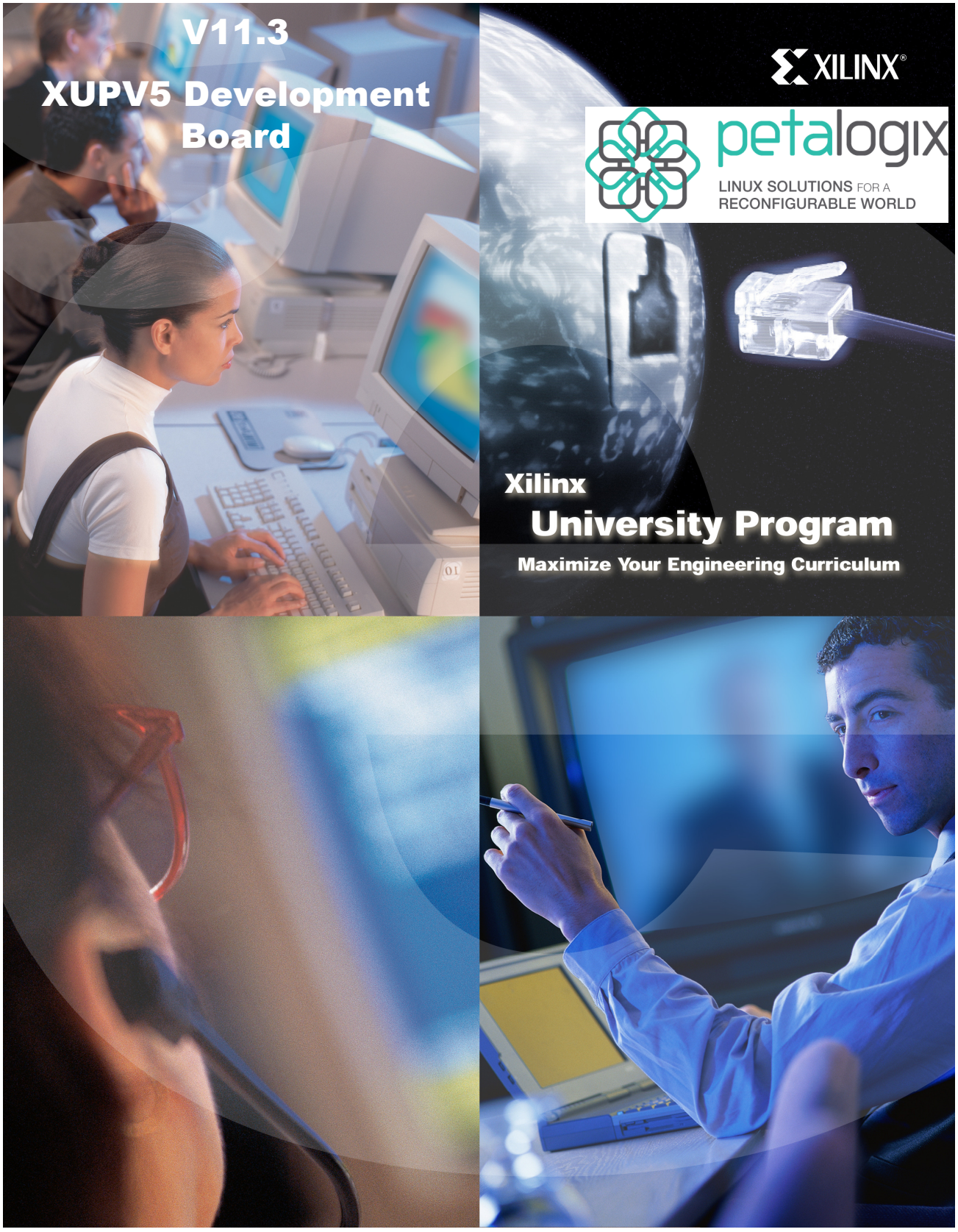
Embedded Linux on Xilinx MicroBlaze

Lab Manual



Lab 1.1 – A First Look

Rationale

Embedded Linux is the use of a Linux operation system in embedded systems. Unlike desktop and server versions of Linux, embedded versions of Linux are designed for devices with relatively limited resources. MicroBlaze is a soft processor core designed for Xilinx FPGAs; it supports Embedded Linux. In most labs of this XUP workshop, we will run Embedded Linux on MicroBlaze.

Objectives

- Learn how to power-on the development board used in the workshop
- Learn how to login to the MicroBlaze Linux system
- Make comparisons between the embedded Linux and desktop Linux environments

Introduction

This first lab session is a basic introduction to embedded Linux, and the development boards that we are using for the workshop. The basic activities covered here will be used repeatedly through the later Lab sessions, so please be sure to ask if you have any questions or concerns.

Time

This lab session will run for approximately 15 minutes.

Typographic Conventions

Commands and directory names are typeset in a `non-proportional font`. Commands to be executed on the development (desktop) workstation are like this:

```
[host]$ command and parameters
```

while commands to be executed on the MicroBlaze Linux target look like this:

```
# run my Linux application
```


Before You Start

- Ensure the power switch is in 'off' position.
- Ensure the JTAG cable is connecting the development board to the PC.
- Ensure the serial cable is connecting the development board to the PC.
- Ensure power cable for the development board is connected.
- Ensure the Ethernet port on the development board is connected to the 10/100 Ethernet.

Initializing the Workshop Environment

By default, your CentOS image has already setup the workshop environment for you. If you want to set up the working environment manually in future, please refer to the section "Workshop preparation" in the Appendix at the end of this lab1.1 manual.

Powering up the Board and logging in

Put the power switch to "`on`" position to apply power to the MicroBlaze Linux system.

Watch the `kermit` terminal as it goes through the Linux boot process. Messages similar to the following should be seen on the `kermit` console:

```
0x00000000-0x00168000 : "ROMfs"
uclinux[mtd]: set ROMfs to be root filesystem index=6
TCP cubic registered
NET: Registered protocol family 1
NET: Registered protocol family 17
VFS: Mounted root (cramfs filesystem) readonly.
Freeing unused kernel memory: 88k freed
Mounting proc:
Mounting var:
Populating /var:
Running local start scripts.
Mounting /etc/config:
Populating /etc/config:
flatfsd: Created 6 configuration files (192 bytes)
Mounting sysfs:
Setting hostname:
Setting up interface lo:
Setting up interface eth0:
Starting portmap:
Starting httpd:

uclinux login:
```

When prompted, login as "root", using password "root" (no quotes)

Exploring

It is interesting to scroll the terminal up and review the bootup log – existing Linux users will recognize much of the output (as they should, it's the same operating system!)

Spend the next 15 minutes exploring! Most of the usual Linux commands are available:

```
ls, vi, cat, gpio-test&
```

Executing:

```
# ls /bin
```

will list the applications currently installed.

Executing `gpio-test` will test the GPIOs which are DIP switches, LEDs and push buttons:

- `e.g.  # gpio-test -d /dev/gpio1 -o 0x1`
  This command will output '0x1' to GPIO LEDs. Watch the status change on the 8 GPIO LEDs on the board.
- e.g. Put any one of the DIP switches to "on" position and type:
  `# gpio-test -d /dev/gpio0 -i`
  The input from the DIP switches will be shown on the `kermit` window.

Another interesting place to explore is the `/proc` directory. This is a virtual directory that provides a window into the kernel. For example, the file `/proc/cpuinfo` contains details about the CPU. `/proc/interrupts` gives interrupt statistics, and so on.
E.g.

```
# cat /proc/cpuinfo
CPU-Family:     MicroBlaze
FPGA-Arch:      spartan3e
CPU-Ver:        7.20.c
CPU-MHz:        50.00
BogoMips:       24.72
HW-Div:         no
HW-Shift:       yes
Icache:        2kB
Dcache:        2kB
HW-Debug:       yes
# cat /proc/interrupts
           CPU0
  0:       7285     level OPB-INTC  timer
  1:          7      edge OPB-INTC  eth0
  2:        212      edge OPB-INTC  uartlite
#
```

The contents of `/proc/cpuinfo` and `/proc/interrupts` shown as the above are just an

example. Your results could be different from it. The details in `/proc/cpuinfo` depends on the underlined FPGA system while the details in `/proc/interrups` depends on the number of interrupts that have happened in the system.

`/tmp` is a writable temporary file system, you can create and edit files there.

`/dev` contains entries for various devices in the system. `/dev/console` is the main console – you could try copying a file to `/dev/console`, see what happens.
E.g.

```
# cp /etc/inetd.conf /dev/console
80 stream tcp nowait root /bin/httpd /home/httpd
ftp     stream tcp nowait root /bin/ftpd -l
dungeon stream tcp nowait root /bin/dungeon
telnet  stream tcp nowait root /bin/telnetd
```

Another thing to note is the standard Linux directory structure - `/bin`, `/dev`, `/tmp`, `/var` and so on. Open up another terminal window on the desktop machine and browse around, see how similar they are. `/proc` is also there in the desktop linux box – try comparing some of the numbers in `/proc/cpuinfo`

If you have time, try `dungeon`! ("e" for east, "w " for west, "s" for south and "n" for north")

Outcomes

The purpose of this lab session was to introduce you to the embedded Linux target, and demonstrate its heritage in the desktop Linux genealogy. This is one of the immediate benefits of embedded Linux, as an application and user environment, it has tremendous commonality with standard desktop Linux platforms.

Although brief, this introduction should have prepared you with some basic experience in powering on, logging into, and navigating around the embedded Linux target. These basic capabilities will be expanded upon in subsequent lab sessions.

Appendix

Working Environment Preparation

In the structured workshop environment, all of the necessary setup procedures have already been completed for you. The following instructions provide a brief overview of the steps necessary to preapre for PetaLinux work on a standard workstation, that has not been specially prepared for this workshop.

To set up a proper working environment, we need to set up Xilinx environment to work on the

hardware projects; set up PetaLinux environment to work on embedded Linux projects and a serial console to monitor and control the embedded system. This section talks about how to set up these working environment in details.

Set up Xilinx Environment

Xilinx Environment setup is necessary to develop a hardware project with Xilinx tools. Here are the steps to set up Xilinx environment:

- Right click your mouse on the Desktop and select "Open Terminal" to open a terminal.
- In the terminal, `source` the Xilinx settings script:

```
[host] $ source <Path to the installed Xilinx ISE>/settings32.sh
[host] $ source <Path to the installed Xilinx EDK>/settings32.sh
```

  In our CentOS image, the Xilinx ISE is installed in /`opt/pkg/xilinx/11.3/ISE` and the Xilinx EDK is installed in `/opt/pkg/xilinx/11.3/EDK`.

  Use `settings32.sh` for bash derivatives while `settings32.csh` for C shell/tcsh.

