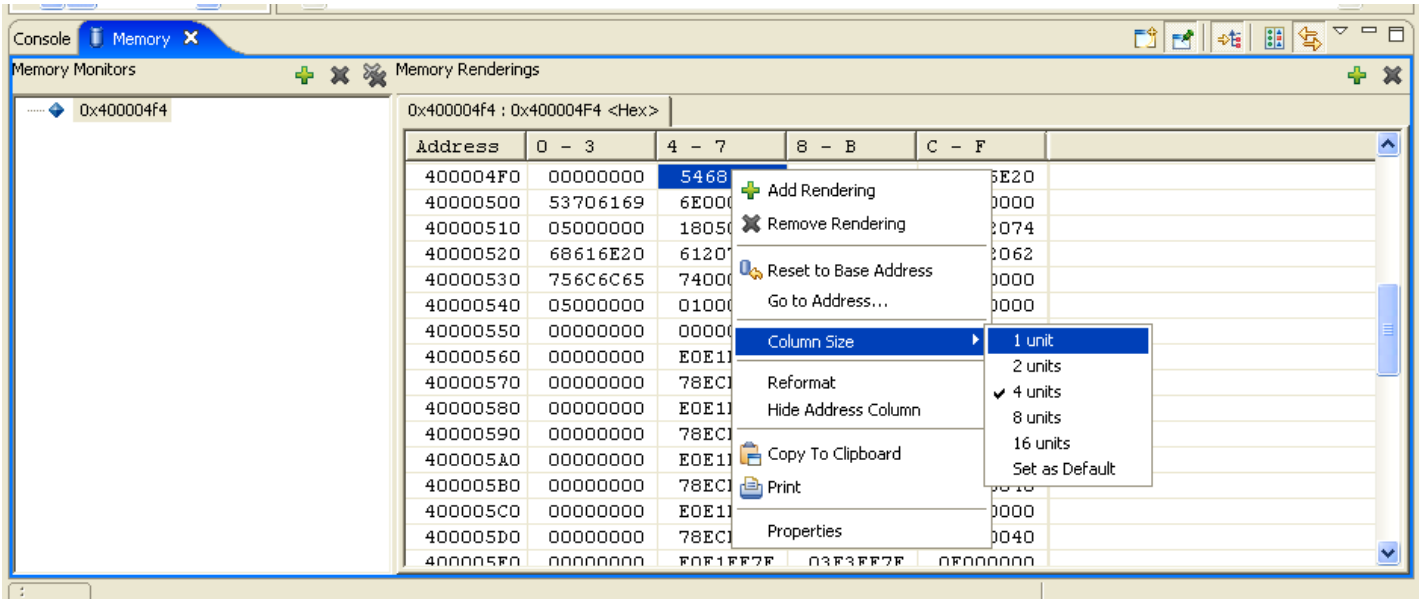
The memory monitor is created, although it defaults to 4-byte display mode. The display of the address columns and the associated memory contents is called a “**Rendering**”.

The address **0x400004F4** is called the Base Address; there’s a right-click menu option “**Reset to Base Address**” that will automatically return you to this address if you scroll the memory display.

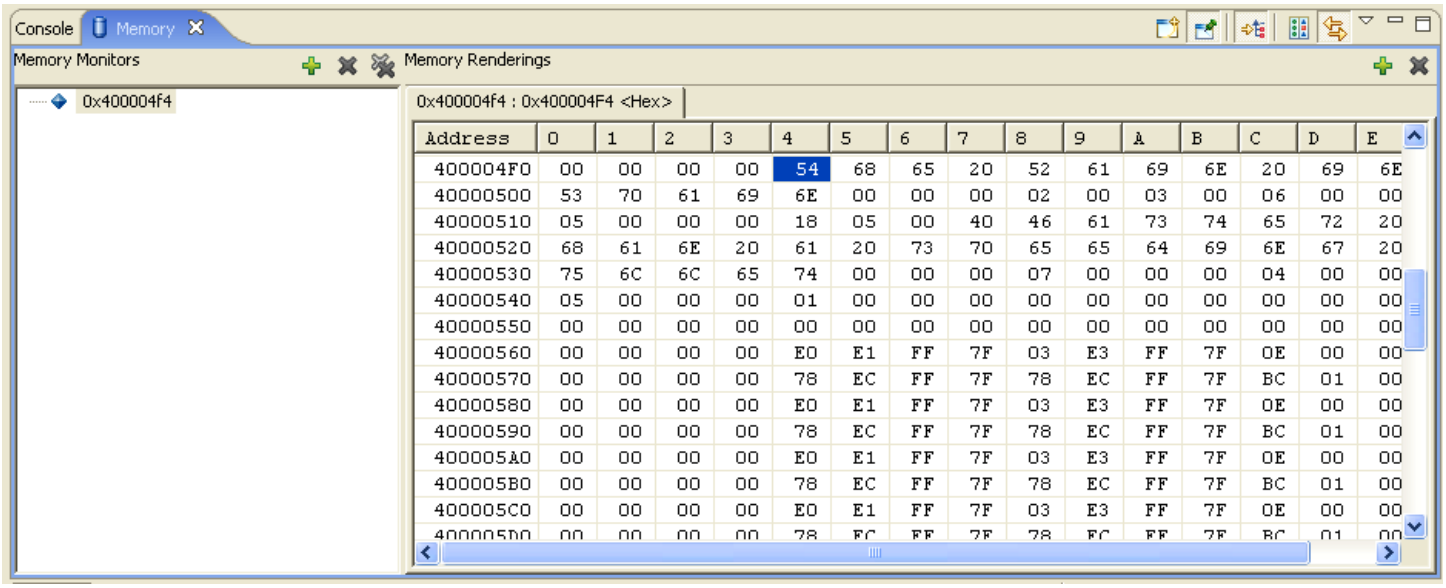


There’s also a “**Go to Address…**” right-click menu option that will jump all over memory for you.

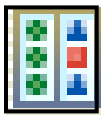
By right-clicking anywhere within the memory rendering (display area), you can select “**Column Size – 1 unit**”.



This will repaint the memory rendering in Byte format.

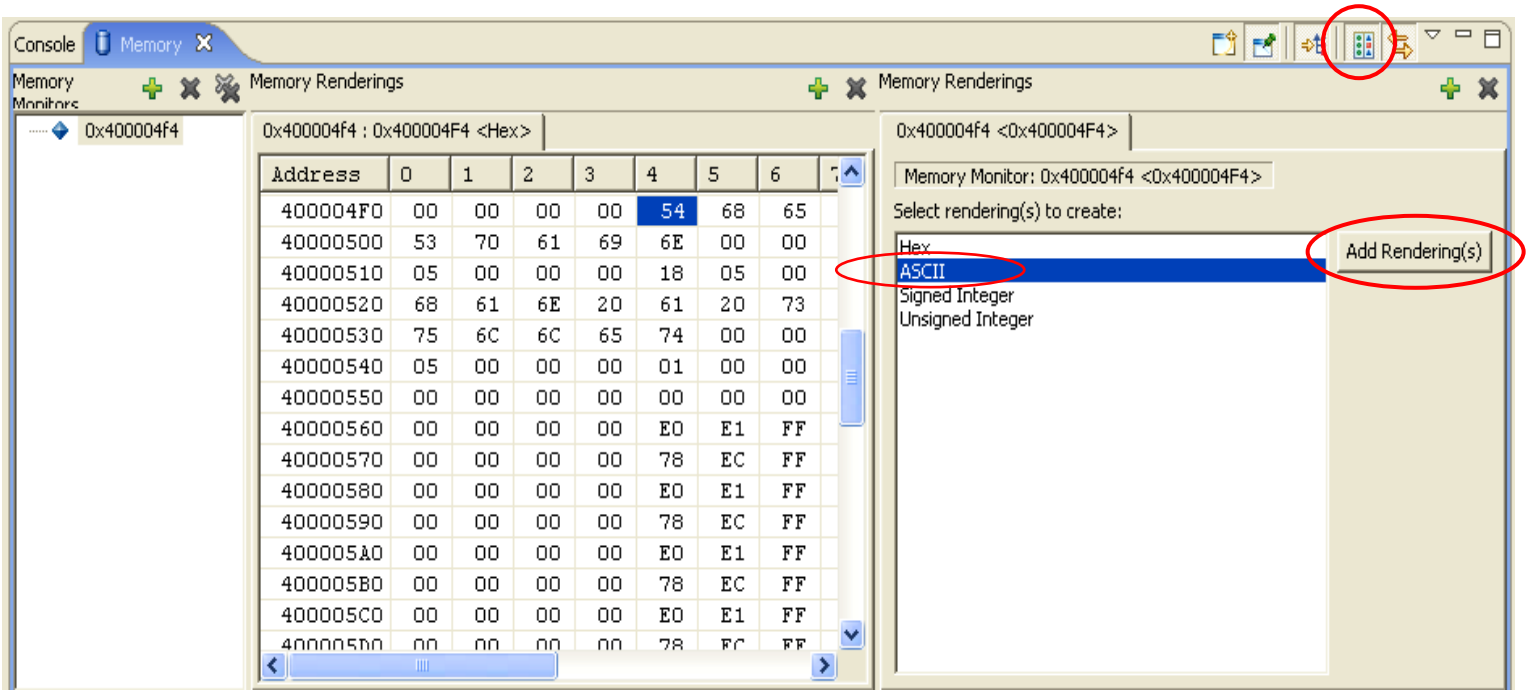


Now we will add a second rendering that will display the memory monitor in ASCII.

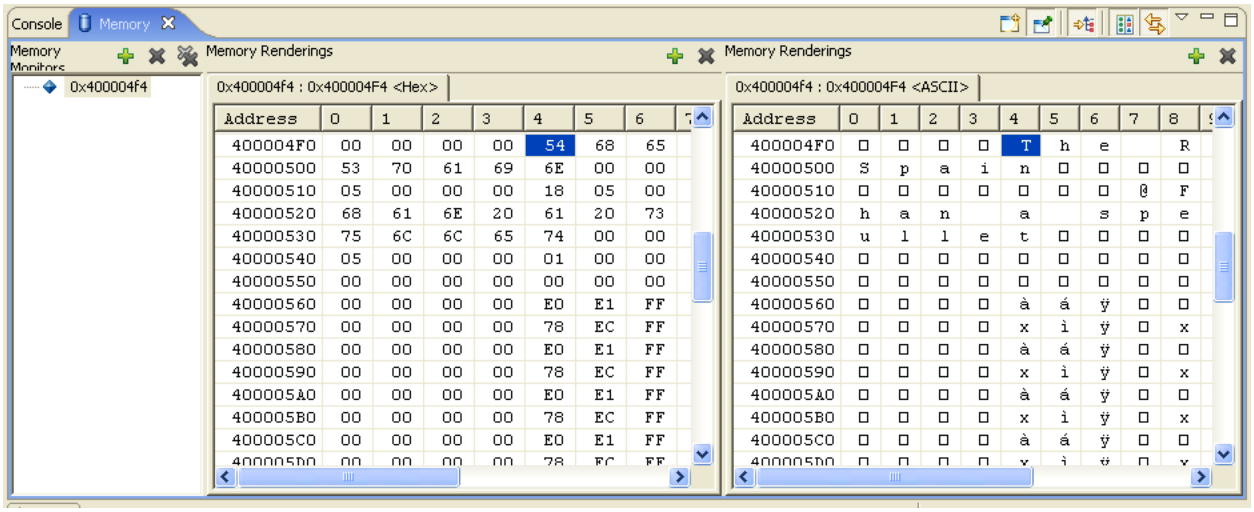
Click on the “**Toggle Split Pane**” button to create a second rendering pane. 

Pick “**ASCII**” display for the new rendering.

Click on the “**Add Rendering(s)**” button to create an additional ASCII memory display.



Now we have a split pane display of the memory in hex and ASCII.

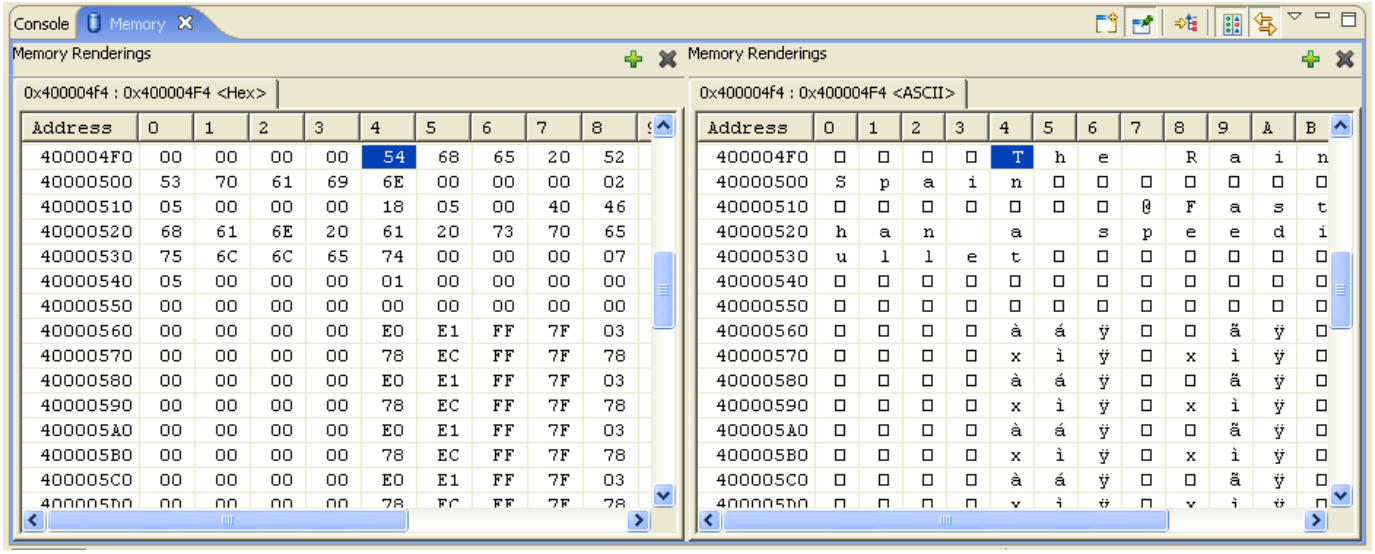


Click on the “**Link Memory Rendering Panes**”  button.

This means that scrolling one memory rendering will automatically scroll the other one in synchronism.

Click on the “**Toggle Memory Monitors Pane**”  button.

This will expand the display erasing the “memory monitors” list on the left.



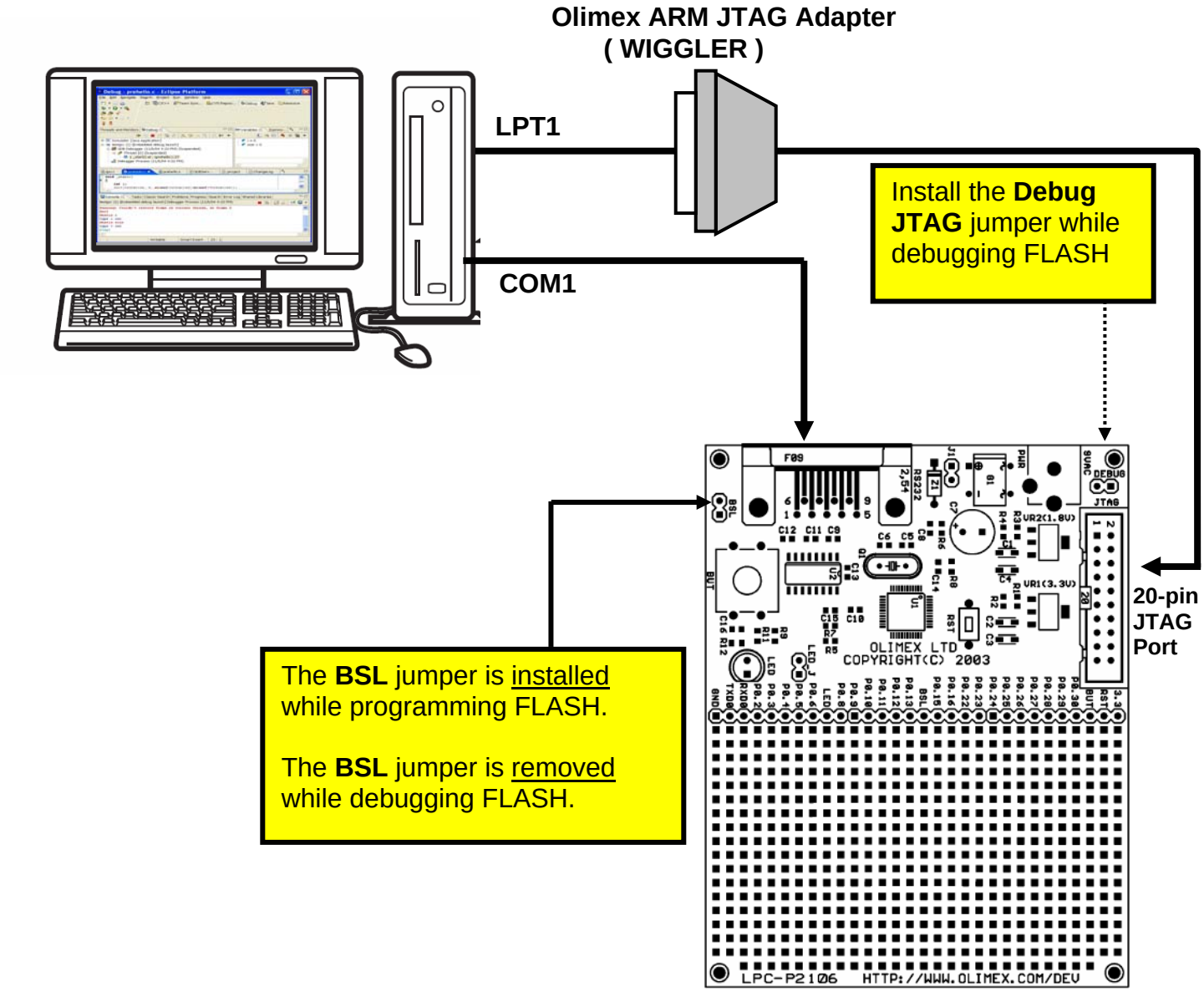
Personally, I think this Eclipse memory display is a bit complex. However, it allows you to define many “memory monitors” and clicking on any one of them pops up the renderings instantly. It’s like so many things in life, once you learn how to do it; it seems easy!

22 Debug the FLASH Project

Debugging an application configured for FLASH execution is not only possible, but fairly easy. It's a two-step process; use the **Philips LPC2000 Flash Utility** to burn the application into onboard FLASH memory and then run the **Eclipse/GDB debugger** to control execution.

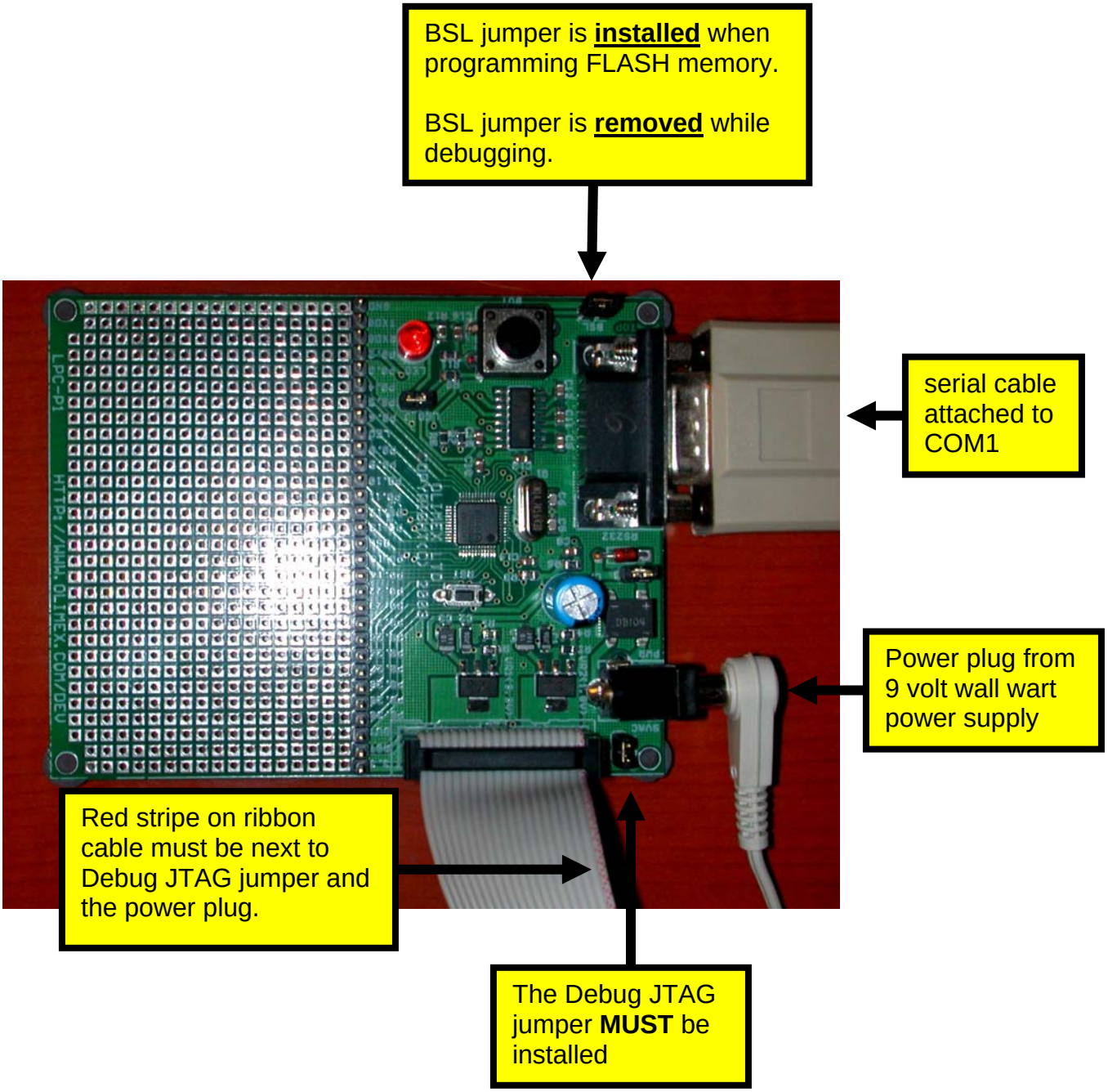
A. Hardware Setup

The following hardware setup is required.



The only thing to remember about the hardware setup is to **fit** the bootstrap loader jumper (**BSL**) while programming the FLASH using the **Philips LPC2000 Flash Utility** and to conversely **remove** the **BSL** jumper while debugging.

To ensure that the hardware is set up correctly for FLASH debugging, refer to the photograph below.



B. Program Application into FLASH

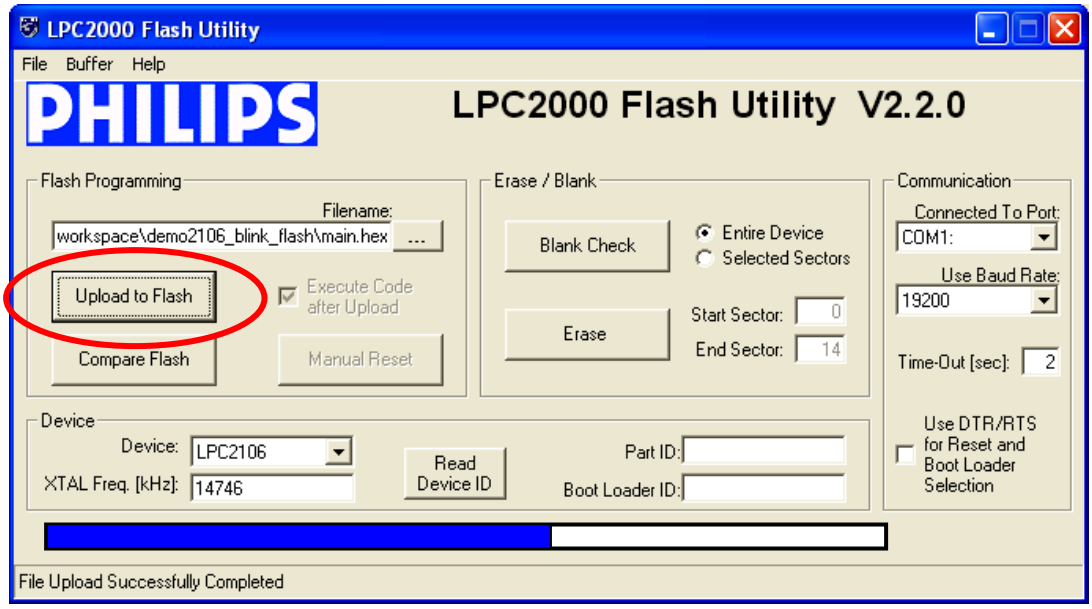
This was covered in Section 18 of the tutorial.

Using the techniques already discussed, restart Eclipse and open the "**demo2106_blink_flash**" project.

Do a "**Clean**" followed by a "**Build All**."

Then start the external tool "**Philips LPC2000 Flash Utility**" and burn the "**main.hex**" file into FLASH, as shown below. You must fit the "**BSL**" jumper to do this.

I also suggest removing the JTAG ribbon cable from the wiggler while operating the **Philips LPC2000 Flash Utility**. Re-connect it when you're finished burning the FLASH memory.



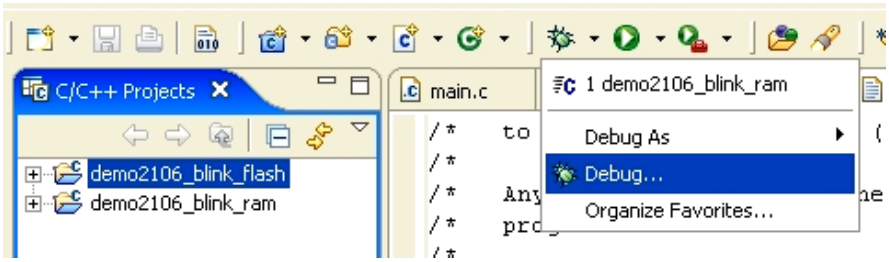
After successfully burning the executable code into FLASH, be sure to remove the "**BSL**" jumper.

C. Create a new FLASH Debug Configuration.

We have already done one of these, creating a "**debug configuration**" for debugging code loaded entirely into RAM.

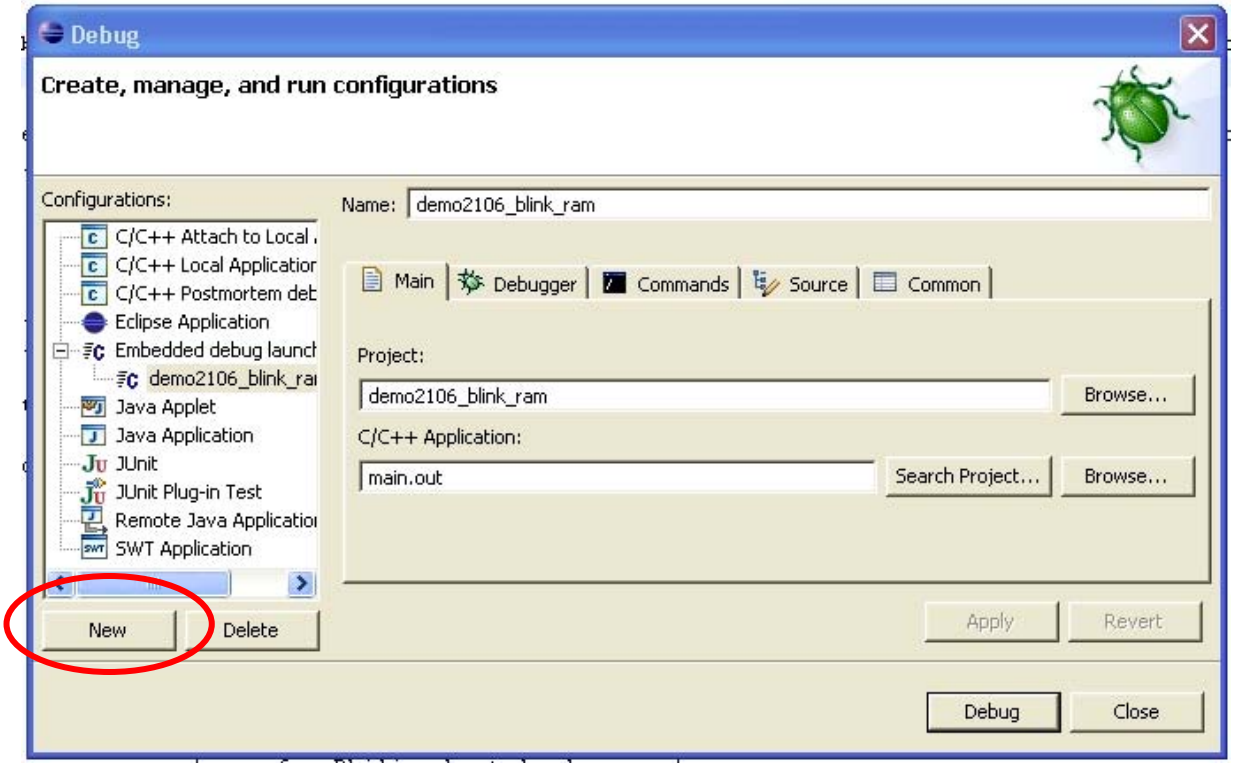
This new configuration will be very similar, just the GDB initialization commands are different.

First click on the “**Debug**” button (specifically the pull-down arrow). Then click on “**Debug…**”



The Debug window reveals that we only have one “**Debug Configuration**” defined under the Zylin “**Embedded debug launch**” configurations. This is “**demo2106_blink_ram**” designed to debug applications loaded entirely into RAM.

Click on “**New**” to permit specification of a new Debug Launch Configuration.