- Confirm the Xilinx environment variables are set:

```
[host] $ set
```

  The following text should be shown in the console.

```
XILINX=<Path to the installed Xilinx ISE>
XILINX_EDK=<Path to the installed Xilinx EDK>
```

  From the result of `set` command, you can also see the `PATH` environment variable is also updated to include Xilinx tool chain at the front.

- Make sure we are allowed to read and write the JTAG driver because we need JTAG to program the FPGA. Below is the command to make all the users in the host system to have read/write permission to the JTAG driver `/dev/windrvr6`:

```
[host] $ sudo chmod a+wr /dev/windrvr6
```

Set up PetaLinux Environment

PetaLinux environment setup is necessary to develop embedded Linux with PetaLinux tools. Here are the steps to set up PetaLinux environment:

- Go to the PetaLinux root directory to source the PetaLinux settings script:

```
[host] $ cd <Path to the PetaLinux root directory>
[host] $ source settings.sh
```

  In our CentOS image, the PetaLinux root directory is installed in `~/petalinux`.

Use `settings32.sh` for bash derivatives while `settings32.csh` for C shell/tcsh.

- Confirm the PetaLinux environment variables are correctly set:

```
[host] $ set
```

Scroll the output from this command on the console, you should find the following text:

```
PETALINUX=<Path to the PetaLinux root directory>
PETALINUX_VER=<PetaLinux Version>
```

From the result of `set` command, you can see the `PATH` environment variable is also updated to include PetaLinux tool chain.

Set up Serial Terminal Console

A serial terminal console is necessary to monitor and control the embedded Linux system running on the target board. There are different serial console applications can be used such as `minicom`, `kermit` and so on. This section talks about how to setup `kermit` only.

By default, `kermit` executes commands from a file called `.kermrc` in your home directory when it starts. For convenience, we can put serial console setting commands in the `~/.kermrc` file. Here are the steps to put serial console setting commands in the `~/.kermrc` file.

- Create `~/.kermrc` file or open it if it already exists by Linux editor such as `vi` or `gedit`:

```
[host] $ vi ~/.kermrc
```

- Put the `kermit` settings to the .`kermrc` file. The most important ones are the serial port device file and the baud rate . Here is an example of a `.kermrc` file:

```
set line /dev/ttyUSB0
set speed 115200
set carrier-watch off
set handshake none
set flow-control none
robust
set file type bin
set file name lit
set rec pack 1000
set send pack 1000
set key \127 \8
set key \8 \127
set window 5
```

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Lab 1.2 – Built and Boot an Image

Rationale

The most basic skill required for developing with Embedded Linux is working in the cross-compilation environment – compiling the kernel, libraries and applications, and downloading the resulting images onto the embedded target. The purpose of this lab session is to familiarize you with this process.

Objectives

- Gain a basic understanding of the uCLinux configuration menus, including
  - how to configure a default uClinux kernel and user environment
- Build the Microblaze uClinux kernel and applications
- Download the resulting system image to the development board

Introduction

This lab session will prepare you for the most basic task of working with embedded Linux – how to build and boot the operating system and applications. Small embedded Linux targets, like the MicroBlaze, are usually developed in a cross-compilation environment. This means that the kernel and applications are compiled on a development machine (in this case, a Linux PC), and then downloaded onto the target.

The standard uClinux-distribution, or "dist" for short, contains a number of tools and a configuration architecture that automates much of this process. In the following, you will learn how to use these tools, and how to download the resulting embedded Linux image onto the hardware platform.

Time

This session will run for approximately 30 minutes.

Preparation

If this is the first lab you are doing then please refer to sections "Before You Start" of Lab 1.1 document for necessary preparatory information on how to setup the hardware environment.

Lab overview

The following diagram is a high level overview of the steps taken in this Lab:

Choose a Linux Platform

A Linux platform tells what to build into the Linux image; it tells the following information:

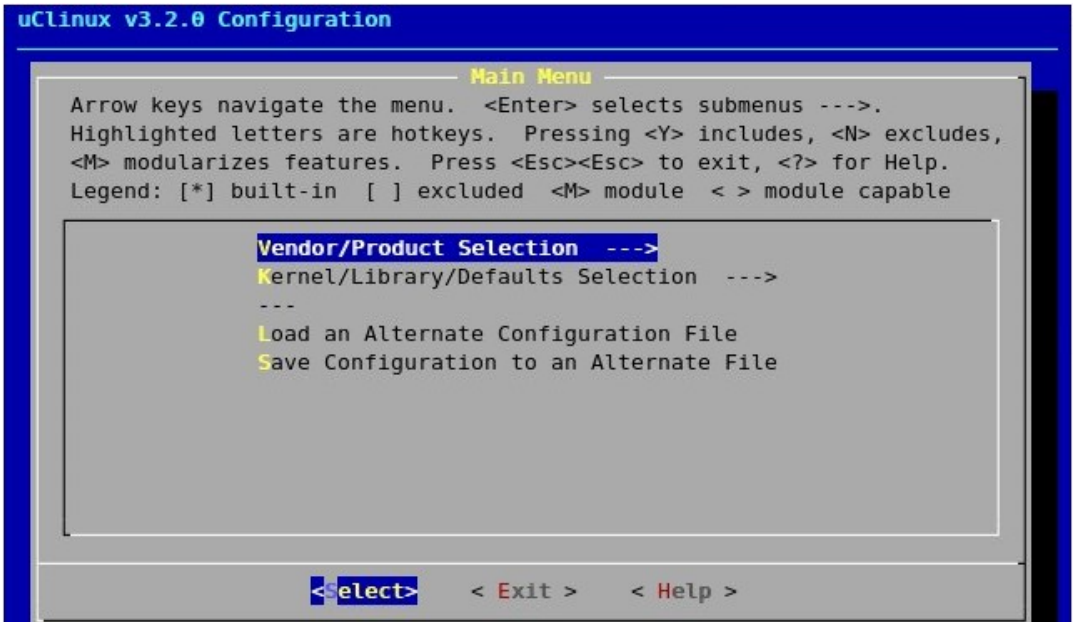
- the hardware platform information such as address mapping, the processor's characteristics and so on;
- the Linux kernel settings;
- User space applications settings;
- File system settings;
- FLASH partition table settings.

To build a Linux image, we need a platform. So, at first, we select a platform. There are some pre-configured reference platforms in PetaLinux. In this lab, we will choose the one for our development board. Here are the steps to to select a platform:

- Launch PetaLinux menuconfig on the Linux host:

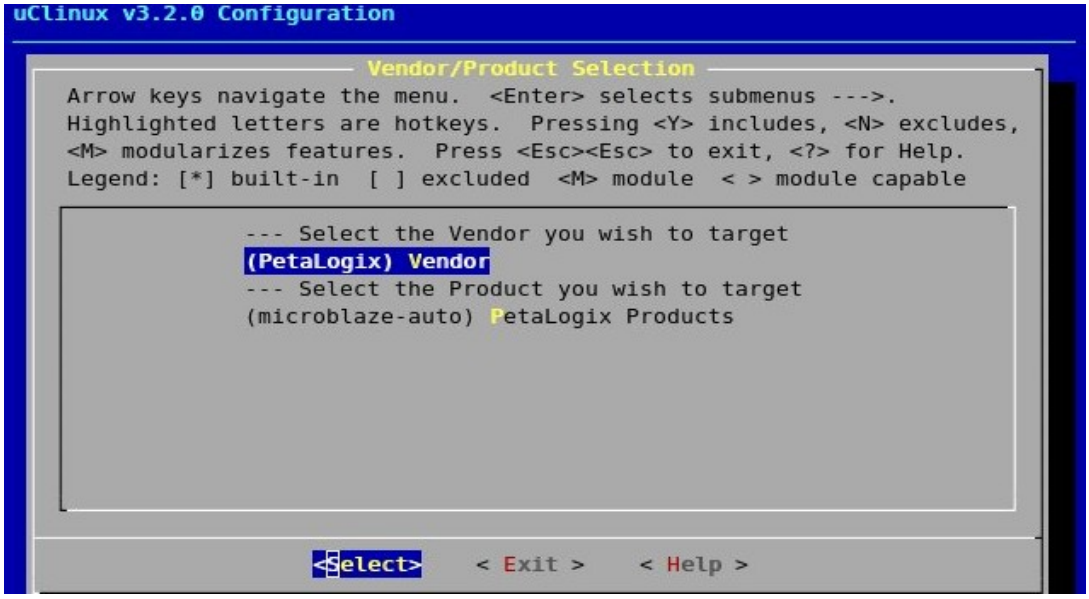
```
[host] $ cd ~/petalinux/software/petalinux-dist
[host] $ make menuconfig
```

- The Linux menu configuration system will display:

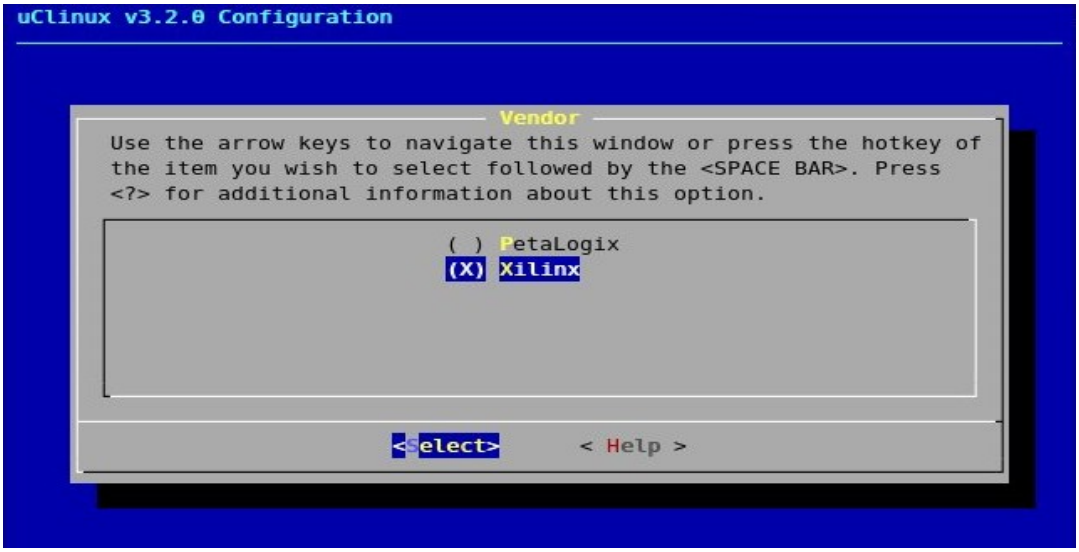


Tips:
You can use arrow keys to navigate the menu.
↑↓ :scroll up and down in the menu;
← → :move left and right among <Select>, <Exit> and <Help> at the bottom;
<Select>: If it is highlighted, pressing <Enter> selects the highlighted option in the menu;
<Exit>: If it is highlighted, pressing <Enter> exits the menu;
<Help>: If it is highlighted, pressing <Enter> shows the help text of the highlighted option in the menu.