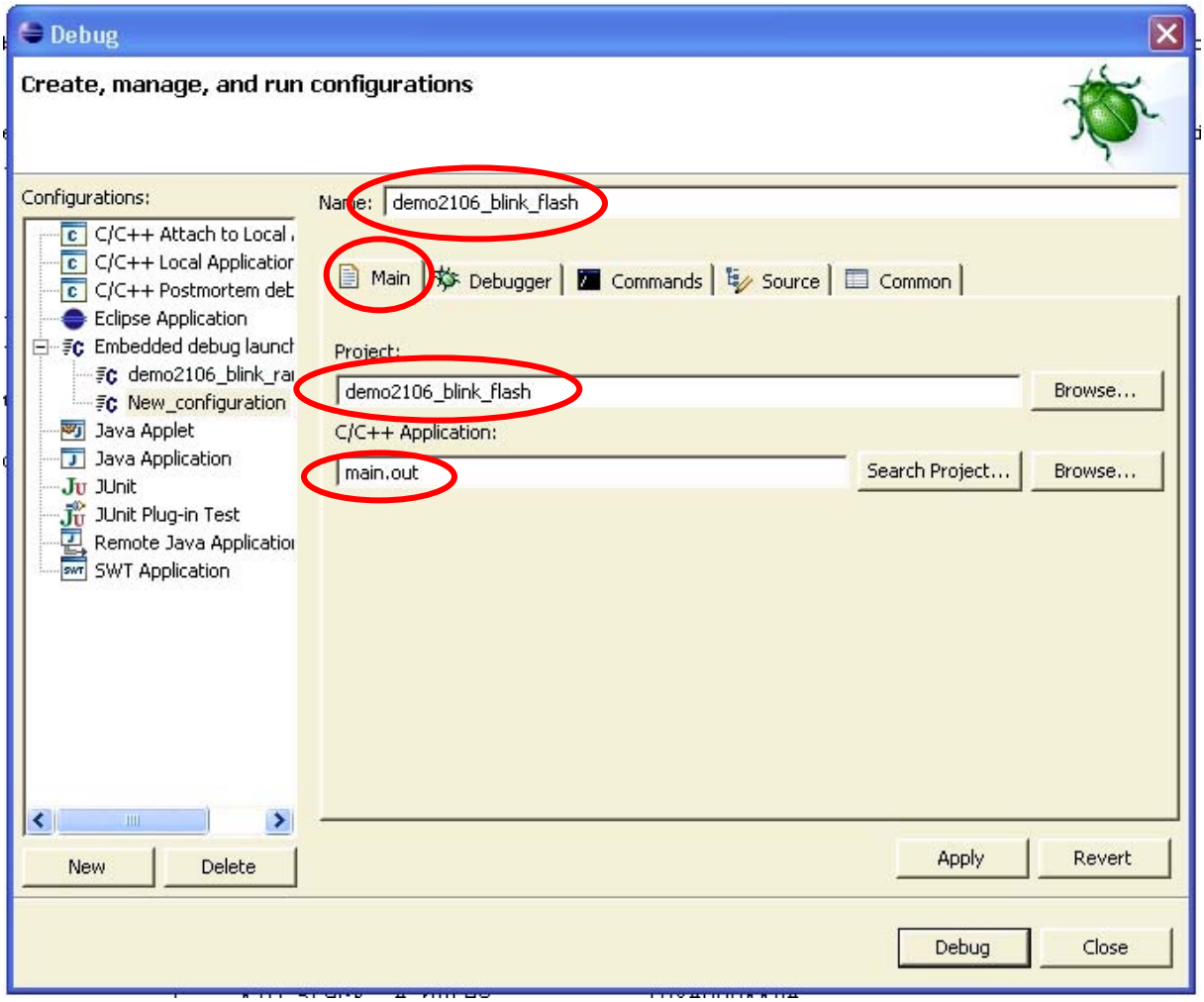
This will bring up a blank window to define the new “Debug **Launch Configuration**.”

Click on the “**Main**” tab.

Give it the name “**demo2106_blink_flash**” which is the same as the project name.

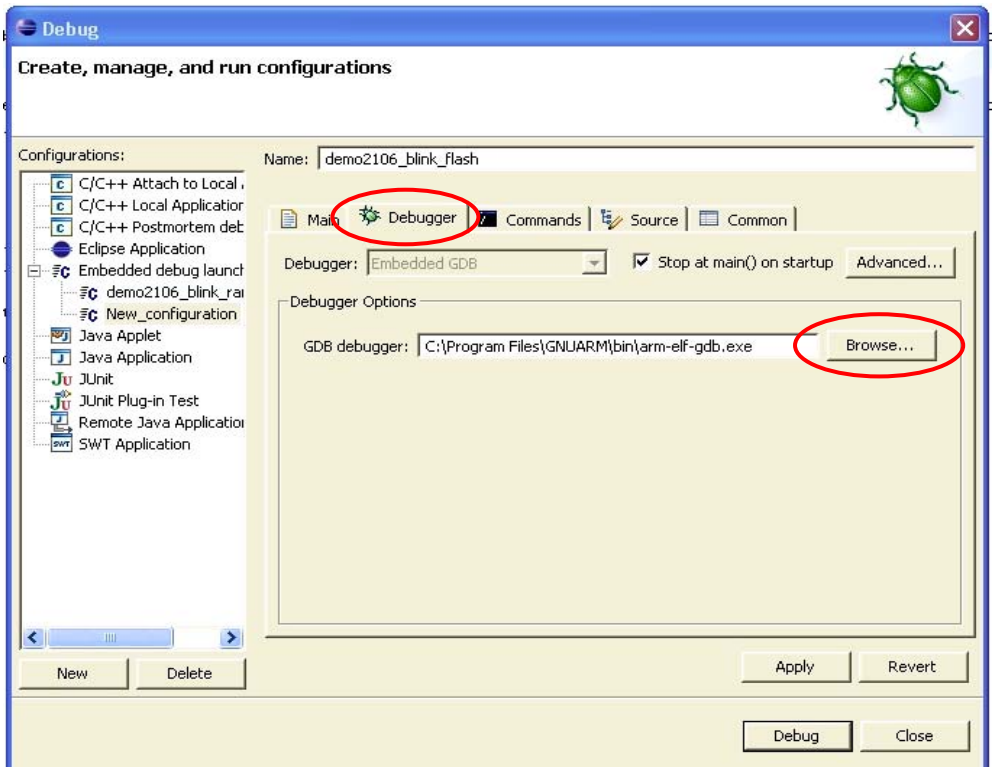
Likewise, enter “**demo2106_blink_flash**” as the project name (you could browse for it).

Finally, specify the file “**main.out**” as the C/C++ application. Note that only the symbols will be used from this file, we’ve already programmed the code into FLASH via the **Philips LPC2000 Flash Utility** as shown above.

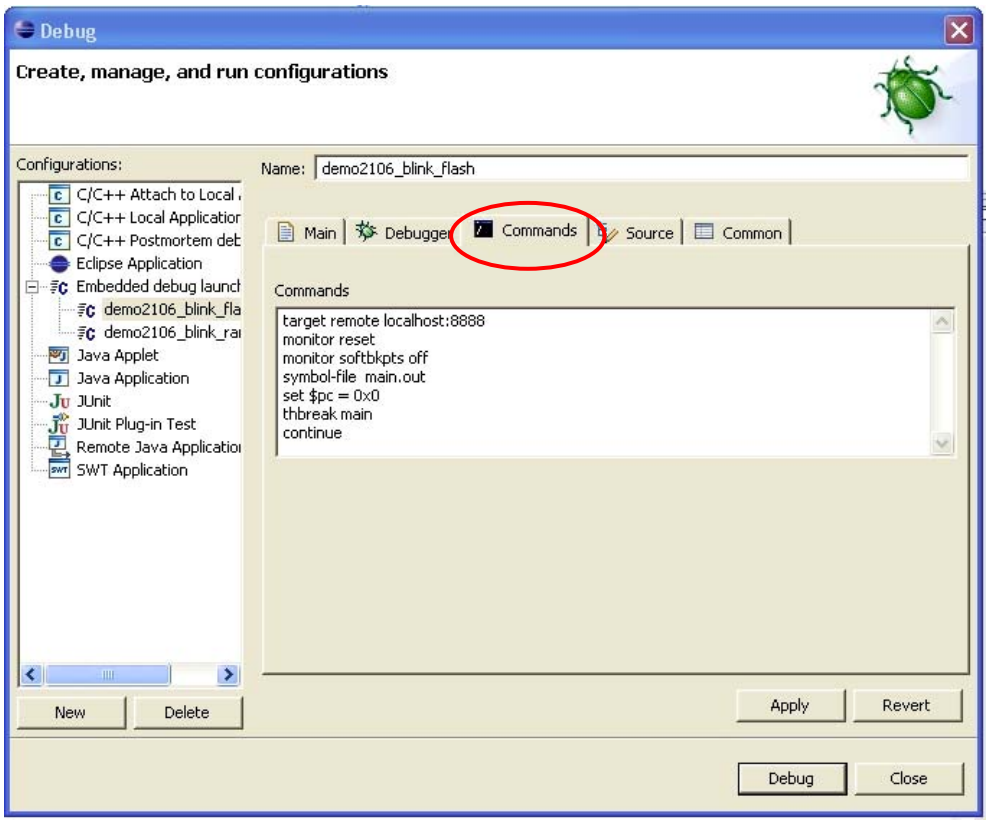


Now click on the “**Debugger**” tab.

Click the “**Browse**” button and locate the “**arm-elf-gdb**” debugger. This executable is in the **c:\Program Files\GNUARM\bin** directory.



Now click on the “**Commands**” tab. Enter the list of commands as shown.



The following is a list of commands that are executed when the Eclipse/GDB debugger starts up.

target remote localhost:8888
monitor reset
monitor softbkpts off
symbol-file main.out
set $pc = 0x0
thbreak main
continue

Let's go through these commands, one-by-one.

target remote localhost:8888

This is a **GDB** command that specifies communication with the remote target via Remote Serial Protocol. GDP will use internet port 8888, which is the default port that the Macraigor **OCDRemote** uses.

monitor reset

Command sent to **OCDRemote** that resets the CPU.

monitor softbkpts off

Command sent to **OCDRemote** that controls breakpoint specification.

softbkpts <ON/OFF>

ON = use both hardware and software breakpoints (default)
OFF = use only hardware breakpoints for stopping and source stepping CPU

This means that all breakpoint commands will be directed to the ARM7 hardware breakpoint circuits. There are just two hardware breakpoint circuits so you must limit yourself to only two breakpoints at a time.

symbol-file main.out

This is a **GDB** command to read the symbol file "**main.out"** to extract its symbol information and statement and variable addresses.

set $pc = 0x0

This is a **GDB** command that sets an ARM register. In this case, we set the PC to 0x000000 so that execution will start from the FLASH reset vector address.

thbreak main

This is a **GDB** command that sets a “temporary hardware-assisted breakpoint” at the address symbol “**main**”.

When the ARM7 breaks at “**main**”, the temporary breakpoint is automatically removed.

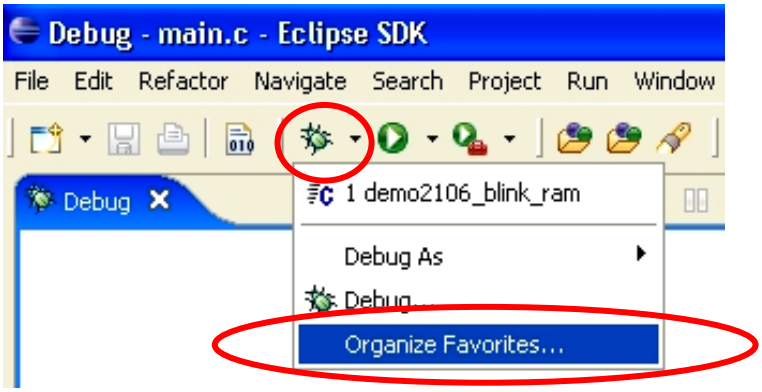
continue

This is a **GDB** command to resume execution. This essentially causes the ARM7 to start execution from the reset vector address 0x0000 and continue through all the initialization code until the address symbol “**main**” is reached. Then it will do a temporary hardware breakpoint.

The “**Source**” and “**Common**” tabs are OK to leave in their default condition.

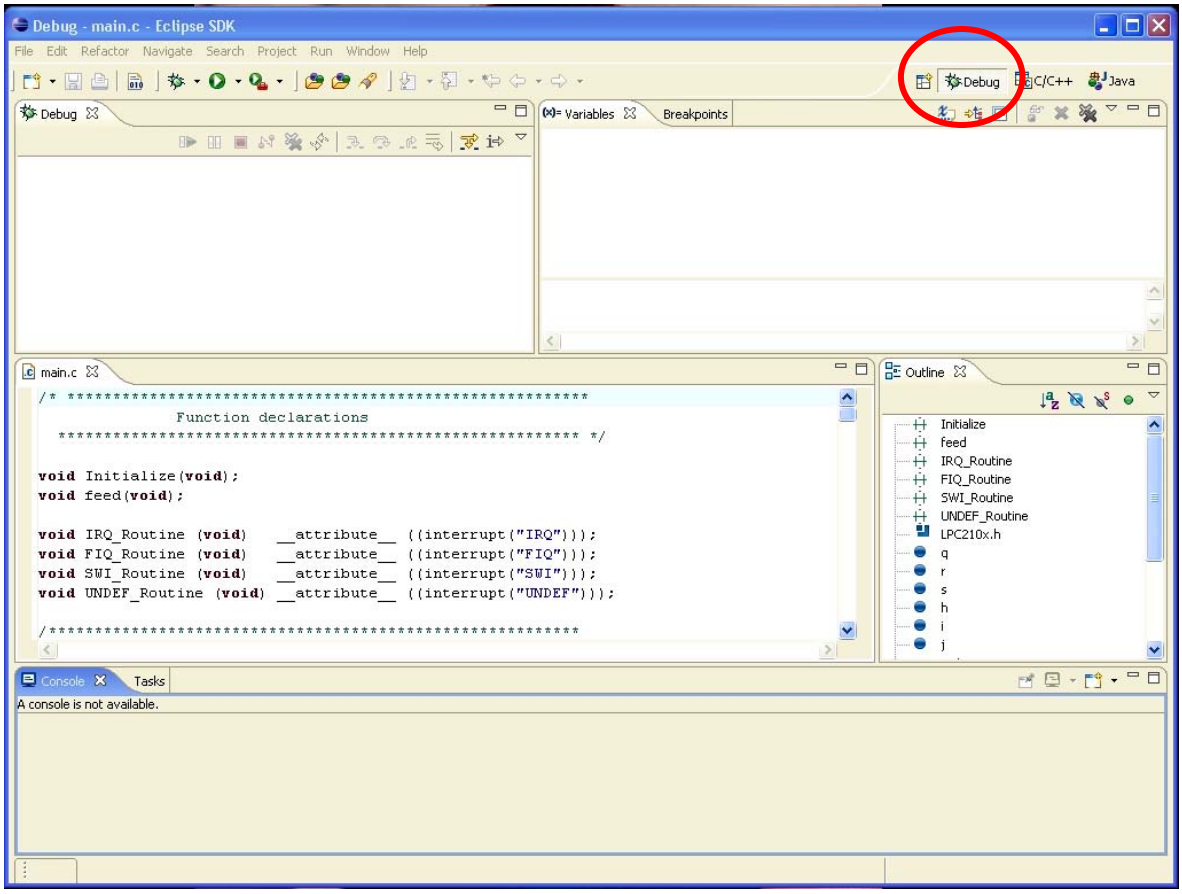
Click on “**Apply**” and “**Close**” to finish. Answer “**Yes**” when the “**Save Changes?**” dialog box pops up.

At this time, it might be a good idea to click the "**debug**" button and then the "**Organize Favorites…**" menu choice to make sure both of our debug launch configurations are in the list of favorites. Just repeat the techniques we've used before in this tutorial.



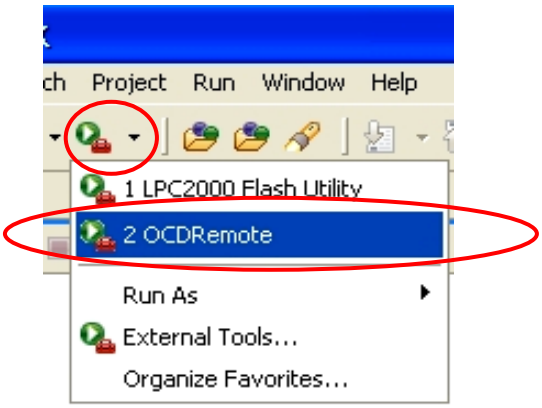
D. Switch to the Eclipse Debug Perspective

Open the "**Debug**" perspective. You can do this by clicking on "**Window – Open Perspective – Other… - Debug**" or you can select the "**Debug**" button at the upper right of the screen.



E. Start the OCDRemote Utility

As before, you can start **OCDRemote** by clicking on the "**External Tools**" button and its pull-down arrow and then click "**OCDRemote**".



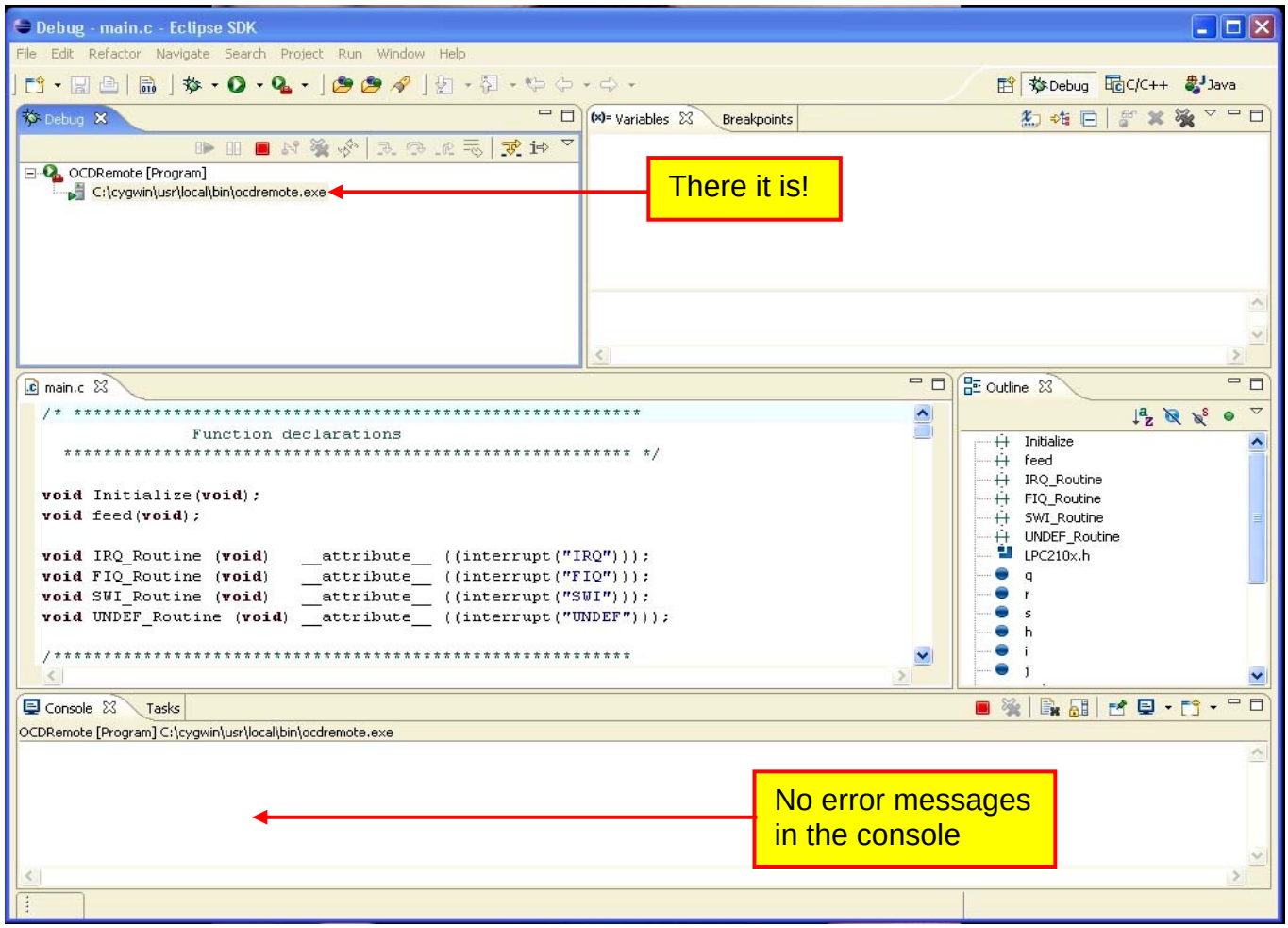
Obviously, we're looking for this result.

Tip:

When you select **OCDRemote** from the pull-down menu, Eclipse remembers your last selection.

Clicking on the **External Tools** button by itself again will automatically select **OCDRemote**.

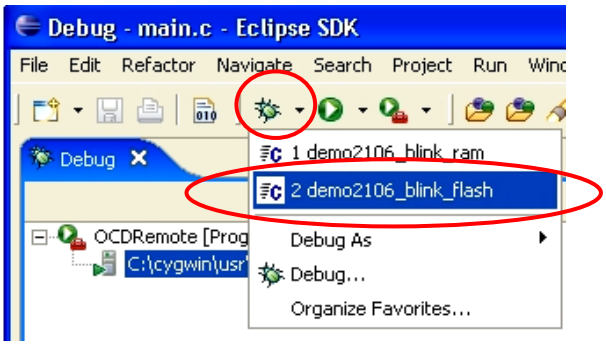
The "tool-tips" will also tell you what it will do.



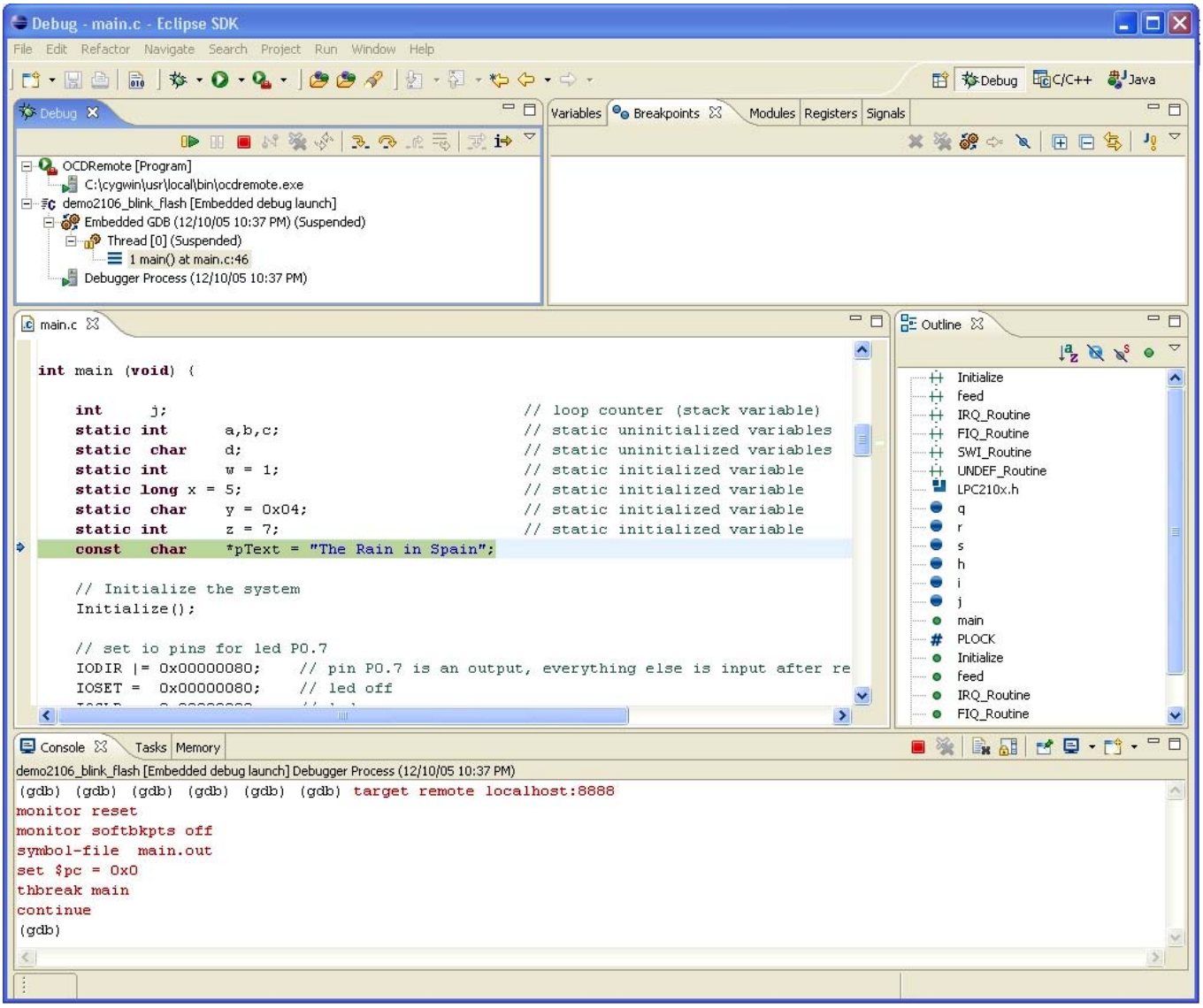
Keep clicking on the **OCDRemote** button until it synchronizes. If you have no luck, refer to the suggestions given in the **section 21-D** concerning debugging of RAM applications.

F. Launch the Debugger

Obviously, we have to launch the right configuration. Click on the "**Debug**" button and its pull-down menu. Select the "**demo2106_blink_flash**" debug launch configuration.



If the debugger launches successfully, you should see the commands executed in the "console" view and the debugger will halt at main (with no breakpoints set).

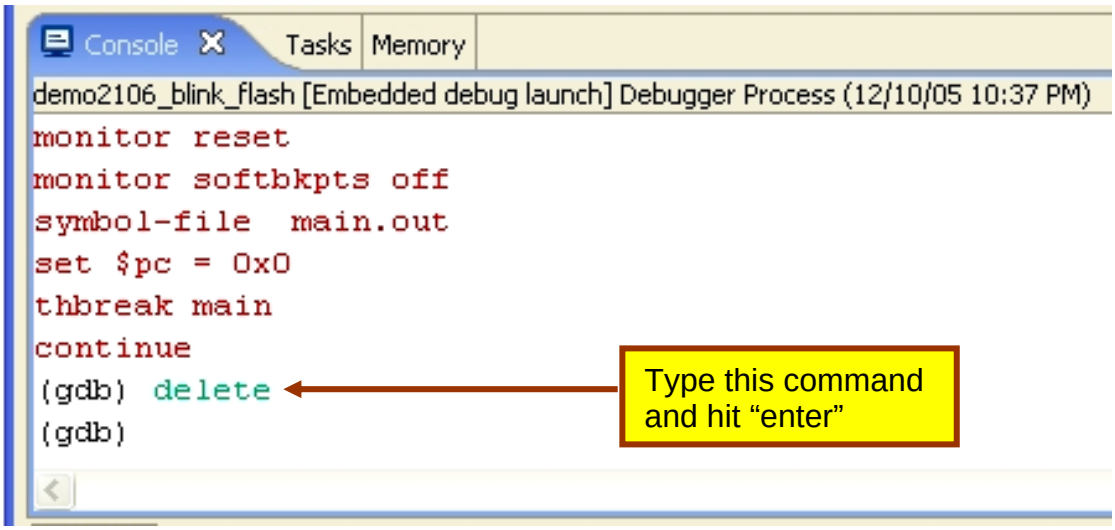


The next maneuver is a bit of a mystery. To get the debugger to operate with two breakpoints, you have to manually enter the GDB console command "**delete**." From the Stallman book "**Debugging with GDB**."

"Delete [breakpoints] [range…]

Delete the breakpoints, watchpoints, or catchpoint of the breakpoint ranges specified as arguments. If no argument is specified, delete all breakpoints (GDB asks for confirmation, unless you have set confirm off). You can abbreviate this command to d."

To enter this command manually, click inside the console view after the (gdb) prompt and type the "**delete**" command.



Obviously, when the debugger starts and stops at main, it must be using one of the two hardware breakpoint circuits as a resource. Entering the **delete** command manually seems to take care of it.

I have experimented with putting the **delete** command in the debugger startup commands to no avail. If any of my readers can figure out why this is required, please e-mail me so I can adjust the tutorial.

My theory is that that temporary breakpoint command "**thbreak main**" is not removing itself as advertised, but I'm really not sure of this.

G. Debugging in FLASH

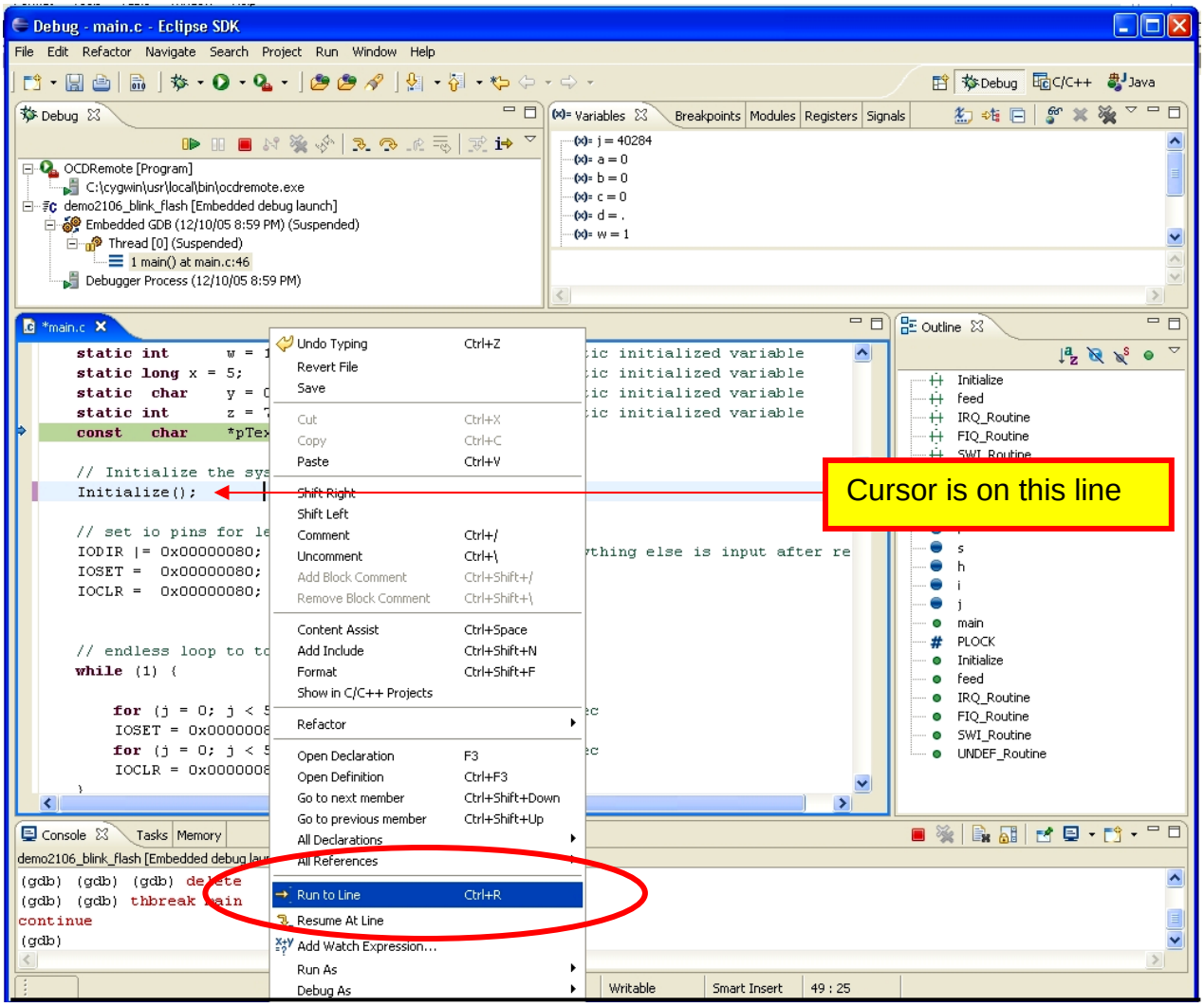
Debugging in FLASH is exactly like debugging in RAM, as described earlier, with just two exceptions.