- Select "Vendor/Product Selection" from "Main Menu" by highlighting and pressing enter, and then the "Vendor/Product Selection" Menu will display:

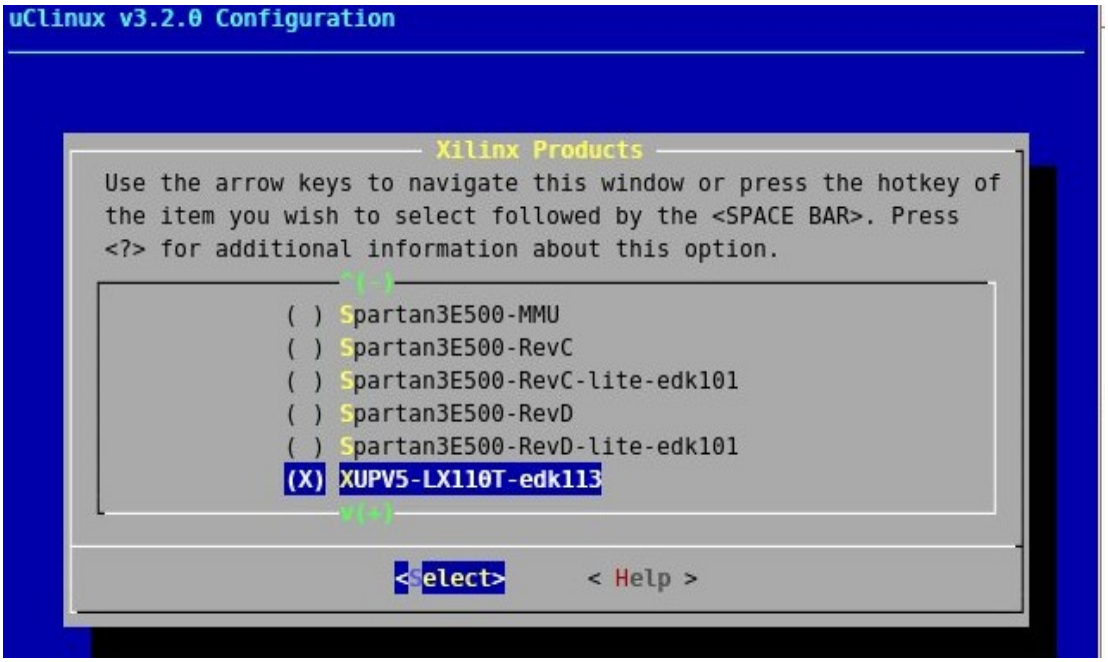


- Move down to the "Vendor" selection, press Space or Enter to select it, the "Vendor" menu will pop up
  - Select "Xilinx" from the vendors list:



- Move down to "`Xilinx Products`" selection in "Vendor/Product Selection" menu, press Space or Enter.

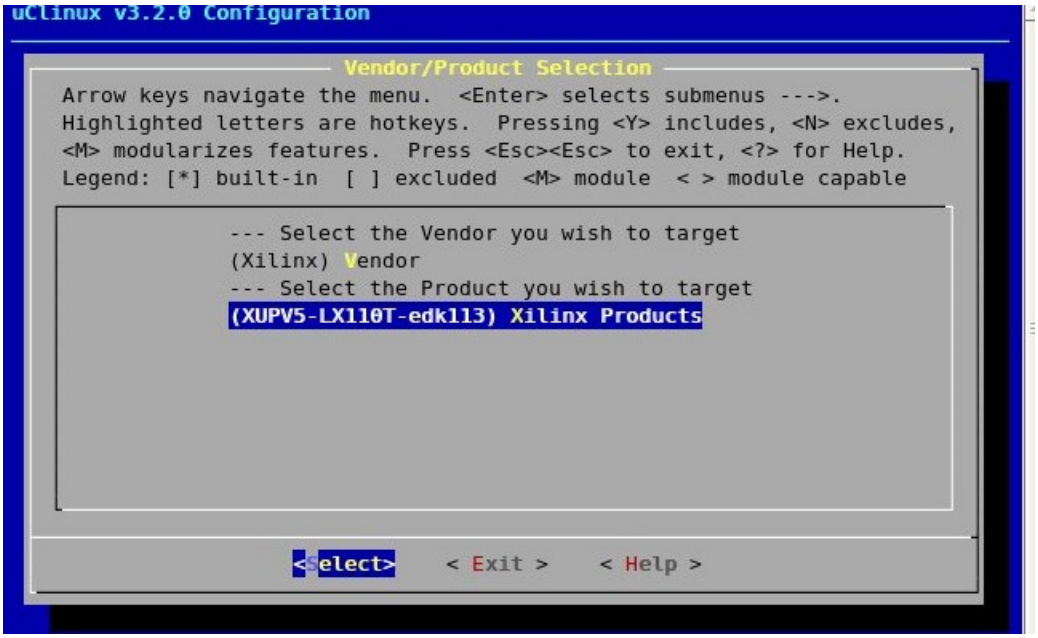
- Select "`-edk113`" from the "Xilinx Products" list.



Tips:
The the "^(-)" at the top of the menu indicates you can scroll up to see more options; the "v(+)" at the bottom of the menu indicates you can scroll down to see more options.

We are using non-MMU configurations in this lab, please don't select the MMU one which is "`-MMU-edk113`".

Here is the "Vendor/Product Selection" snapshot after selecting the desired vendor and the product:



Press <Esc> to Exit, then "Yes" when asked if you want to save your kernel configuration.

Now, we have selected a platform, let's move on to build a Linux image based on this platform.

Make a Fresh Image

Make everything by executing the following command in the `~/petalinux/software/petalinux-dist` directory by executing:

```
[host] $ make
```

This may take a few minutes. In this time, the following are occurring:

- Compiling and linking the Linux kernel (linux-2.6.x/*)
- Compiling and archiving the C libraries (uClibc/*)
- Compiling and linking the default user applications (user/*)
- Converting these applications to the uClinux flat binary format
- Building a local image of the MicroBlaze Linux root file system (romfs/*)
- Assembling the kernel and file system image into a single downloadable binary image file (images/*)
- Copying the image files in from images/ to /tftpboot

If you are prompted to provide values for any configuration parameters, simply press enter to accept the default.

Once completed, look in the images subdirectory by executing:

```
[host] $ ls -1s images
```

Example output:

```
total 24336
3300 image.bin
3568 image.elf
9844 image.srec
3300 image.ub
1908 linux.bin
1392 romfs.img
  16 romfs-inst.log
   4 rootfs.cpio
   8 ub.config.img
 116 u-boot.bin
 116 u-boot-s.bin
 116 u-boot-s.elf
 332 u-boot.srec
 332 u-boot-s.srec
```

You can see the various components that constitute the final image – linux.bin and romfs.img.

Also, examine the contents of the `/tftpboot` directory by executing:

```
[host] $ ls /tftpboot
```

All the image files in `~/petalinux/software/petalinux-dist/images` directory have a copy in `/tftpboot`, because as part of the build process, the images file have also been copied there. The development machine has been configured as a TFTP (trivial FTP) server, allowing the board to pull new kernel images directly over the network. We will use this capability in the next exercise.

Image Name	Descriptions
Linux Kernel and System Images	
`image.bin`	The Linux kernel and root filesystem image in binary format
`image.elf`	The Linux kernel and root filesystem image in ELF format
`image.srec`	The Linux kernel and root filesystem image in SREC format
`image.ub`	The Linux kernel and root filesystem image in U-Boot format
`linux.bin`	Binary image - kernel only, no filesystem
`romfs.img`	The ROMFS image in binary format
U-Boot	
`u-boot.bin`	The U-Boot image in binary format
`u-boot.srec`	The U-Boot image in SREC format
`u-boot.elf`	The U-Boot image in ELF format
`u-boot-s.bin`	The relocatable U-Boot image in binary format
`u-boot-s.elf`	The relocatable U-Boot image in ELF format
`u-boot-s.srec`	The relocatable U-Boot image in SREC format
`ub.config.img`	U-Boot platform configuration script in binary format

Booting the New Image

- Check the host's IP address to make sure it is 192.168.0.1 by executing:

```
[host] $  /sbin/ifconfig
```

- Power on the development board.
- Watch the booting process on kermit window.
- Hit any key to stop auto-boot when messages similar to the following are shown in the kermit window:

```
================================================
FS-BOOT First Stage Bootloader (c) 2006 PetaLogix
================================================
FS-BOOT: System initialisation completed.
FS-BOOT: Booting from FLASH. Press 's' for image download.
FS-BOOT: Booting image...
SDRAM :
        Enabling caches :
                Icache:OK
                Dcache:OK
        U-Boot Start:0x8ffc0000
        Malloc Start:0x8ff80000
        Board Info Start:0x8ff7ffd0
        Boot Parameters Start:0x8ff6ffd0
FLASH: 16 MB
ETHERNET: MAC:00:0a:35:00:22:01

Hit any key to stop autoboot:  4
```

- Download and boot the new image using TFTP by executing this command in the u-boot console (the kermit console):

```
U-Boot> run netboot
```

This command will download the (`image.ub`) from `/tftpboot` on host to the main memory of the MicroBlaze system, decompress the image and boot the system with the image.

Watch the kermit window. Messages similar to the following show the image download progress:

```
Hit any key to stop autoboot:  0
U-Boot> run netboot
TFTP from server 192.168.0.4; our IP address is 192.168.0.10
Filename 'image.ub'.
Load address: 0x88002000
Loading: #################################################################
         #################################################################
         #################################################################
         #################################################################
         #################################################################
         #################################################################
         #################################################################
         #################################################################
         ######
done
Bytes transferred = 3023056 (2e20d0 hex)
```

The `netboot` command will automatically boot the system as soon as finish downloading the image.

Watch the booting messages on the kermit window; the message which is similar to the following can be found.

```
## Booting image at 88002000 ...
   Image Name:   PetaLinux Kernel 2.6
   Image Type:   Microblaze Linux Kernel Image (uncompressed)
   Data Size:    3022992 Bytes =  2.9 MB
   Load Address: 88000000
   Entry Point:  88000000
   Verifying Checksum ... OK
OK
Found romfs @ 0x881b608c (0x0012c000)
#### klimit 881ce000 ####
Moving 0x0012c000 bytes from 0x881b608c to 0x881cd868
New klimit: 0x882fa000
Linux version 2.6.20-uc0 (centos@localhost) (gcc version 3.4.1 ( PetaLinux
0.20 Build -rc1 050607 )) #2 Wed Oct 21 17:10:24 EST 2009
setup_cpuinfo: initialising
setup_cpuinfo: No PVR support in CPU.  Using static compile-time info
set_cpuinfo_static: Using static CPU info.
setup_memory: max_mapnr: 0x8bfff
```

This message shows when the image is built.