- **You can only set two breakpoints at a time. If you are stepping, you should have no breakpoints set since Eclipse needs the hardware breakpoints for single-stepping.**

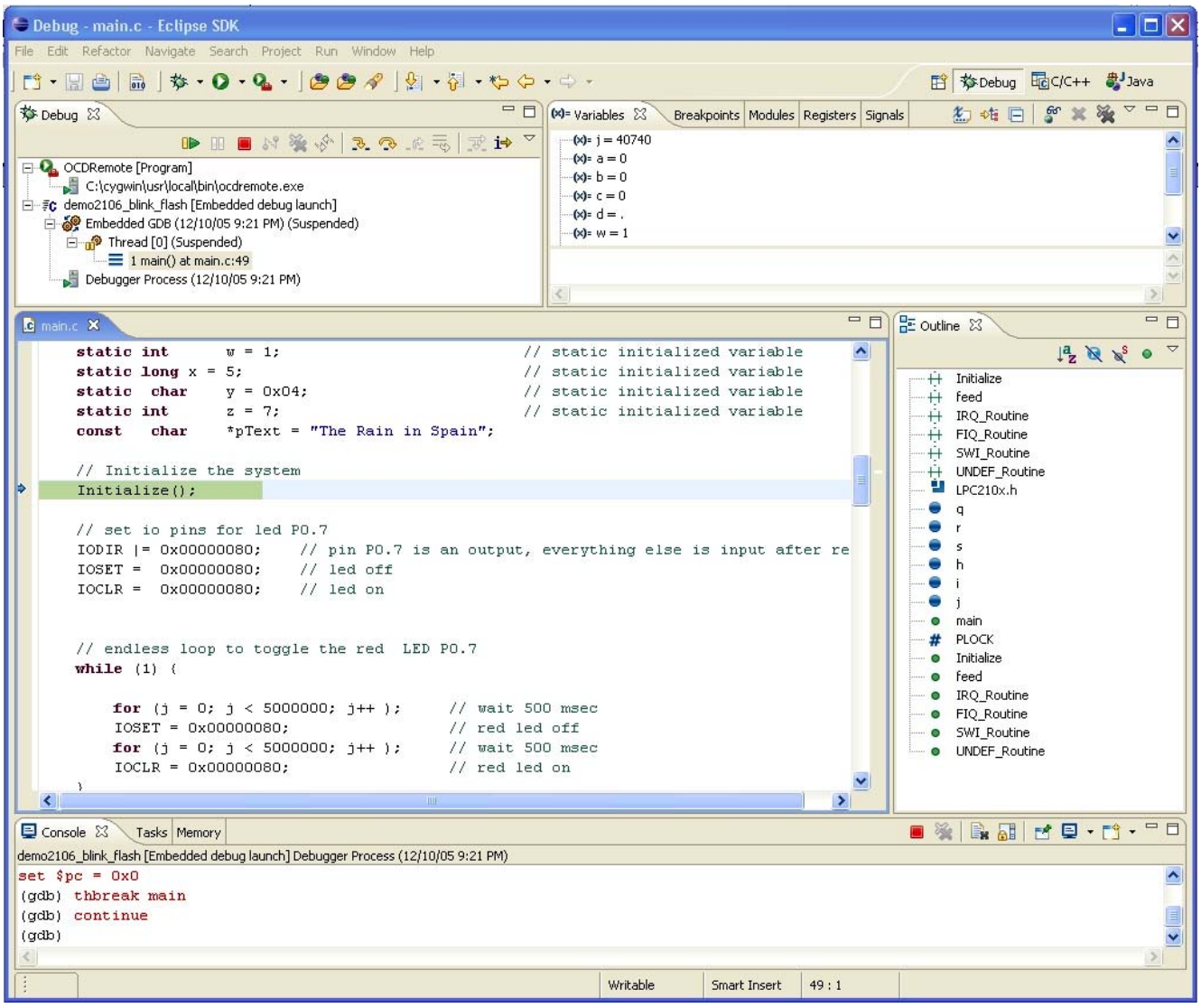
- **If you re-compile your application, you must stop the debugger, re-build and burn the main.hex file into FLASH using the Philips LPC2000 Flash Utility. The Eclipse/GDB debugger cannot program FLASH memory.**

The right-click menu function "**Run to Line**" is best in this scenario since it does a "temporary" hardware breakpoint and you don't have to remember if you left a breakpoint on somewhere.

Let's practice with our example. Click on the source line ***Initialize();*** and bring up the right-click menu. Click on the "**Run to Line**" menu choice

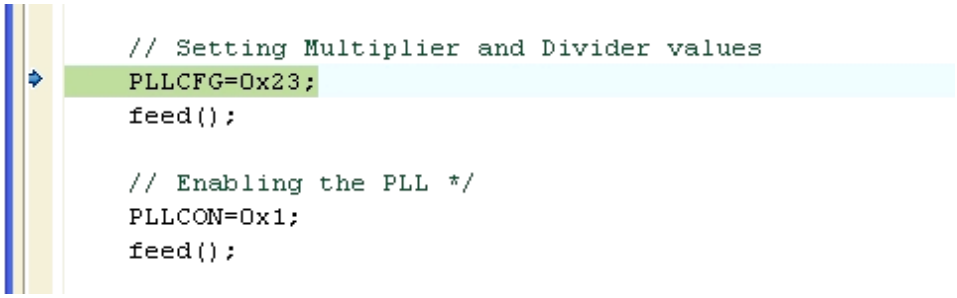


The debugger will execute to the source line you specified.



Let's step into the initialize() function. Click on the "Step Into" button. 

Note that we have no breakpoints specified at this point. The debugger executes to the first source line in the initialize() function and stops.



Now let's click the "**Step Over**" button to advance one source line. 

Now we're at another function call**, feed().**

```
    // Setting Multiplier and Divider values
    PLLCFG=0x23;
    feed();

    // Enabling the PLL */
    PLLCON=0x1;
    feed();
```

Now click the “Step Into” button. 

The debugger will execute to the first source line in the function feed().

```
void feed(void)
{
  PLLFEED=0xAA;
  PLLFEED=0x55;
}
```

Now click the “Step Out” button. 

The debugger will execute out of the feed() routine to the next source line in the calling function, which is initialize().

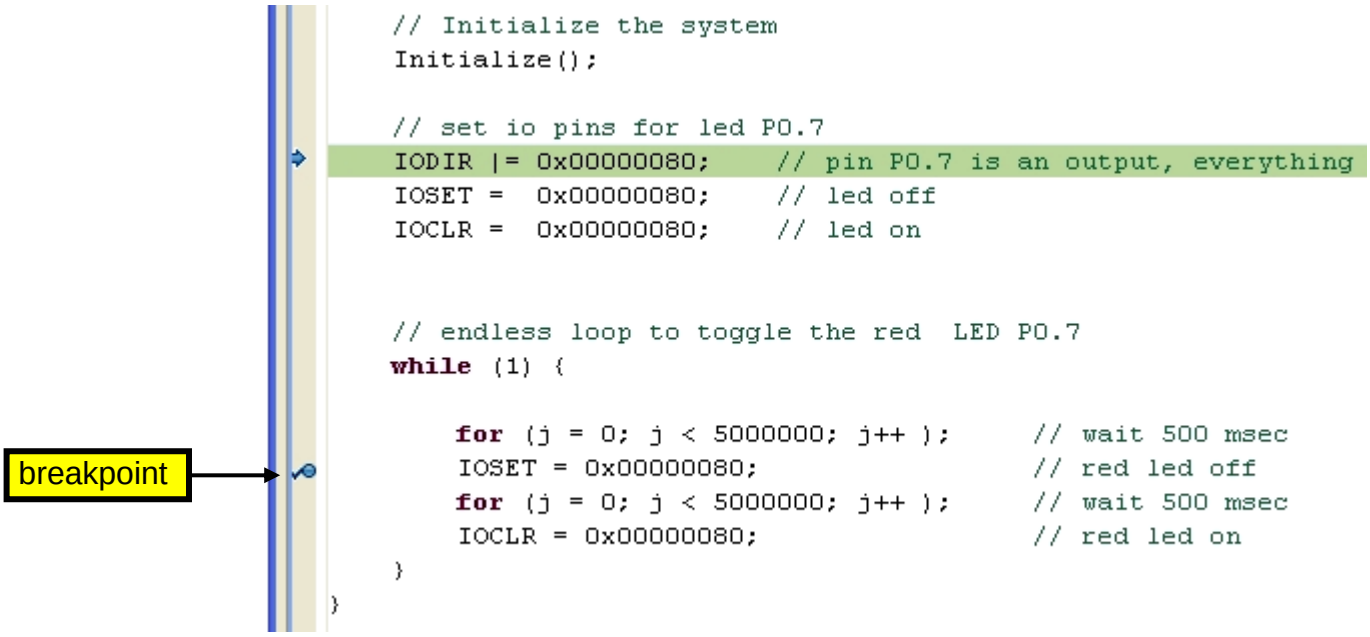
```
    // Setting Multiplier and Divider values
    PLLCFG=0x23;
    feed();

    // Enabling the PLL */
    PLLCON=0x1;
    feed();

    // Wait for the PLL to lock to set frequency
    while(!(PLLSTAT & PLOCK)) ;
```

Now click the “Step Out” button again. 

The debugger will execute out of the initialize() routine to the next source line in the calling function, which is main().

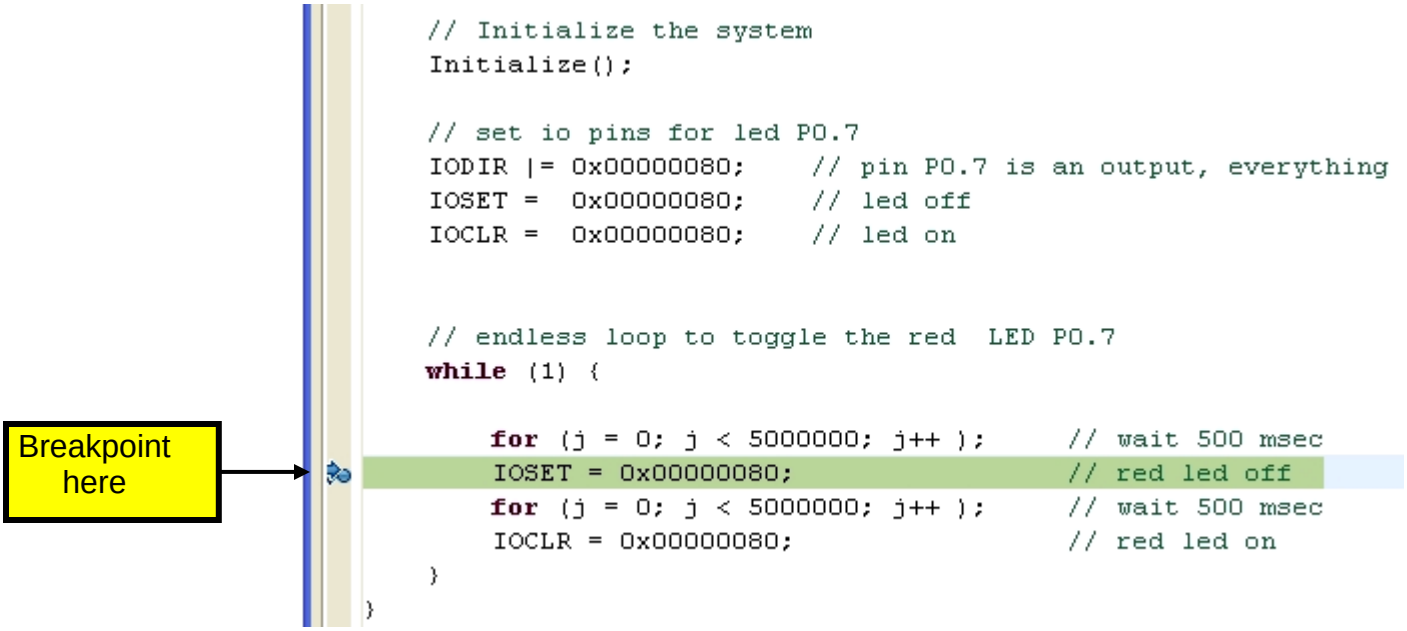
```
    // Initialize the system
    Initialize();

    // set io pins for led P0.7
    IODIR |= 0x00000080;     // pin P0.7 is an output, ev
    IOSET =  0x00000080;     // led off
    IOCLR =  0x00000080;     // led on


    // endless loop to toggle the red  LED P0.7
    while (1) {
```

Now let's set a breakpoint. A good choice is the endless loop at the points where we turn on the LED. Click on the far left margin to set the breakpoint.




```
    // Initialize the system
    Initialize();

    // set io pins for led P0.7
    IODIR |= 0x00000080;    // pin P0.7 is an output, everything
    IOSET =  0x00000080;    // led off
    IOCLR =  0x00000080;    // led on


    // endless loop to toggle the red  LED P0.7
    while (1) {

        for (j = 0; j < 5000000; j++ );     // wait 500 msec
        IOSET = 0x00000080;                 // red led off
        for (j = 0; j < 5000000; j++ );     // wait 500 msec
        IOCLR = 0x00000080;                 // red led on
    }
}
```

Now click on the "resume" button to execute to the breakpoint.




```
    // Initialize the system
    Initialize();

    // set io pins for led P0.7
    IODIR |= 0x00000080;    // pin P0.7 is an output, everything
    IOSET =  0x00000080;    // led off
    IOCLR =  0x00000080;    // led on


    // endless loop to toggle the red  LED P0.7
    while (1) {

        for (j = 0; j < 5000000; j++ );     // wait 500 msec
        IOSET = 0x00000080;                 // red led off
        for (j = 0; j < 5000000; j++ );     // wait 500 msec
        IOCLR = 0x00000080;                 // red led on
    }
}
```

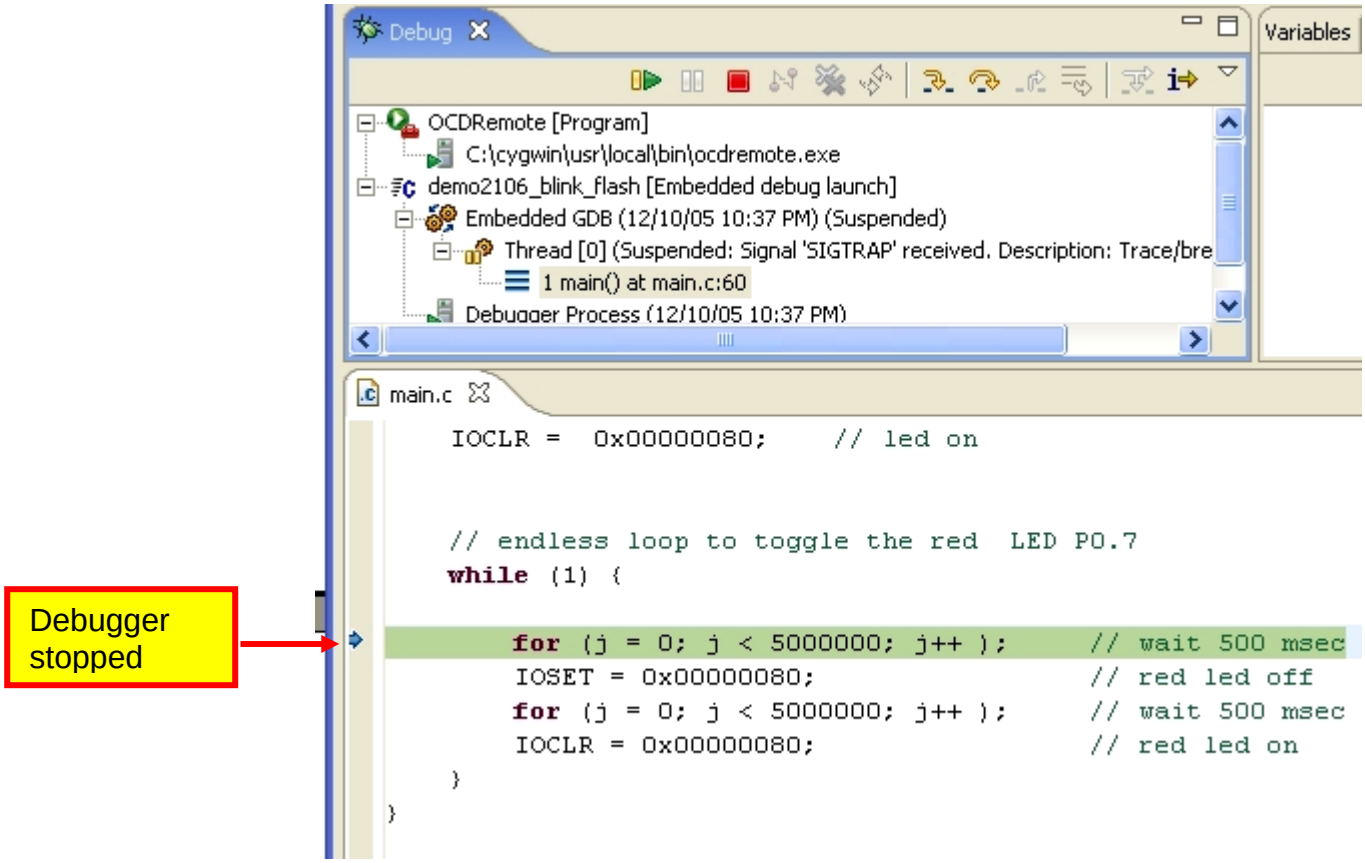
If you want to execute normally, remove all the breakpoints (use the breakpoints view to see all the ones you have used and use the right-click menu to remove all).

Then click on the "Resume" button to execute continuously.

Now the application should run and blink the LED.

If you want to stop execution, hit the “suspend” button. 

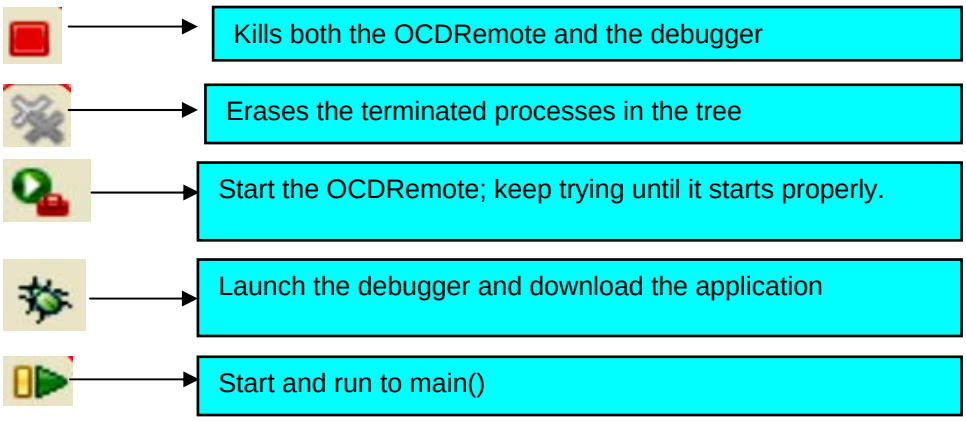
In the screen shown below, the debugger has stopped within one of the delay for loops.



Of course, all the Eclipse debugging features such as “hover” variable display, display of local and global variables and structures, memory dumps, assembler language debugging, etc. all work great in this FLASH debugging motif.

I’m not going to repeat that information; please review the material on RAM-based application debugging and try these features.

If you have to restart the debugger, recall this sequence from our RAM debugging.



H. FLASH Debugging Check List

If you can commit the following simple points to memory, you will be rewarded with hours of worry-free FLASH debugging.

- Program the FLASH with the **Philips LPC2000 Flash Utility** after compiling (your hex file)
- **BSL** jumper fitted for FLASH burning, removed for FLASH debugging
- Manually enter the "**delete**" GDB command after starting the debugger
- Never set more than two breakpoints
- Clear all breakpoints while single-stepping

23 The Author Sounds Off

Last year I decided to see if it was possible to put together a complete, low cost ARM software development system for embedded programming. Purchasing a commercial package seemed out of the question since the price ranged from $900 to several thousand dollars. Affordable quick-start packages typically have a time limit on usage or limitations on the code size. Microsoft has recently developed “express” versions of their tools for free, non-commercial use. However, their code targets are typically for the Windows/Intel platform.

That’s when I looked into the GNU tools and the Eclipse platform. They’re open-source and free. The problem, I discovered, is that the documentation is targeted for experts. The GNU documentation assumes you are a Linux expert and the Eclipse documentation is targeted for JAVA programmers. The CDT plug-in for Eclipse currently has no books available for reference.

Recognizing the difficulty in finding and assembling all these software components, I decided to make copious notes for myself concerning how I went about this task. The result is this tutorial; the purpose being a detailed exposition of all the procedures required to build a completely free ARM software cross development package. This tutorial is designed for novices; I assume only that you are familiar with C language.

I used the Philips LPC2000 family of embedded ARM controllers as the tutorial’s hardware examples. These chips are inexpensive, rich in onboard peripherals and contain significant onboard RAM and FLASH (512K of Flash in the LPC2148). Other manufacturers such as Analog Devices, Atmel, Cirrus Logic, OKI, ST Microelectronics, Texas Instruments, Intel, Freescale, Samsung, Sharp and Hynix all produce ARM offerings worthy of consideration. I’m sure that many of the ideas in my tutorial can be transposed to these other manufacturer’s designs.

This tutorial was written for students and grown up “kids at heart”; its purpose is to foster their interest in computer science and electrical engineering. It described in great detail how to download and install all the component parts of a complete ARM software development system and gave two simple code examples to try out. Of course, the beauty of this is that it’s completely free.

I’m not finished writing tutorials. My next tutorial will involve using ARM interrupts and how to design and implement I2C port expanders to interface to LCD displays and keypads. Later tutorials will go into motion control, free real-time operating systems and other hardware projects. Stay tuned, just like you, I’m just getting started!

24 About the Author

Jim Lynch lives in Grand Island, New York and is a Project Manager for Control Techniques, a subsidiary of Emerson Electric. He develops embedded software for the company's industrial drives (high power motor controllers) which are sold all over the world.

Mr. Lynch has previously worked for Mennen Medical, Calspan Corporation and the Boeing Company. He has a BSEE from Ohio University and a MSEE from State University of New York at Buffalo. Jim is a single Father and has two children who now live in Florida and Nevada. He has two brothers, one is a Viet Nam veteran in Hollywood, Florida and the other is the Bishop of St. Petersburg, also in Florida. Jim plays the guitar and is collecting woodworking machines for future projects that will integrate woodworking and embedded computers.

Lynch can be reached via e-mail at: lynch007@gmail.com

25 Acknowledgements

I have been very fortunate to have the advice and constructive comments from readers all across the world. I give my heartfelt appreciation to all and specifically to:

Kjell Eirik Andersen is the "R&D Chief Engineer" at Tandberg Storage ASA, a company that designs and manufactures half-height LTO tape drives.

Kjell helped me with the GDB startup commands that prepare the debugger for FLASH debugging.

His favorite hobby is playing with small microcontrollers.

Kjell lives in Oslo (Norway) with his family and two cats.

Design/Applications Engineer Spencer Oliver from the United Kingdom also provided me with valuable guidance on how to set up the Eclipse system for FLASH debugging. Spencer was too bashful to send me a picture.

26 Some Books That May Be Helpful

The following is a short compendium of books that I've found helpful on the subject of ARM microprocessors and the GNU tool chain. I've reproduced the Amazon.com data on them.

GCC: The Complete Reference

by Arthur Griffith "The GNU Compiler Collection (GCC) is the most important piece of open source software in the world..." (more)
SIPs: instruction scheduling parameters, builtin apply, execute the configure script, release eqcs, call insn (more)

List Price: ~~$59.99~~
Price: **$39.59** and this item ships for **FREE with Super Saver Shipping**. See details
You Save: $20.40 (34%)
Availability: Usually ships within 24 hours. Ships from and sold by Amazon.com.
Only 5 left in stock--order soon (more on the way).

57 used & new available from $8.70
Edition: Paperback

An Introduction to GCC

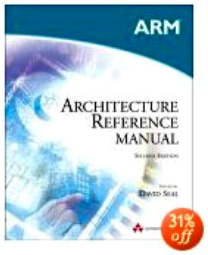
by Brian J. Gough, Richard M. Stallman (Foreword) "The purpose of this book is to explain the use of the GNU C and C++ compilers, gcc and g++..." (more)
SIPs: void hello, math library libm, default gcc, object file containing, options gcc (more)

List Price: ~~$19.95~~
Price: **$13.57** and eligible for **FREE Super Saver Shipping** on orders over $25. See details
You Save: $6.38 (32%)
Availability: Usually ships within 24 hours. Ships from and sold by Amazon.com.

14 used & new available from $13.16
Edition: Paperback

ARM Architecture Reference Manual (2nd Edition)

by David Seal



List Price: ~~$57.99~~
Price: **$40.24** and this item ships for **FREE with Super Saver Shipping**. See details
You Save: $17.75 (31%)
Availability: Usually ships within 24 hours. Ships from and sold by Amazon.com.

Want it delivered Tuesday, June 21? Order it in the next 44 hours and 57 minutes, and choose **One-Day Shipping** at checkout. See details

39 used & new available from $28.00
Edition: Paperback

ARM System-on-Chip Architecture (2nd Edition)

by Steve Furber

List Price: ~~$44.99~~
Price: **$29.39** and this item ships for **FREE with Super Saver Shipping**. See details
You Save: $15.60 (35%)
Availability: Usually ships within 24 hours. Ships from and sold by Amazon.com.

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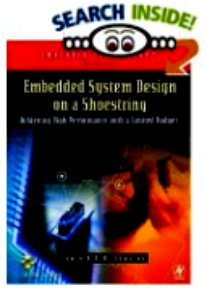
64 used & new available from $20.00
Edition: Paperback

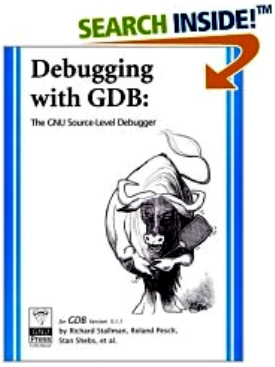
Embedded System Design on a Shoestring (Embedded Technology Series)

by Lewin Edwards "There exist a large body of literature focused on teaching both general embedded systems principles and design techniques, and tips and tricks for specific microcontrollers..." (more)
SIPs: current output section, bss end, qdb stubs, sourcecode files, clear bss (more)



List Price: $49.95
Price: **$49.95** and this item ships for **FREE with Super Saver Shipping**. See details
Availability: Usually ships within 24 hours. Ships from and sold by Amazon.com.

11 used & new available from $47.97
Edition: Paperback



Debugging with GDB: The GNU Source-Level Debugger (Paperback)

by Richard Stallman, Roland H. Pesch, Stan Shebs "You can use this manual at your leisure to read all about GDB..." (more)
SIPs: running qdb, your prograut, qdb data, trace snapshot, selected stack frame (more)
CAPs: Command Synopsis, Examining the Symbol Table, Command There, Free Software Foundation, Configuration-Specific Information (more)

(5 customer reviews)

List Price: ~~$30.00~~
Price: **$19.80** & eligible for **FREE Super Saver Shipping** on orders over $25. See details
You Save: $10.20 (34%)

Availability: Usually ships within 24 hours. Ships from and sold by Amazon.com. See more on holiday shipping.

Want it delivered Tuesday, December 13? Order it in the next 30 hours and 4 minutes, and choose **One-Day Shipping** a checkout. See details

18 used & new available from $19.79

The ARM documentation can be downloaded free from the ARM web site.http://www.arm.com/documentation/

The Philips Corporation has extensive documentation on the LPC2000 series here:

http://www.semiconductors.philips.com/pip/LPC2106.html

All the GNU documentation, in PDF format, is maintained by, among others, the University of South Wales in Sidney, Australia. I found the GNU assembler and linker manuals very readable; the GNU C compiler manuals are very difficult

http://dsl.ee.unsw.edu.au/dsl-cdrom/gnutools/doc/

Of course, the bookstore is full of Eclipse books but they are all about the JAVA toolkit. So far, no one has published anything on the CDT plugin.

Finally, avail yourself of the many discussion groups on the web:

www.yahoo.com	GNUARM group LPC2000 group
www.sparkfun.com	tech support forum
www.newmicros.com	tech support forum
www.eclipse.org	**C/C++ Development Tools User Forum**

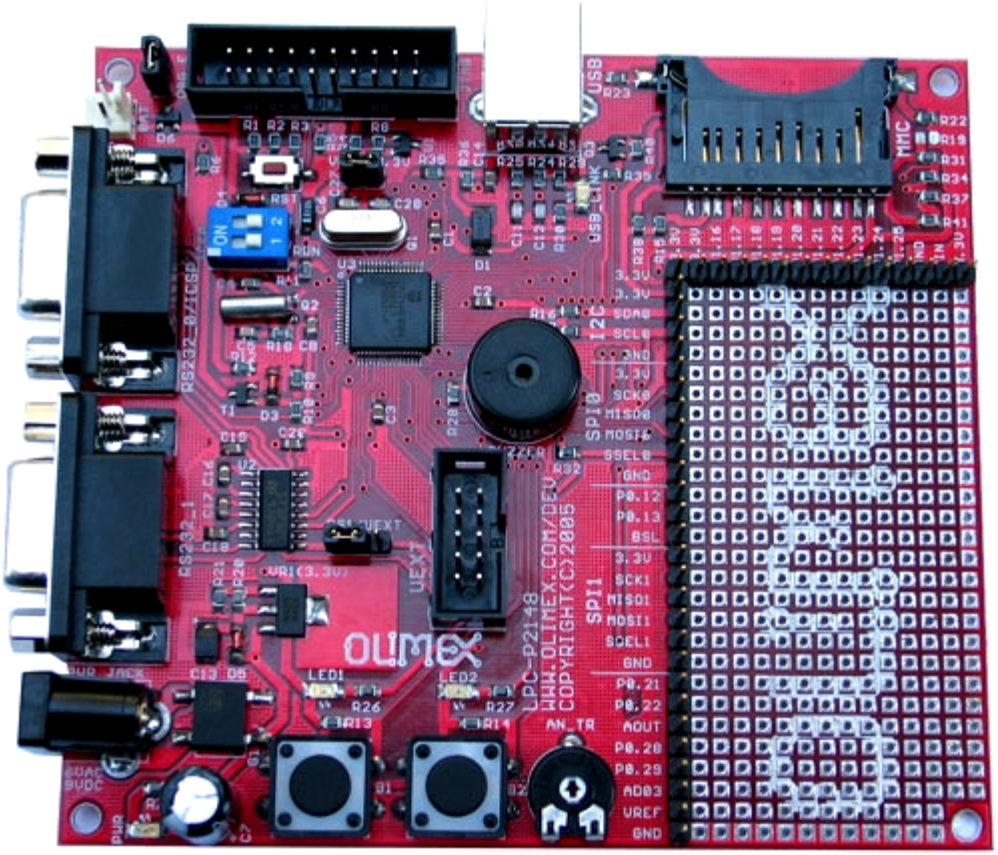
HAVE FUN, EVERYBODY!

APPENDIX 1 - Porting LPC2106 Projects to other Processors

The Olimex **LPC-P2106** board was arbitrarily chosen as the hardware example for this tutorial. Many readers will be interested in how to modify the projects shown in this tutorial to other ARM processors. This process is not difficult; I will demonstrate conversion of the demo2106_blink_flash project to the Philips **LPC2148** ARM7 processor (specifically the Olimex LPC-P2148 board).

To make this conversion, you need two things; the Olimex LPC-P2148 schematic and the Philips UM10139 LPC214x User Manual (can be downloaded from their web sites).

LPC-P2148 PROTOTYPE FOR LPC2148 ARM7TDMI-S MICROCONTROLLER



Note that the BSL jumper has been replaced with a blue dip-switch #1 at the upper left. Set towards the crystal is the “run” position; set to the left near the RS-232 connector is the “flash programming” position. The JTAG jumper and the 20-pin JTAG connector are at the extreme upper left. The red “reset” button is between the dip-switch and the JTAG connector.

The “wall wart” power supply, the RS-232 programming cable and the JTAG adapter are all the same.

Note that there are two LEDs above the two push buttons. The schematic shows that LED1 is connected to GPIO port **P0.10**. That's different from the LPC-P2106 board.