Other booting messages are the same as lab 1.1 because we use the default configuration.

Move On

If you have time, try 'petalinux-jtag-boot' to boot the MicroBlaze system using JTAG.

- petalinux-jtag-boot
  - Change to "`~/petalinux/hardware/reference-designs/Xilinx--edk113`" directory on the Linux host by executing:

```
[host]$ cd ~/petalinux/hardware/reference-designs/Xilinx--edk113
```

  - Execute petalinux-jtag-boot to download and boot the image:

```
[host]$ petalinux-jtag-boot -t 0 -a 0x50000000 -i /tftpboot/image.bin
```

Here is the explanation of the commonly used `petalinux-jtag-boot` parameters:

- -t – The target CPU (0 to N-1). In this lab, we have only one MicroBlaze, we put "0" to this parameter.
- -a – The load address of the image. We use the base address of the main mememory.
- -i – image file. We use image.bin in this lab.

The `petalinux-jtag-boot` uses Xilinx XMD utility to boot the system. After entering the command, messages similar to the following one will be shown on the host console in which the command is input in one or two minutes.

```
Downloading /tftpboot/image.bin to target 0 at 0x50000000
System Reset .... DONE
Downloading Data File -- /tftpboot/image.bin at 0x50000000

Booting target 0 at 0x50000000
Info:Processor started. Type "stop" to stop processor

RUNNING> Booting MicroBlaze is still in progress.
Please wait until the shell prompt shows...
[host]$
```

Use Completed Resource

The completed Linux image for this lab is available in ~/xup_materials/labs/lab1.2/completed/. If you are stuck in any problem in the lab, you are welcome to use the completed resource. Here is the instruction on how to use the completed resource:

- Copy the completed Linux images to /tftpboot directory by executing the following command on the host::

  ```
  [host] $ ~/xup_materials/complete_lab 1.2
  ```

- Boot the board with tftp as usual. You are now able to complete the on-board activities of this

lab worksheet.

Outcomes

In this lab session, you have learned how to

- select a default vendor/product combination in the configuration menu
- build a default kernel and uclinux image
- download a new image to the board, via Ethernet

These capabilities will be used in subsequent workshop lab sessions, please ask the instructors if you have any questions!

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Lab 1.3 – Application Development and Debug

Rationale

PetaLinux allows you to easily write your application and and build it into the embedded Linux image. In most cases, you write your application on your general computer system instead of the embedded system on which the Embedded Linux runs. In those cases, we need cross compilation. PetaLinux provides tools to cross compile the Embedded Linux application on Desktop Linux.
GDB is the standard debugger for the GNU software system. It is a portable debugger running on many Unix-like systems. With GDB you are allowed to debug your application running on the target remotely.

Objectives

- Create a simple user application with PetaLinux tools
- Build the new user application by cross-compilation and added it into the system image.
- Run the application on the development board
- Debug the application using GDB.

Introduction

In previous sessions you have learned how to configure and build the standard embedded Linux target for a MicroBlaze system. While the embedded Linux distribution contains a large number of useful applications and utilities, it is very likely that to achieve your purposes you will need to write your own application programs, and include them in the final image to download onto the board.

That is the goal of this lab session – to write, build, and run your own application on the MicroBlaze target. The example application will be simple, however the concepts and principles all apply directly to large, complex applications.

This session builds directly on the skills learned in previous sessions, specifically building and booting the Linux system and logging in to the MicroBlaze Linux system. Refer to earlier lab session worksheets if you have any doubts about these processes, or speak to your instructor.

Time

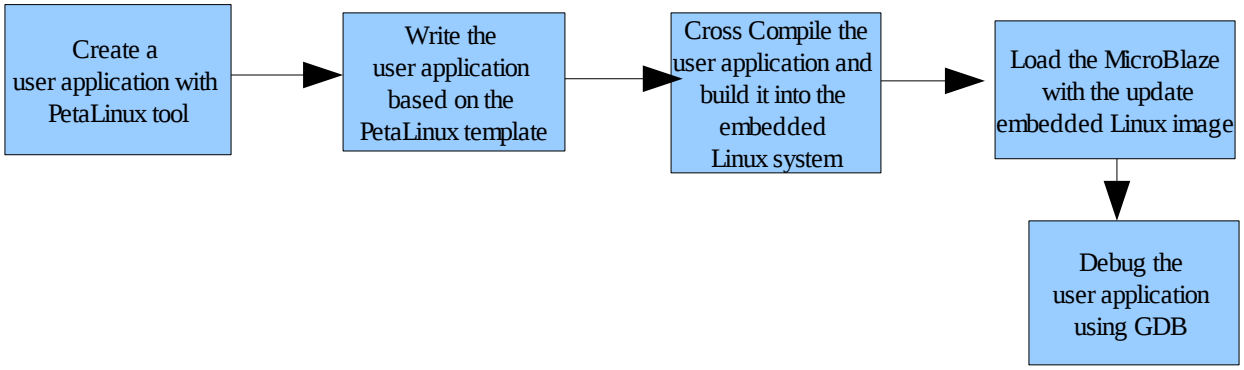
This session will run for approximately 45 minutes.

Preparation

If this is the first lab you are doing then please refer to sections "Before You Start" of Lab 1.1 document for necessary preparatory information on how to setup the hardware environment.

Lab overview

The following diagram is a high level overview of the steps taken in this Lab:



Add a New User Application

To run a user application on a MicroBlaze system, we need to cross compile it and build it into the embedded Linux image on a host machine. PetaLinux provides a tool to make these steps easy. This section and the next section will describe how to develop and build a user application for MicroBlaze system.

At first, let's look at how to create a user application using PetaLinux tools. Here are steps:

- The `petalinux-new-app` command will create a directory for a user application in the `~/petalinux/software/user-apps` directory. The created user application directory contains useful templates. Now, let's create a user application called `mytest` by executing the following command in any directory:

  ```
  [host] $ petalinux-new-app mytest
  ```

- Go to `~/petalinux/software/user-apps/mytest` directory and explore it by executing:
  ```
  [host] $ cd ~/petalinux/software/user-apps/mytest; ls
  ```

In the directory, there are 3 files created by `petalinux-new-app` which are:

`mytest.c`	A very simple hello world program.
`Makefile`	The cross-compilation Makefile file for the application.
`README`	Instructions on how to build the new application.

Write the User Application Based on the Templates

So far, source file and Makefile templates are in the user application directory. Now, we can write our own user application based on the templates. Let's write a very simple test application. Here are the steps:

- Change the `mytest.c` file by Linux editor `vi` or `gedit` to:

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

int func1(int x)
{
        int i, sum;
        sum = 0;
        for (i = 1; i <= x; i++)
                sum += i;
        return sum;
}

int main(int argc, char *argv[])
{
        int val, result;
        printf("Hello, PetaLinux World!\n");

        if (argc >= 2)
                val = atoi(argv[1]);
        else
                val = 100;
        result = func1(val);
        printf("summation(%d) = %d\n", val, result);

        return 0;
}
```

- Modify the `Makefile` :
  With the PetaLinux default settings, the compiler will do optimization when compiling the source. This will possibly result in GDB showing wrong information when we use GDB to debug our application. Thus, if we want to use GDB to debug the application, we should force the compiler not to do any optimization.

Because we will debug the application with GDB later in this lab, we should put "`CFLAGS += -O0`" into the Makefile to disable optimization:

```
12          UCLINUX_BUILD_USER = 1
13          -include $(ROOTDIR)/.config
14          -include $(ROOTDIR)/$(CONFIG_LINUXDIR)/.config
15          LIBCDIR = $(CONFIG_LIBCDIR)
16          -include $(ROOTDIR)/config.arch
17          ROMFSDIR=$(ROOTDIR)/romfs
18          ROMFSINST=$(ROOTDIR)/tools/romfs-inst.sh
19
20          APP = mytest
21
22          CFLAGS += -O0
```

Note: The numbers on the left-most column are line numbers, shown for clarify. DO NOT enter the line number into the text when you are editing!

Build the User Application

After the source file and the Makefile modification, let's move on to build our user application. Since the Makefile generated by `petalinux-new-app` is ready for cross compiling, it is very simple to cross compile the user application.

Here are the steps to build the application:

- Cross compile the application by executing:

  ```
  [host] $ make
  ```

- Build the execution file into root file system for the MicroBlaze target by executing:

  ```
  [host] $ make romfs
  ```

- Build the execution file into root file system for the MicroBlaze target and update the MicroBlaze Linux image by executing:

  ```
  [host] $ make image
  ```

Alternatively, you can build the user application into the MicroBlaze Linux image in one step by

executing:

```
[host] $ make all image
```

Boot the Board with the New Image

- Boot the board with updated image using TFTP. Please refer to the "Booting the New Image" section in the Lab 1.2 manual for the instructions

- After the system has booted, login the system. Examine the `/bin` directory, you should see `mytest` application is there. Here is the command to see what's in the `/bin` directory on the `kermit` console:

  ```
  # ls /bin
  ```

- Execute the `mytest` application on the `kermit` console:

  ```
  # mytest
  ```

  Here is the output of the command in the `kermit` console:

  ```
  Hello, PetaLinux World!
  summation(100) = 5050
  ```

Debug the new Application

GDB server has already included in the system image through the default configuration. Below are the steps to use GDB:

- On the MicroBlaze `kermit` window, start GDB server by executing:

  ```
  # gdbserver host:1234 /bin/mytest 10
  ```

  This tells GDB server to listen on TCP/IP port 1234 for a remote debugging connection. Parameter "`10`" is passed to the `mytest` application. Messages similar to the following will be shown after executing the command.