The schematic also shows that the crystal is 12 MHz. That's different also. This means that the Phased Lock Loop (PLL) setup will have to be revised.

The memory map is different as the newer LPC2148 has 512k of FLASH and 40K of RAM. We'll have to recalculate all stack locations.

The User Manual shows that the LPC2148 supports high-speed IO ports; this changes the addressing of the ports if we wish to utilize this new high-speed port feature.

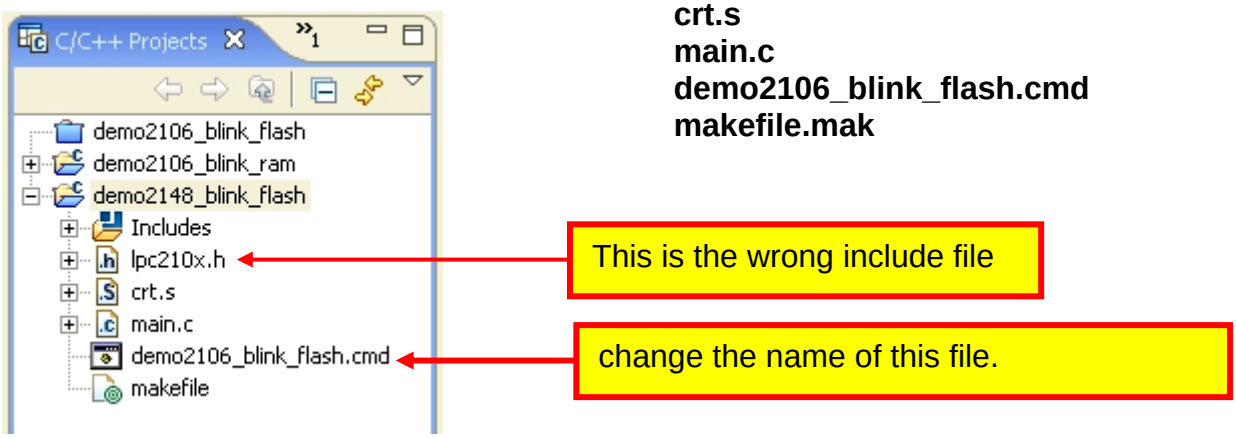
1. Create a New Project

Using the techniques described earlier in the tutorial, create a new Eclipse Standard Make C project and give it the name "**demo2148_blink_flash**".

2. Import the Tutorial Files

You can use the "**File – Import**" pull-down menu and browse to the **demo2106_blink_flash** project and pick the following five files to import:

lpc210x.h
crt.s
main.c
demo2106_blink_flash.cmd
makefile.mak



3. Find the Right Include File

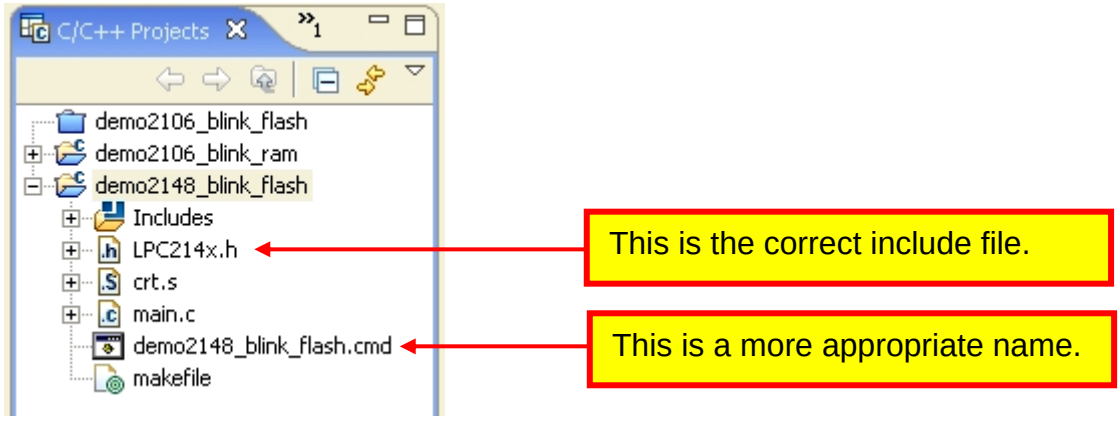
The include file **lpc210x.h** is the incorrect file for the LPC2148. I found an include file posted by Philips Applications Group on the Yahoo LPC2000 message board.

http://f1.grp.yahoofs.com/v1/QEeeQyAcAaF5GWXpBCeeHj6uY4N-C2R5PijwYZB9Eu7CRO6XOIqIDhlhsdYnraxKA2y81CdwRCQa9Y-vw1qIe_IHhqBWgGaFiQ/LPC214x.h

That's some web address, isn't it! Delete the lpc210x.h file and import the correct one which is lpc214x.h.

4. Rename the Linker Command File

Use the Eclipse right-click menu in the projects view and rename the linker command file to lpc2148.cmd.



5. Change all Text Strings "2106" to "2148"

Basically, search all five files and replace all occurrences of "**2106**" with "**2148**".

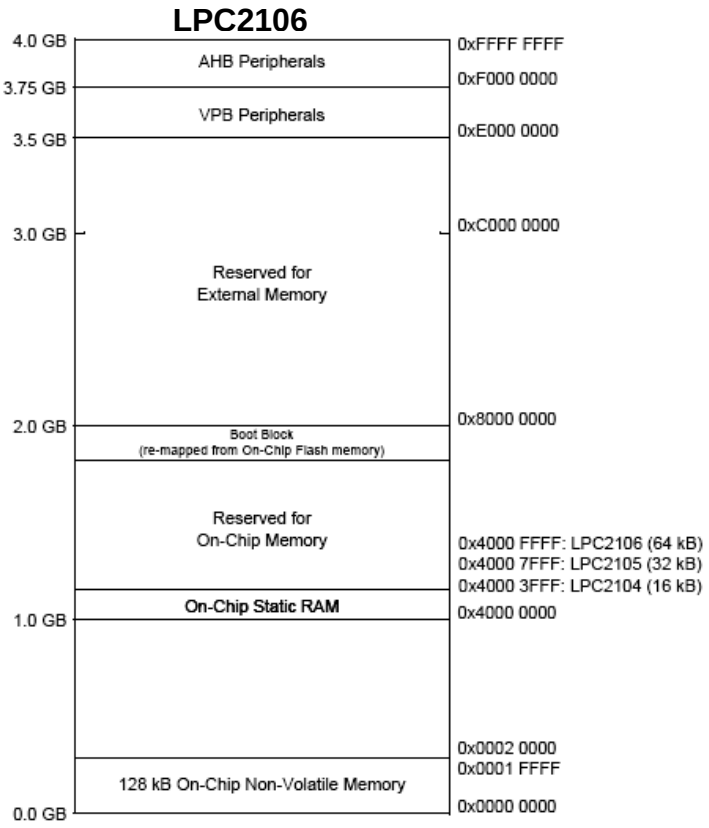
The safest thing to do is to open each file and search/replace using the Edit menu. I found that the "Search" pull-down menu doesn't look at the makefile.

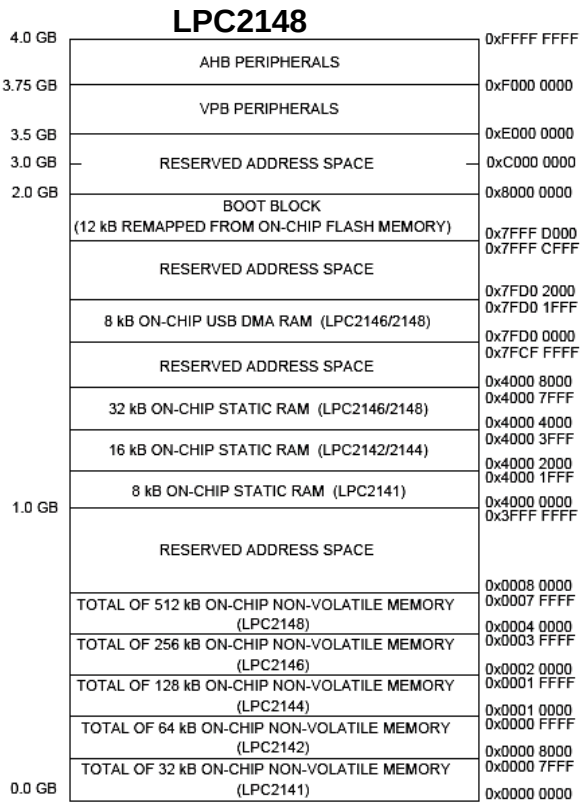
Most of these changes are to annotation, but in the case of the makefile, it effects a filename. The linker command file is a good example.

```
/* ********************************************************************************************
/*   demo2148_blink_flash.cmd              LINKER  SCRIPT
/*
/*
/*   The Linker Script defines how the code and data emitted by the GNU C compiler and assembler
/*   to be loaded into memory (code goes into FLASH, variables go into RAM).
/*
/*   Any symbols defined in the Linker Script are automatically global and available to the rest
/*   program.
/*
/*   To force the linker to use this LINKER SCRIPT, just add the -T demo2148_blink_flash.cmd dire
/*   to the linker flags in the makefile.
/*
/*             LFLAGS  =  -Map main.map -nostartfiles -T demo2148_blink_flash.cmd
/*
/*
```

6. Recalculate the Stacks

The memory maps of the LPC2106 ARM processor and the newer LPC2148 ARM processor are different. The LPC2148 has more FLASH and less RAM. This effects the stack placement.





The end-of-RAM for the LPC2106 is at **0x4000FFFF**. The end of RAM for the LPC2148 is **0x40007FFF** (there also is an 8K RAM block at **0x7FD00000** for USB DMA operations, but we won't use that for the stacks).

The LPC2148 also has 512K of FLASH eprom.

The linker command file has been reproduced in its entirety below. There is extensive annotation showing the new memory map for the LPC2148.

The linker commands that have changed are noted also.

```
/* ********************************************************************************************************* */
/*   demo2148_blink_flash.cmd               LINKER  SCRIPT                                                   */
/*                                                                                                           */
/*                                                                                                           */
/*   The Linker Script defines how the code and data emitted by the GNU C compiler and assembler are         */
/*   to be loaded into memory (code goes into FLASH, variables go into RAM).                                 */
/*                                                                                                           */
/*   Any symbols defined in the Linker Script are automatically global and available to the rest of the      */
/*   program.                                                                                                */
/*                                                                                                           */
/*   To force the linker to use this LINKER SCRIPT, just add the -T demo2148_blink_flash.cmd directive       */
/*   to the linker flags in the makefile.                                                                    */
/*                                                                                                           */
/*             LFLAGS  =  -Map main.map -nostartfiles -T demo2148_blink_flash.cmd                            */
/*                                                                                                           */
/*                                                                                                           */
/*   The Philips boot loader supports the ISP (In System Programming) via the serial port and the IAP        */
/*   (In Application Programming) for flash programming from within your application.                         */
/*                                                                                                           */
/*   The boot loader uses RAM memory and we MUST NOT load variables or code in these areas.                  */
/*                                                                                                           */
/*   RAM used by boot loader:  0x40000120 - 0x400001FF  (223 bytes) for ISP variables                        */
/*                             0x40007FE0 - 0x4000FFFF  (32 bytes)  for ISP and IAP variables                */
/*                             0x40007EE0 - 0x40007FE0  (256 bytes) stack for ISP and IAP                    */
/*                                                                                                           */
/*                                                                                                           */
/*                              MEMORY MAP                                                                   */
/*                       |                                  |0x40008000                                     */
/*             .-------->|----------------------------------|                                               */
/*             .         |     variables and stack          |0x40007FFF                                     */
/*          ram_isp_high |     for Philips boot loader      |                                               */
/*             .         |     32 + 256 = 288 bytes         |                                               */
/*             .         |                                  |                                               */
/*             .         |   Do not put anything here       |0x40007EE0                                     */
/*             .-------->|----------------------------------|                                               */
/*                       |    UDF Stack  4 bytes            |0x40007EDC  <---------- _stack_end             */
/*             .-------->|----------------------------------|                                               */
/*                       |    ABT Stack  4 bytes            |0x40007ED8                                     */
/*             .-------->|----------------------------------|                                               */
/*                       |    FIQ Stack  4 bytes            |0x40007ED4                                     */
/*             .-------->|----------------------------------|                                               */
/*                       |    IRQ Stack  4 bytes            |0x40007ED0                                     */
/*             .-------->|----------------------------------|                                               */
/*                       |    SVC Stack  4 bytes            |0x40007ECC                                     */
/*             .-------->|----------------------------------|                                               */
/*             .         |                                  |0x40007EC8                                     */
/*             .         |     stack area for user program  |                                               */
/*             .         |                |                 |                                               */
/*             .         |                |                 |                                               */
/*             .         |                |                 |                                               */
/*             .         |                V                 |                                               */
/*             .         |                                  |                                               */
/*             .         |                                  |                                               */
/*             .         |                                  |                                               */
/*             .         |          free ram                |                                               */
/*           ram         |                                  |                                               */
/*             .         |                                  |                                               */
/*             .         |                                  |                                               */
/*             .         |..................................|0x40000234 <---------- _bss_end                */
/*             .         |                                  |                                               */
/*             .         |  .bss   uninitialized variables  |                                               */
/*             .         |..................................|0x40000218 <---------- _bss_start, _edata      */
/*             .         |                                  |                                               */
/*             .         |  .data  initialized variables    |                                               */
/*             .         |                                  |0x40000200 <---------- _data                   */
/*             .-------->|----------------------------------|                                               */
/*             .         |     variables used by            |0x400001FF                                     */
/*          ram_isp_low  |     Philips boot loader          |                                               */
/*             .         |           223 bytes              |0x40000120                                     */
/*             .-------->|----------------------------------|                                               */
/*             .         |                                  |0x4000011F                                     */
/*          ram_vectors  |          free ram                |                                               */
/*             .         |----------------------------------|0x40000040                                     */
/*             .         |                                  |0x4000003F                                     */
/*             .         |  Interrupt Vectors (re-mapped)   |                                               */
/*             .         |          64 bytes                |0x40000000                                     */
/*             .-------->|----------------------------------|                                               */
/*                       |                                  |                                               */
/*                                                                                                           */
/*                                                                                                           */
/*                                                                                                           */
/*                       |                                  |                                               */
/*           .--------> |----------------------------------|                                               */
/*           .          |                                  |0x0001FFFF                                     */
/*           .          |                                  |                                               */
/*           .          |                                  |                                               */
/*           .          |                                  |                                               */
/*           .          |                                  |                                               */
/*           .          |                                  |                                               */
```

```
/*           .          |                                |                                                    */
/*           .          |................................|0x0000032c                                          */
/*           .          |                                |                                                    */
/*           .          |      copy of .data area        |                                                    */
/*         flash        |                                |                                                    */
/*           .          |--------------------------------|0x00000314 <---------- _etext                       */
/*           .          |                                |                                                    */
/*           .          |                                |0x00000180  main                                    */
/*           .          |                                |0x00000278  feed                                    */
/*           .          |         main()                 |0x000002c4  FIQ_Routine                             */
/*           .          |                                |0x000002d8  SWI_Routine                             */
/*           .          |                                |0x000002ec  UNDEF_Routine                           */
/*           .          |                                |0x000002b0  IRQ_routine                             */
/*           .          |--------------------------------|0x000001cc  initialize                              */
/*           .          |                                |0x000000D4                                          */
/*           .          |         Startup Code           |                                                    */
/*           .          |         (assembler)            |                                                    */
/*           .          |                                |                                                    */
/*           .          |--------------------------------|0x00000040 Reset_Handler                            */
/*           .          |                                |0x0000003F                                          */
/*           .          | Interrupt Vector Table (unused)|                                                    */
/*           .          |          64 bytes              |                                                    */
/*           .--------->|--------------------------------|0x00000000 _startup                                 *
/*                                                                                                           */
/*                                                                                                           */
/*    The easy way to prevent the linker from loading anything into a memory area is to define              */
/*    a MEMORY region for it and then avoid assigning any .text, .data or .bss sections into it.            */
/*                                                                                                           */
/*                                                                                                           */
/*             MEMORY                                                                                        */
/*             {                                                                                             */
/*                ram_isp_low(A)  : ORIGIN = 0x40000120, LENGTH = 223                                        */
/*                                                                                                           */
/*             }                                                                                             */
/*                                                                                                           */
/*                                                                                                           */
/*  Author:  James P. Lynch                                                                                  */
/*                                                                                                           */
/* ********************************************************************************************************* */


/* identify the Entry Point  */

ENTRY(_startup)
```

```
/* specify the LPC2148 memory areas  */

MEMORY
{
    flash               : ORIGIN = 0,          LENGTH = 512K    /* FLASH ROM                                */
    ram_isp_low(A)      : ORIGIN = 0x40000120, LENGTH = 223     /* variables used by Philips ISP bootloader */
    ram                 : ORIGIN = 0x40000200, LENGTH = 32513   /* free RAM area                            */
    ram_isp_high(A)     : ORIGIN = 0x40007FE0, LENGTH = 32      /* variables used by Philips ISP bootloader */
    ram_usb_dma         : ORIGIN = 0x7FD00000, LENGTH = 8192    /* on-chip USB DMA RAM area (not used)      */
}


/* define a global symbol _stack_end  */

_stack_end = 0x40007EDC;


/* now define the output sections  */

SECTIONS
{
    . = 0;                              /* set location counter to address zero  */

    startup : { *(.startup)} >flash     /* the startup code goes into FLASH */



    .text :                             /* collect all sections that should go into FLASH after startup  */
    {
        *(.text)                        /* all .text sections (code)  */
        *(.rodata)                      /* all .rodata sections (constants, strings, etc.)  */
        *(.rodata*)                     /* all .rodata* sections (constants, strings, etc.)  */
        *(.glue_7)                      /* all .glue_7 sections  (no idea what these are) */
        *(.glue_7t)                     /* all .glue_7t sections (no idea what these are) */
        _etext = .;                     /* define a global symbol _etext just after the last code byte */
    } >flash                            /* put all the above into FLASH */

    .data :                             /* collect all initialized .data sections that go into RAM  */
    {
        _data = .;                      /* create a global symbol marking the start of the .data section  */
        *(.data)                        /* all .data sections  */
        _edata = .;                     /* define a global symbol marking the end of the .data section  */
    } >ram AT >flash                    /* put all the above into RAM (but load the LMA copy into FLASH) */

    .bss :                              /* collect all uninitialized .bss sections that go into RAM  */
    {
        _bss_start = .;                 /* define a global symbol marking the start of the .bss section */
        *(.bss)                         /* all .bss sections  */
    } >ram                              /* put all the above in RAM (it will be cleared in the startup code */

    . = ALIGN(4);                       /* advance location counter to the next 32-bit boundary */
    _bss_end = . ;                      /* define a global symbol marking the end of the .bss section */
}
    _end = .;                           /* define a global symbol marking the end of application RAM */
```

7. PLL Setup

The Olimex LPC-P2148 board has a 12 mhz crystal. The setup of the phased lock loop (PLL) must be revised.

On page 34 of the LPC214x User Manual are two examples of how to calculate the needed PLL initialization values. One example is for a system without USB and the other one is for an application that does employ the USB. This tutorial does NOT use the USB version.

Fosc = 12000000 hz (crystal frequency)
Fcco = 2 (PLL current controlled oscilator frequency)
cclk = 60000000 hz (desired system clock)

$$M = \frac{cclk}{Fosc} = \frac{60000000}{12000000} = 5 \quad \text{(PLL multiplier value)}$$

Therefore, we write M-1 or 4 into the 5 bits of the PLLCFG register.

PLLCFG[4 : 0] = 00100

The PLL divider value, P, must have one of the values 1, 2, 4, 8.

$$P = \frac{Fcco}{Cclk * 2}$$ as long as Fcco is in the range of 156 Mhz to 320 Mhz

Let's calculate the high and low limits of Fcco

$$P = \frac{156000000}{60000000 * 2} = 1.3 \quad (156\ Mhz)$$

$$P = \frac{320000000}{60000000 * 2} = 2.6 \quad (320\ Mhz)$$

Obviously, the highest value of P that we can pick is 2. This value will not exceed the limitation that Fcco is less than 320 Mhz.

Therefore, we look at Table 22 of the Philips LPC214x User Guide and see that a value of P = 2 will require us to enter binary 01 into bits 6-5 of the PLLCFG register.

PLLCFG = 0 01 00100 = 0x24

The only change to the initialize() code in the main.c source code is the setting of the PLL configuration register, as shown below.

```
// Setting Multiplier and Divider values
PLLCFG=0x24;
feed();

// Enabling the PLL */
PLLCON=0x1;
feed();

// Wait for the PLL to lock to set frequency
while(!(PLLSTAT & PLOCK)) ;

// Connect the PLL as the clock source
PLLCON=0x3;
feed();

// Enabling MAM and setting number of clocks used for Flash memory fetch (4 cclks in this case)
MAMCR=0x2;
MAMTIM=0x4;

// Setting peripheral Clock (pclk) to System Clock (cclk)
VPBDIV=0x0;
```

8. Controling the LED I/O Port

There are two things to consider here. First, the Olimex LPC-P2106 board had the LED attached to port P0.7 while the newer LPC-P2148 board has two LEDs. LED1 is attached to port P0.10.

Also, the LPC2148 has the new “fast” I/O ports; designed to satisfy the scores of customers who complained about how slow the toggle rate was on the LPC2106 ports.

In the code snippet from main.c below, note that we set the System Control and Status Flags Register (**SCS**) to enable the “fast” I/O ports. The LED1 is in the port 0 setup, so that is identified as **FIO0xxx** in the lpc214x.h file.

MAIN.C Code Snippet

```
// set io pins for led P0.10
SCS = 0x03;             // select the "fast" version of the I/O ports
FIO0DIR |= 0x00000400;  // pin P0.10 is an output, everything else is input after reset
FIO0SET =  0x00000400;  // led off
FIO0CLR =  0x00000400;  // led on


// endless loop to toggle the red  LED P0.7
while (1) {

    for (j = 0; j < 5000000; j++ );     // wait 500 msec
    FIO0SET = 0x00000400;                   // red led off
    for (j = 0; j < 5000000; j++ );     // wait 500 msec
    FIO0CLR = 0x00000400;                   // red led on
}
```

This completes the conversion of the flash-based demo2106_blink_flash project to the LPC2148 processor. I noticed that the JTAG/Wiggler works much better on this Olimex board, this might be a result of every JTAG pin now having 10K pull-up and pull-down resistors.

For those readers planning to port these example projects to other manufacturers; this will be much more difficult. Programming onboard flash is usually different. Layout of the I/O pins will certainly be different. There is no substitute for detailed and careful reading of the manufacturer’s User Manuals.

APPENDIX 2 - Cygwin Heap Allocation Problems

Quite unexpectedly, my cygwin/gnuarm system started occasionally crashing due to a "heap allocation" problem. This can occur during any of the gnuarm utilities (C compiler, assembler, objdump, etc.)

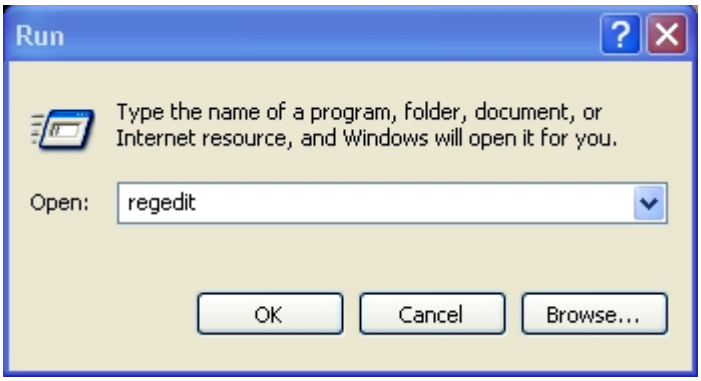
This is a typical error message:

.compiling
arm-elf-gcc -I./ -c -fno-common -O0 -g main.c
*c:\program files\gnuarm\bin\arm-elf-gcc.exe (3828): *** couldn't*
allocate cygwin heap, Win32 error 487, base 0x480000, top 0x48A000,
reserve_size 40960, allocsize 40960, page_const 4096
7 [main] arm-elf-gcc 968 fork_parent: child 3828 died waiting
for longjmp before initialization
make: Target `all' not remade because of errors.

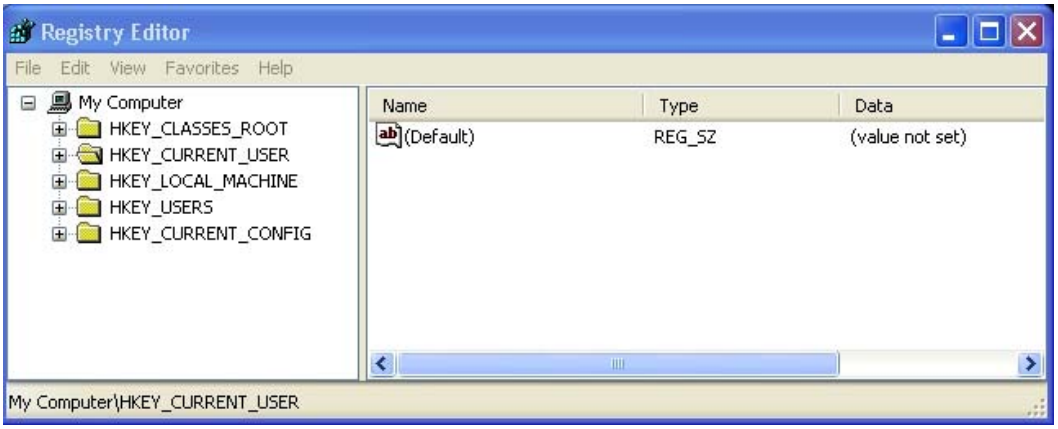
In this situation, you may have to change Cygwin's maximum memory. The following is a link to the Cygwin description of the procedure.

http://www.cygwin.com/cygwin-ug-net/setup-maxmem.html

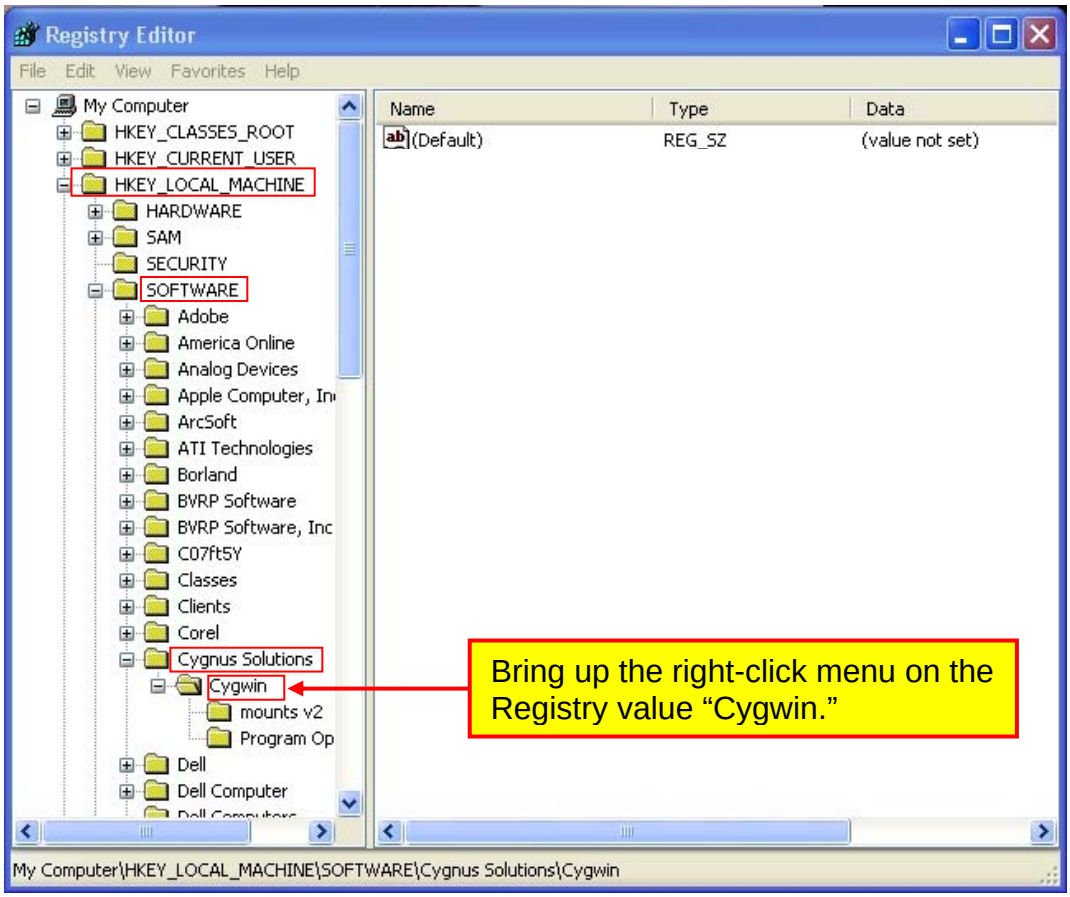
To change Cygwin's maximum memory, click on "**Start – Run**" and run the program "**regedit**"



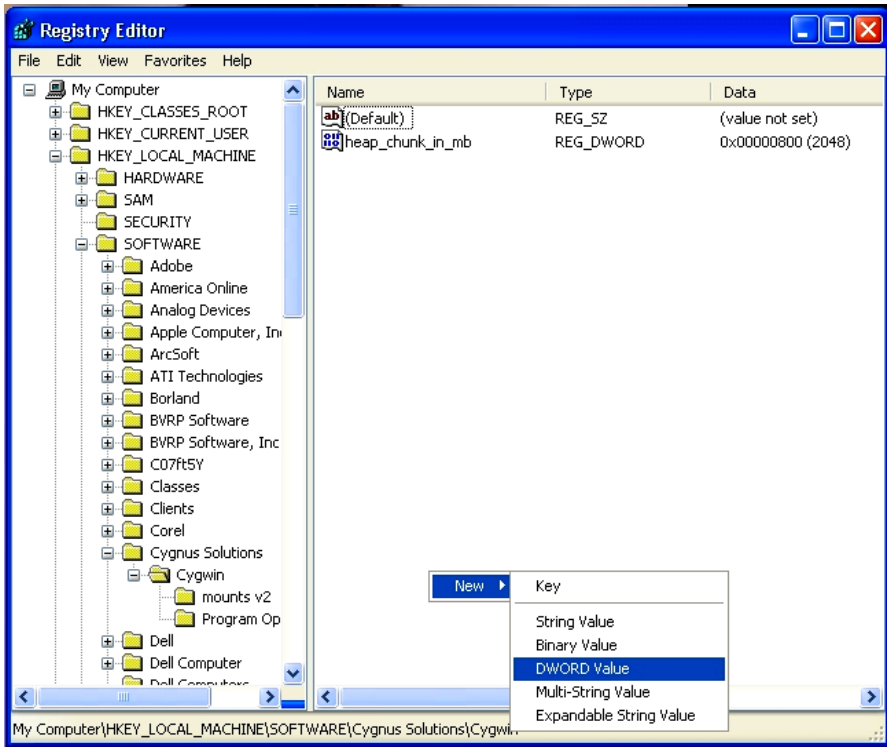
When the Registry Editor starts up, you should see the following:



Click on **HKEY_LOCAL_MACHINE – SOFTWARE – Cygnus Solutions – Cygwin**" and you will see the following display.



Enter a new **DWORD** entry "**heap_chunk_in_mb**" = **0x0000800** (256 mb)" as shown below.



Reboot your computer and pray!