  ```
  # gdbserver host:1234 /bin/mytest 10
  Process /bin/mytest created; pid = 54
  Listening on port 1234
  ```

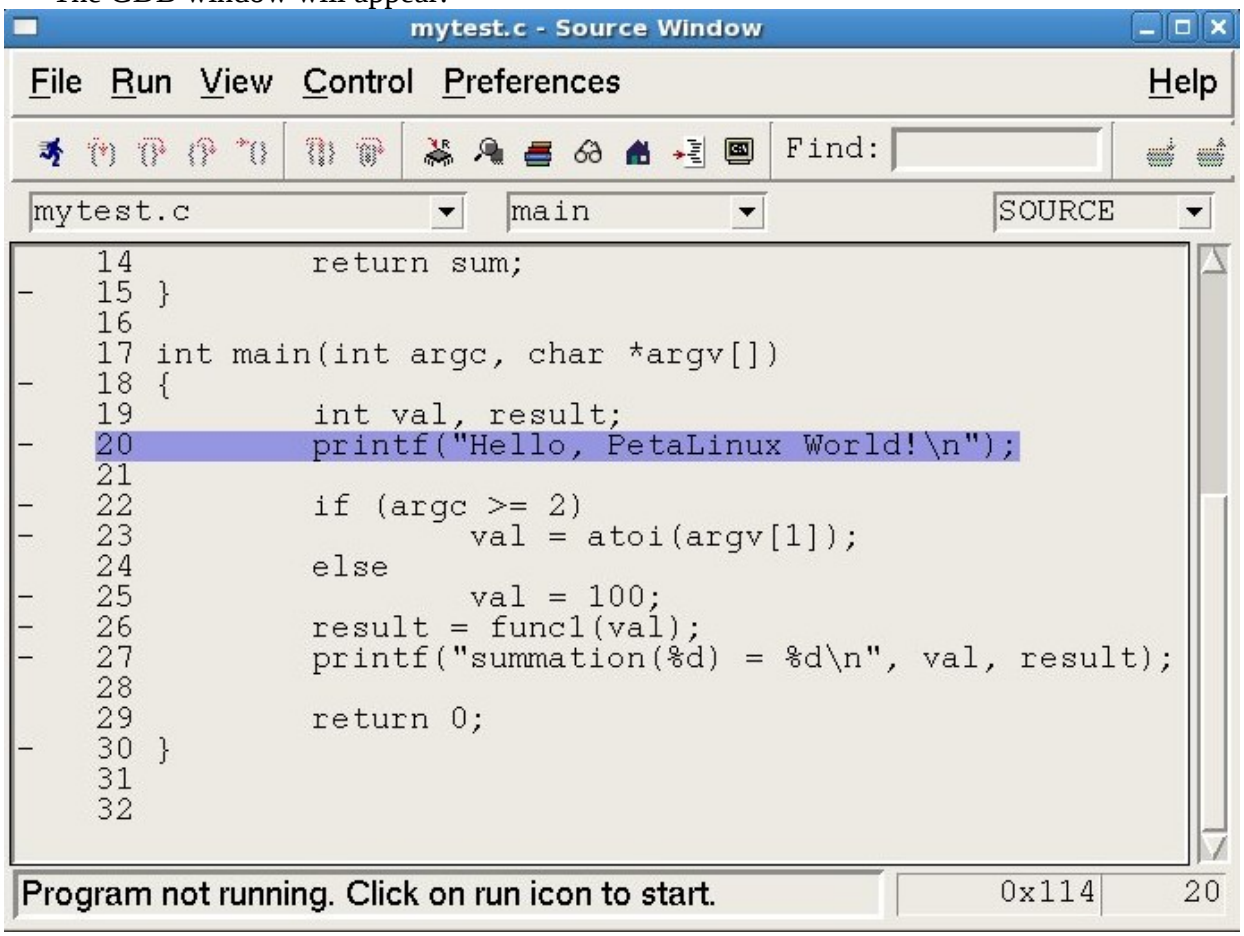
- On a host console, start GDB client by executing:

  ```
  [host] $ cd ~/petalinux/software/user-apps/mytest
  ```

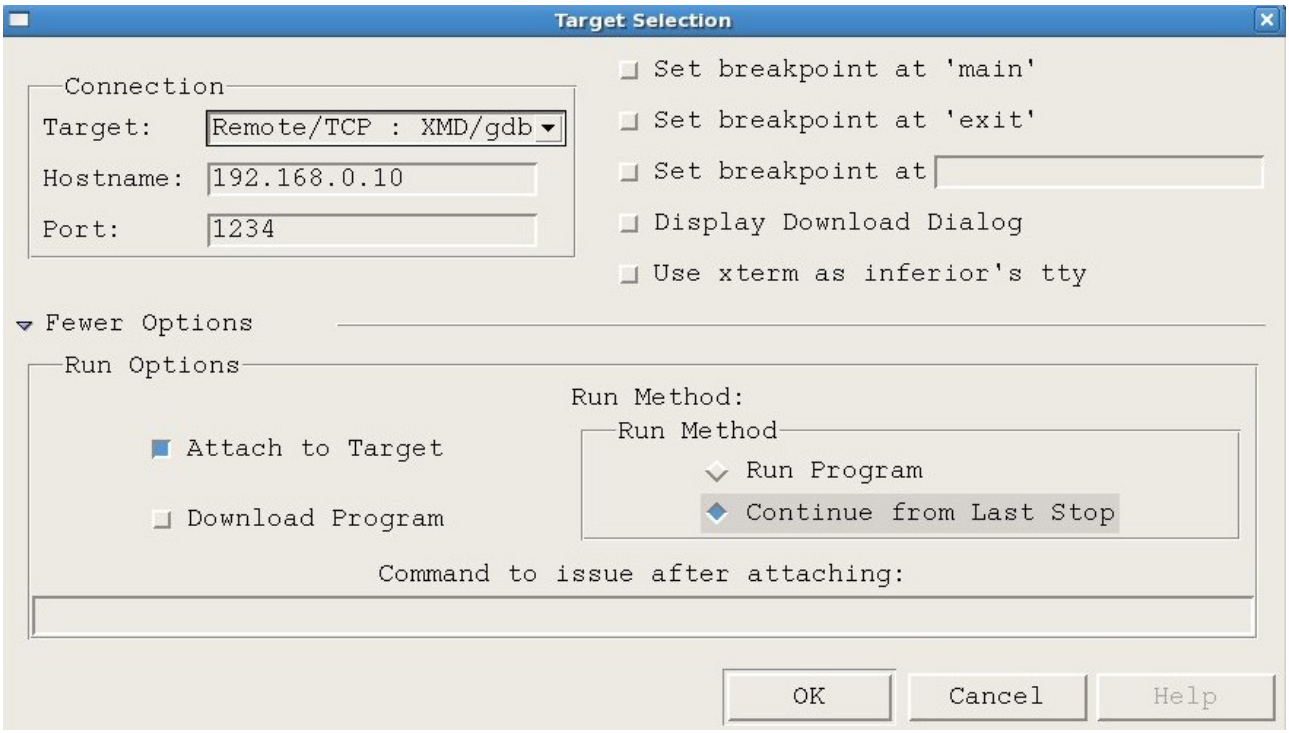
```
[host] $ microblaze-uclinux-gdb mytest.gdb
```

`microblaze-uclinx-gdb` is a special GDB version for debugging MibroBlaze uCLinux applications. `mytest.gdb` is a special version of `mytest` application that helps the GDB debugger to work.

The GDB window will appear:

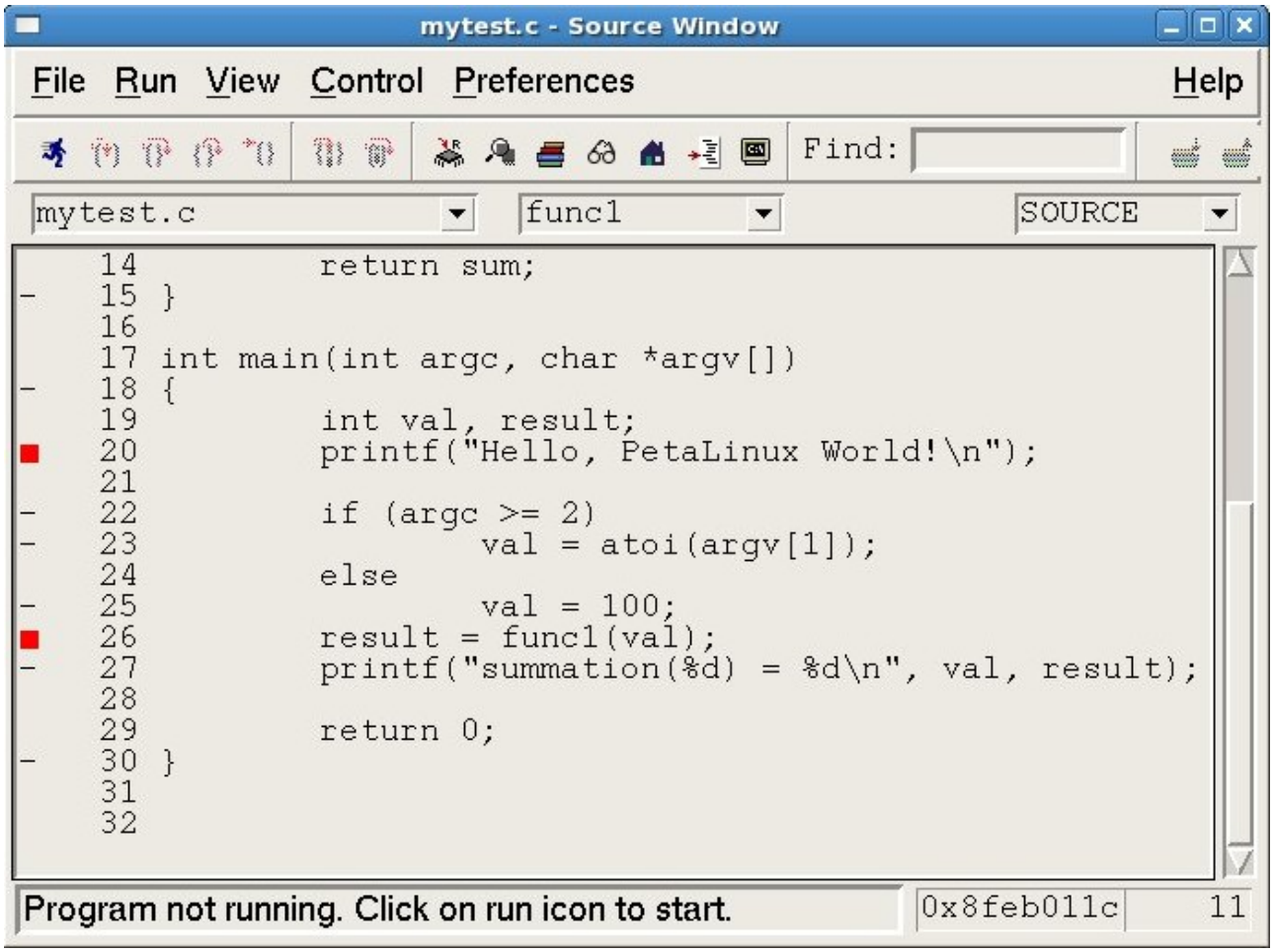


- Connect to the GDB server using TCP:
  - Select "`Target Settings...`" in the "`File`" menu. A "`Target Selection`" dialog will appear:



- In the "`Target Selection`" dialog:
  - Set "`Target`" to "`Remote/TCP : XMD/gdbserver`"
  - Set "`Hostname`" to the IP address of the MicroBlaze system which is `192.168.0.10`.
  - Set "`Port`" to "`1234`".
  - Turn off "`Set breakpoint at `main`` " and "`Set breakpoint at `exit``".
  - Enable more options by expanding the "`More options`" icon.
    - Select "`Attach to Target`" and turn off "`Download program`" in "`Run Options`";
    - Select "`Continue from Last Stop`" as "`Run Method`".
  - Click "`OK`" button.

- Set Breakpoints in the source by clicking the mouse at the beginning of the line of the source code. Lines that are "breakable" are shown by '-' on the left most column in the "`Source Window`". The diagram below shows the breakpoints:

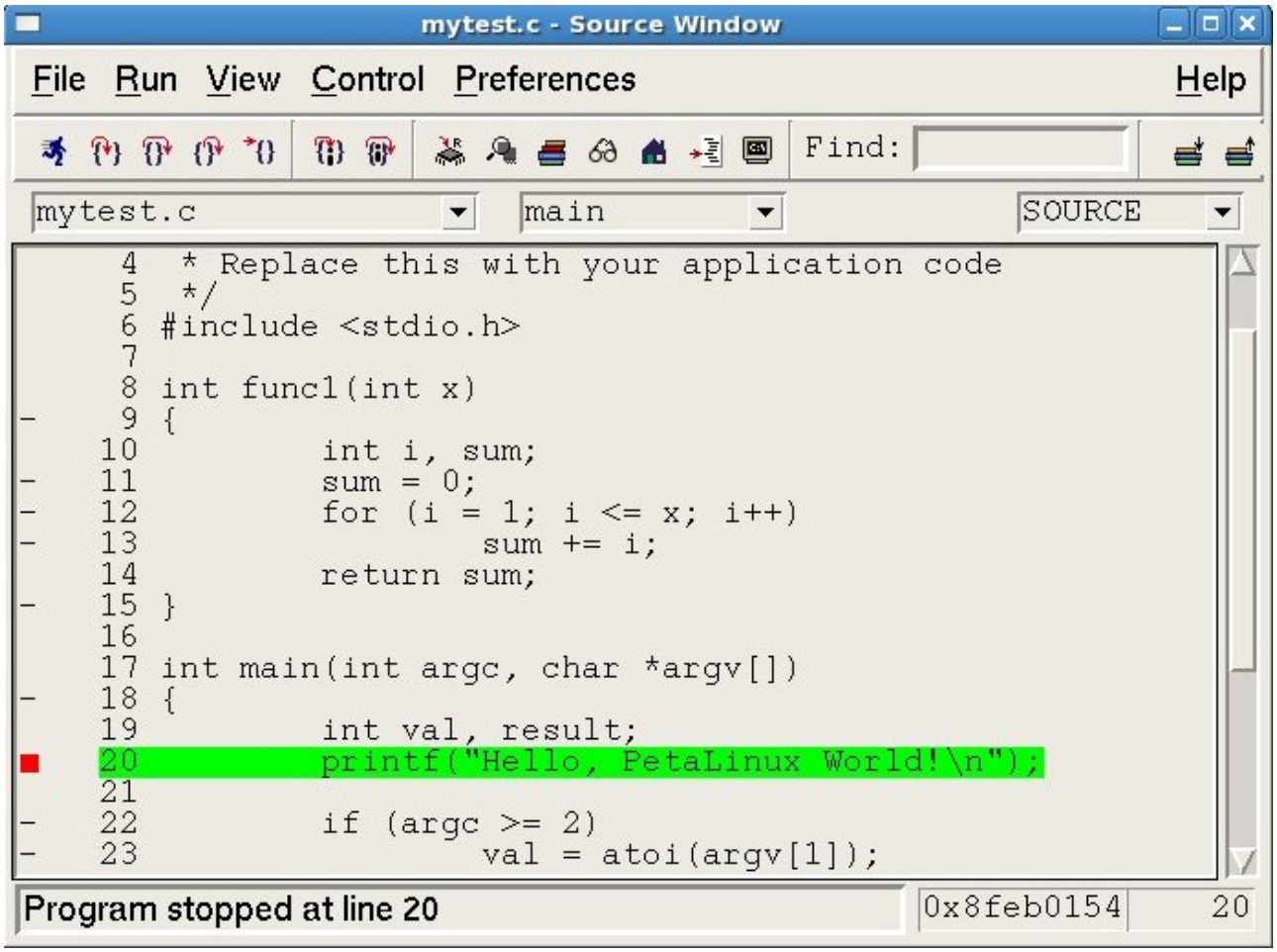


The red squares are the breakpoints.

- Run program by clicking the run icon  at the left corner of the tool bar. The GDB client will connect to the GDB server running on the MicroBlaze and run the program and then stop at the first breakpoint.
  - Messages shown on the MicroBlaze window:

```
# gdbserver host:1234 /bin/mytest 10
Process /bin/mytest created; pid = 54
Listening on port 1234
Remote Debugging from host 192.168.0.1
```

  - Here is the source window of GDB client on host:



- Try "step", "next" and "continue" GDB commands by clicking the icons next to the run icon on tool bar of the source window. And try setting breakpoints. Click the breakpoints (squares on the left most column) will remove that breakpoint.

  The output of the program will be shown on the MicroBlaze Window:

```
# gdbserver host:1234 /bin/mytest 10
Process /bin/mytest created; pid = 54
Listening on port 1234
Remote Debugging from host 192.168.0.1
Hello, Petalinux World!
Summation(10) = 55
```


- When the program finishes, the GDB server application running on MicroBlaze will exit. Message to show GDB server exit will be shown on the `kermit` console:

```
# gdbserver host:1234 /bin/mytest 10
Process /bin/mytest created; pid = 54
Listening on port 1234
Remote Debugging from host 192.168.0.1
Hello, Petalinux World!
Summation(10) = 55

Child exited with retcode = 0

Child exited with status 0

GDBserver exiting
#
```

Moving On

If you have time, try GDB command line debugging.

- The debugger may also be used in command line mode, by starting it on the host with the "`-nw`" parameter:

```
[host]# microblaze-uclinux-gdb   nw mytest.gdb
```

- Start gdbserver on the target.
- Connect the target by entering the following command on the GDB console on the host:

```
(gdb) target remote 192.168.0.10:1234
```

- Debug the program by entering commands on the GDB console.
  - Breakpoints are set with the break command. e.g. to set a breakpoint at the start of the `main()` function:

```
(gdb) break main
```

  - To Continue

```
(gdb) continue
```

  - To single step, use the `step` command:

```
(gdb) step
```

  - To step over functions, use the `next` command:

```
(gdb) next
```

- To exit, use the `quit` command:

```
(gdb) quit
```

Use Completed Resource

The completed Linux image for this lab is available in `~/xup_materials/labs/lab1.3/completed/`. If you are stuck in any problem in the lab, you are welcome to use the completed resource. Here is the instruction on how to use the completed resource:

- Copy the completed user applications to PetaLinux tree and the Linux images to `/tftpboot` directory by executing the following command on the host:

```
[host] $ ~/xup_materials/complete_lab 1.3
```

- Boot the board with tftp as usual. You are now able to complete the on-board activities of this lab worksheet.

Outcomes

In this lab session, you have learned how to

- Create your MicroBlaze Embedded Linux application.
- Build your application and added it into the system image.
- Debug your application using GDB

These capabilities are very useful, please ask the instructors if you have any questions!
Note however, although GDB can be used to debug your application, print or log information whenever necessary in your application is very important for tracking issues.

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Lab 1.4 – Networking and TCP/IP

Rationale

The ready availability of a complete TCP/IP stack, as well as a wide array of networking applications, is a prime capability that argues in favor of using embedded Linux. This lab session will introduce you to Embedded Linux networking, and demonstrate how it can be useful both during application development and deployment.

Objectives

- Explore the kernel configuration menu
  - Learn about the configuration sub-menus that enable Linux TCP/IP networking
- Login to the MicroBlaze Linux system using telnet
- Transfer files to and from Linux using FTP
- Use NFS (Network File System) to mount your host file system on the Linux targe
  - Investigate how this capability impacts the cross-development cycle
- Experiment with the embedded web server on the Linux target
- Build and experiment with web-based applications under Linux

Introduction

In the previous sessions you have already used Linux's networking capabilities – the TFTP utility – that pulls kernel/user images over the network.

In this lab session, you will make more explicit use of the system's networking capabilities, and in particular see how they can be used to dramatically speed up the application building/download/test cycle. We will also build a web-enabled application that can control some physical I/O on the development board. This will be a fairly simple (some might say trivial) program, but it hints at something much more powerful.

Time

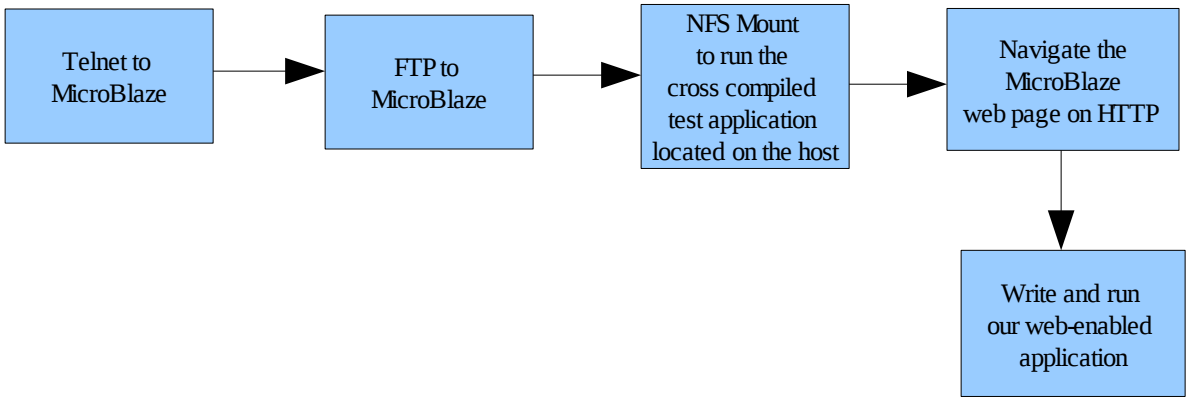
This session will run for approximately 45 minutes.

Preparation

If this is the first lab you are doing then please refer to sections "Before You Start" of Lab 1.1 document for necessary preparatory information on how to setup the hardware environment.

Lab overview

The following diagram is a high level overview of the steps taken in this Lab:



Explore Network Features

The default embedded Linux image on the board supports Ethernet and HTTPD server. If you are interested in Linux settings to enable Ethernet support and the network applications used in this lab, please refer to the "Explore the Linux Network Settings" section in the "Appendix" at the end of this document.

Now, let's try some commonly used network features, telnet, ftp, NFS mount and HTTP.

Telnet to the Board

In the previous labs, we have logged in to the MicroBlaze system using `kermit` over a serial line. While this is convenient for debugging and development, it requires a direct serial connection, which may not be available when a system is deployed. Linux supports the standard telnet protocol directly – in fact this is already enabled on your MicroBlaze Linux system. Now, let's try to telnet to the MicroBlaze system by following these steps:

- Power on the development board and log into the MicroBlaze system.
- Execute `telnet` command on the host:
  ```
  [host] $ telnet 192.168.0.10
  ```

  Here is the output in the `telnet` console on the host:
  ```
  Trying 192.168.0.10...
  Connected to 192.168.0.10 (192.168.0.10).
  Escape character is '^]'.
  login: root
  Password:
  #
  ```

- We have telnet to the MicroBlaze. Try some Linux commands on the `telnet` console such as `ls`, `pwd` and so on.

Transferring Files with FTP

FTP is another frequently used network feature. Your MicroBlaze Linux system is also pre-configured with a FTP server. Here the steps to use the FTP:

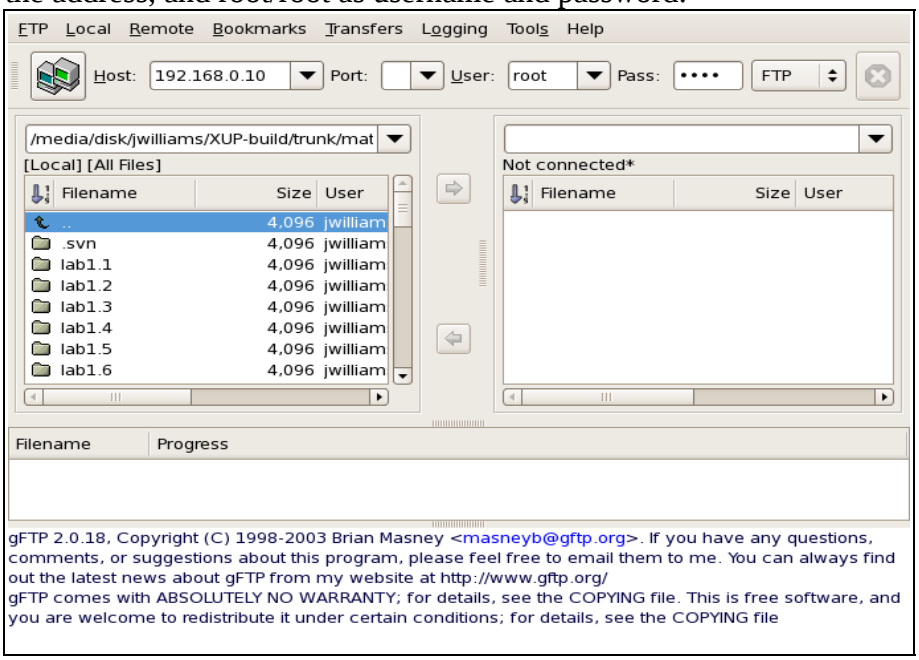
- To connect, simply launch the ftp application from your host by executing:

```
[host] $ ftp 192.168.0.10
```

- Login as `root` with the `root` password.

You can now transfer files to and from the MicroBlaze system. If you are sending files to the MicroBlaze, remember that only the `/tmp` subdirectory is writable and its contents are not persistent between reboots because in this lab we are using read-only root file system on MicroBlaze.

If you prefer, you may also use the graphical FTP program, `gftp`. Select the "Applications" desktop menu, then "Internet", and finally gFTP. Alternatively, run `` `gftp` `` from the host command line. Enter 192.168.0.10 as the address, and root/root as username and password:



Using NFS

As mentioned in the accompanying lecture, NFS (Network File System) is a long-supported capability of Linux (and thus Embedded Linux). It allows a remote file system to be mounted over the network,

and used as though it were physically on the local host. In the context of cross-compiled embedded Linux systems, this can be invaluable.

NFS is very useful when you are debugging your application. Instead of rebuilding and downloading an entire image every time you make a change to your application, you can simply mount your development directory onto the MicroBlaze system. When you recompile your application, the new version is immediately available to run on the target.

Host Support

To allow your MicroBlaze system to mount a remote file system from you host, the host must be configured to allow it. This is specified in the `/etc/exports` file. Go and look at the contents of this file by executing:

```
[host] $ cat /etc/exports
```

You can find this line in the file:

```
/home/centos 192.168.0.* (rw,sync,no_root_squash)
```

This says that the directory `/home/centos` may be exported to the machine with IP address `192.168.0.*` (IP address from 192.168.0.1 to 192.168.0.255) and that it may be mounted with read-write permission.

Let's try it out. Restart the NFS server on host:

```
[host] $ sudo /etc/init.d/nfs restart
```

This command will stop the running NFS service if there is NFS service running and then restart it. Here is the output on the host from this command:

```
Shutting down NFS mountd:                                  [  OK  ]
Shutting down NFS daemon:                                  [  OK  ]
Shutting down NFS services:                                [  OK  ]
Starting NFS services:                                     [  OK  ]
Starting NFS daemon:                                       [  OK  ]
Starting NFS mountd:                                       [  OK  ]
```

If you want to change the share folder, you should:

- Edit the `/etc/exports` file;
- Restart the NFS server by executing:
  `[host] $ sudo /etc/init.d/nfs restart`

Now, the host allows our MicroBlaze system to NFS mount to its `/home/centos` directory. Let's move to NFS mount this directory on the MicroBlaze system.

NFS Mount on MicroBlaze

Scroll the `kermit` console back and take a closer look at the bootup output. You should see where the network device driver is initialized, where the Linux networking stack is configured, and, towards the end, when the "`portmap`" application is run. This "`portmap`" application is required for NFS mount.

You are now ready to mount the file system on the desktop PC on the MicroBlaze system by executing the following command on the `kermit` console:

```
# mount -t nfs 192.168.0.1:/home/centos /mnt -otcp,rsize=4096,wsize=4096
```

This is telling `mount` that

- you want to mount a file system of NFS type(`-t NFS`);
- the host of this file system has IP address `192.168.0.1`;
- the directory on that host you wish to mount is `/home/centos` (ie. your home directory);
- you want this file system to be mounted underneath the local `/mnt` directory (this is known as the "mount point");
- data transfer uses TCP protocol (`-otcp`);
- the read and write operations should use blocks of size 4096 (`-o rsize=4096,wsize=4096`). This prevents the fast desktop PC overrunning the little Microblaze target with data.

Now, change into the `/mnt` directory on the MicroBlaze system, and have a look around by executing:

```
# cd /mnt
# ls
...
#ls petalinux/software/petalinux-dist
...
```

Does it all seem strangely familiar? It should – it's the home directory on your desktop machine. You have read/write access, so be careful. Delete a file on this mounted NFS drive – it's deleted from your desktop, and vice-versa.

To see how NFS mounting can be useful, on your host machine, return to the out-of-tree `mytest` application from an earlier Lab session by executing:

```
[host]$ cd ~/petalinux/software/user-apps/mytest
```

Similarly, on the MicroBlaze system, find the equivalent NFS directory by executing the following command on the `kermit` console:

```
# cd /mnt/petalinux/software/user-apps/mytest
```


You should be able to run the hello application directly over the network by executing:

```
# ./mytest
```

Try making some changes to the `mytest.c` file, e.g. change "`printf("Hello, Petalinux World!\n")`" to "`printf("Hello, Welcome to XUP workshop!\n")`", and then rebuild it on the host by executing:

```
[host] $ vi mytest.c
&
[host] $ make
```

Then, run it again on MicroBlaze over the NFS mount by executing the following command in `/mnt/petalinux/software/user-apps/mytest` directory:

```
# ./mytest
```

The output of the application should change to "`Hello, Welcome to XUP workshop!`". Any changes made on the host to the application can be tested on MicroBlaze immediately over NFS mount!

Embedded Web Server

More and more embedded systems and applications are becoming web-enabled, allowing for remote control, management, and monitoring. In this exercise, you will experiment with the `httpd`.

Firstly, reboot the development board by power it off and power it on again. It is not necessary to login yet. At the bottom of the boot-up messages, you can see the `httpd` has been started during boot.

On your host machine, open up a web browser, and point it to the following URL:

```
http://192.168.0.10
```

You will see the default placeholder page which is installed on the MicroBlaze Linux system. Logon to the MicroBlaze, and explore the `/home` subdirectory by executing:

```
# cd /home
# ls

httpd

# ls httpd
```



```
index.html

# cat httpd/index.html
...
```

Back on the host, to change or add static HTML pages, we must do so on the host. These files live in the `~/petalinux/software/petalinux-dist/vendors/PetaLogix/common/http-content` directory. Have a look at what is in the `http-content` directory by executing:

```
[host]$ cd ~/petalinux/software/petalinux-
dist/vendors/PetaLogix/common/http-content

[host]$ ls
```

Here are what are in the directory:

```
cgi-bin images index.html
```

Feel free to edit `index.html`, or add new HTML files – they will be automatically included when you rebuild the MicroBlaze root file system and the MicroBlaze Linux image by executing:

```
[host]$ cd ~/petalinux/software/petalinux-dist
[host]$ make romfs image
```

To try your new HTML file, you can reboot the MicroBlaze with the new MicroBlaze Linux image using tftp (Please refer to "Booting the New Image" section in the Lab 1.2 manual for the instructions), and then navigate to the updated/new HTML file(s) on your host's web browser..

If you have changed the `index.html` but you cannot see the updated web page on your host's web browser, it is probably because your browser doesn't get the new page from the web server on the board. In this case, clear the private data of your web browser:

- Select "`Tools`" --> "`Clear Private Data`" on Firefox's menu bar.

Web-enabled applications

Web serving embedded applications become a lot more useful when the web interface can be used to control the device, or monitor sensor inputs. In this exercise you will build and experiment with a simple web-enabled application on the MicroBlaze system.

The Sample Program

We have a sample CGI application to control the on/off of LEDs on the board. Let's try to build this program and run it step by step:

- Copy the `cgi-leds` application from the Lab 1.4 materials to the `user-apps` of the PetaLinux tree by executing the following commands on the host machine:

```
[host] $ cd ~/petalinux/software/user-apps
[host] $ cp -r ~/xup-materials/labs/lab1.4/resources/user-apps/cgi-leds ./
```

- Change to the `user-apps/cgi-leds` directory of the PetaLinux tree on the host machine by executing:

```
[host] $ cd ~/petalinux/software/user-apps/cgi-leds
```

  The main application are composed of `cgi_leds.c` and `led.cgi.c`; other files are for a small CGI library.

- Compile the application and update the MicroBlaze Linux image by executing:

```
[host] $ make all image
```

- Reboot the board with updated image using tftp. Please refer to the "Booting the New Image" section in the Lab 1.2 manual for the instructions.

- Once the board reboots, point the web browser on the host back to the board:

```
http://192.168.0.10
```

  Again, the index page will display. Append the path to our new `led.cgi` application, to the URL:

```
http://192.168.0.10/cgi-bin/led.cgi
```

- Try the demo web page:
  Press the "`ON/OFF`" on the web page and watch what happens on the board and the web page.

Manually entering the URL to the cgi-bin applications is a bit tedious – try editing the `index.html` file (It is in `~/petalinux/software/petalinux-dist/vendors/PetaLogix/common/http-content` directory) to include a link to the script. An HTML snippet like this should do the trick:

```
<a href=cgi-bin/led.cgi>Go Blinken-demo!</a>
```


Don't forget you'll need to regenerate the `romfs` and update the MicroBlaze Linux image to include both the new `index.html` and the `led.cgi` after changing the original `index.html` file. Here is the steps to do it after you finish editing the `index.html` file:

```
[host] $ cd ~/petalinux/software/petalinux-dist
[host] $ make romfs
[host] $ cd ~/petalinux/software/user-apps/cgi-leds
[host] $ make romfs image
```

After rebuilding the image, reboot the board with the new image. This time, you should be able to enter the LED demo web page by clicking the link on the updated home page.

Use Completed Resource

The completed Linux image for this lab is available in `~/xup_materials/labs/lab1.4/completed/`. If you are stuck in any problem in the lab, you are welcome to use the completed resource. Here is the instruction on how to use the completed resource:

- Copy the completed user applications to PetaLinux tree and Linux images to `/tftpboot` directory by executing the following command on the host:

  ```
  [host] $ ~/xup_materials/complete_lab 1.4
  ```

- Boot the board with tftp as usual. You are now able to complete the on-board activities of this lab worksheet.

Outcomes

At the completion of this lab you should

- Understand how to use NFS to mount your development system onto the Linux target;
- Have experience in executing a Linux application directly over the NFS mount, instead of updating and downloading an entirely new image file;
- Understand how to create and modify simple static HTML pages so that they can be served by the embedded web server;
- Have a basic understanding of simple web-enabled applications running on the Linux target.

Appendix

Explore the Linux Network Settings

The MicroBlaze Linux system has been configured to support all the network operations we use in this lab. This section is to show you where these network related configurations are in the `menuconfig`

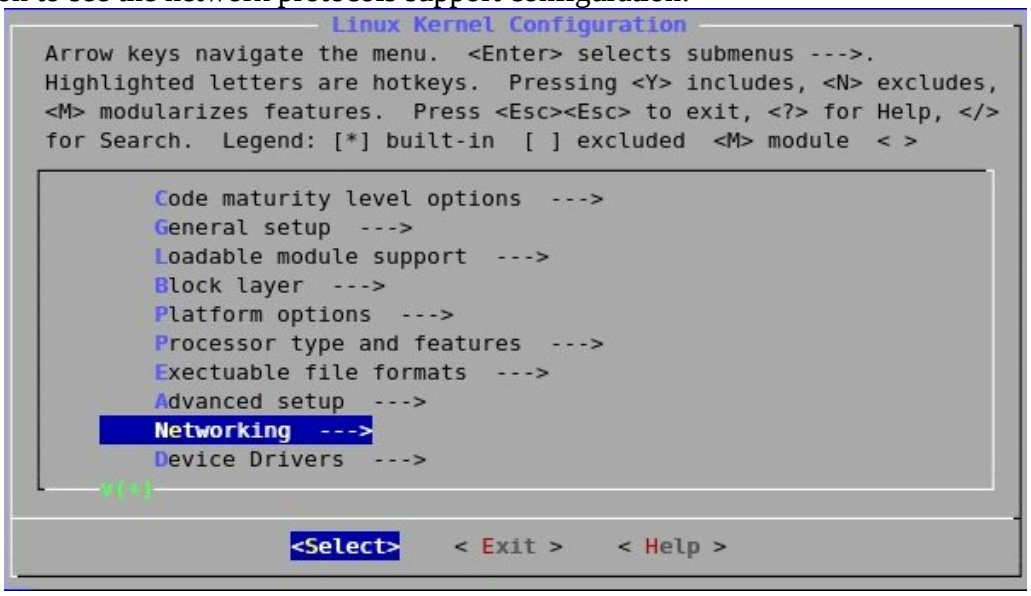
such that you know how to configure Linux to support network in future when you configure your own embedded Linux with PetaLinux tools.

! Please don't change anything in `menuconfig`, navigate only!

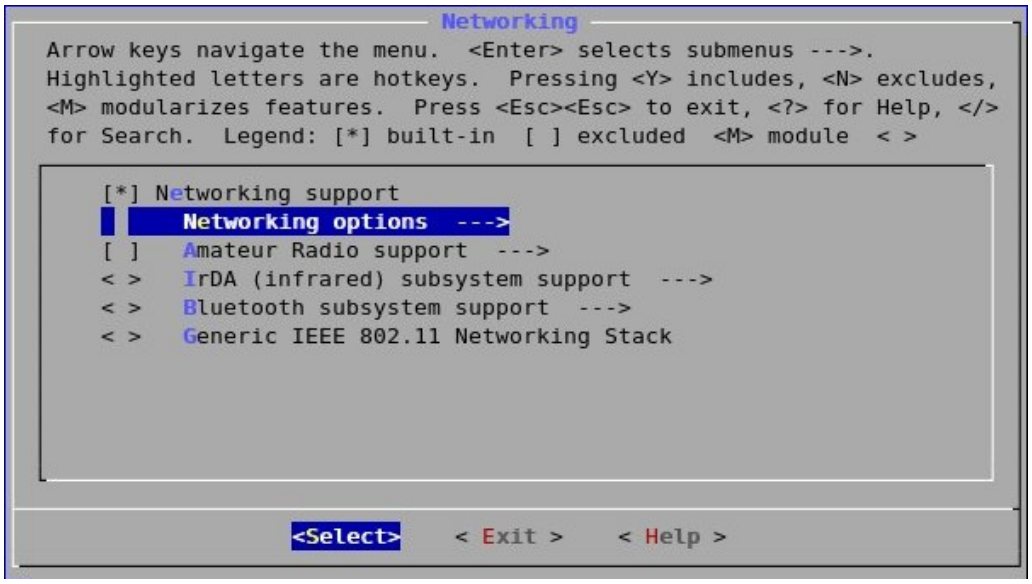
Embedded Linux Kernel Settings to Support Network

This section gives instructions on how to configure embedded Linux kernel to support Network. Here are the instructions:

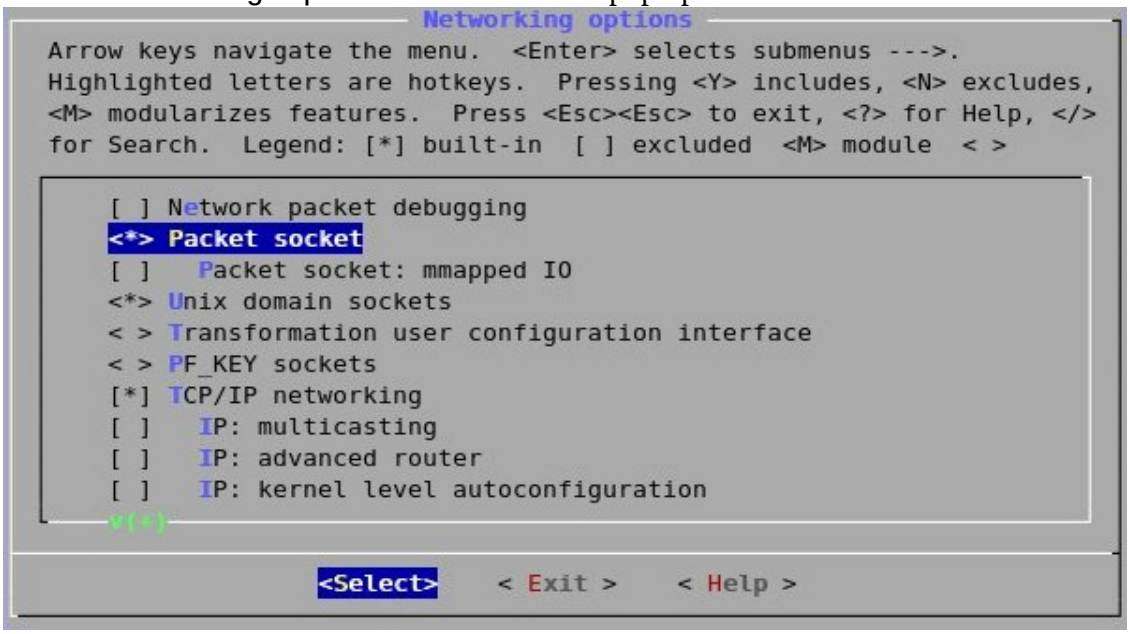
- Run `menuconfig` on the host by executing:
  ```
  [host] $ cd ~/petalinux/software/petalinux-dist
  [host] $ make menuconfig
  ```
- In the pop-up configuration window, select `` `Kernel/Library/Defaults Selection` --> `Customize Kernel Settings` ``:
  ```
  [*] Customize Kernel Settings
  ```
- Exit the menu and select "`Yes`" to "`save your new kernel configuration`", the "`Linux Kernel Configuration`" menu window will pop up.
- There are lots of interesting sub-menus here that control various configuration options of the kernel. Feel free to explore them later, but for now, go down to select the "`Networking`" option to see the network protocols support configuration:



  - The "`Networking`" sub-menu will pop up. The "`Networking support`" option is selected. Selecting this option enables the "`Networking options`" option and other network support options to be configured.
  - Go down and select the "`Networking options`":



- The "`Networking options`" window will pop up:



- We can see "`TCP/IP networking`", "`Packet socket`" and "`Unix domain socket`" are selected in the "`Networking options`" menu:

```
[*] Packet socket
[*] Unix domain socket
[*] TCP/IP networking
```

  - "`TCP/IP networking`" option is necessary to enable mandatory network protocol

support in embedded Linux. To see more information about each option, go down to that option and then enter <?> or <h> for help.

- Even though "`Packet socket`" is not required for most operations - the most that is required is to enable main "`TCP/IP networking`" - it is selected because some applications communicate directly with the network without an intermediate network protocol implemented in the kernel, e.g. NFS.
- "`Unix domain socket`" option is to support Unix domain sockets. It is required to some commonly used network applications such as `ssh`. But it is not necessary for this lab.

- A network device driver is also required to connect the TCP/IP stack and the physical Ethernet device. The network device driver depends on the Ethernet device hardware.
  In this workshop, because we use `Xilinx LL_TEMAC` as the network adapter, the "`Xilinx 10/100/1000 EMACLITE`" driver is selected by default. Here is where the "`Xilinx 10/100/1000 EMACLITE`" driver is in `menuconfig`:

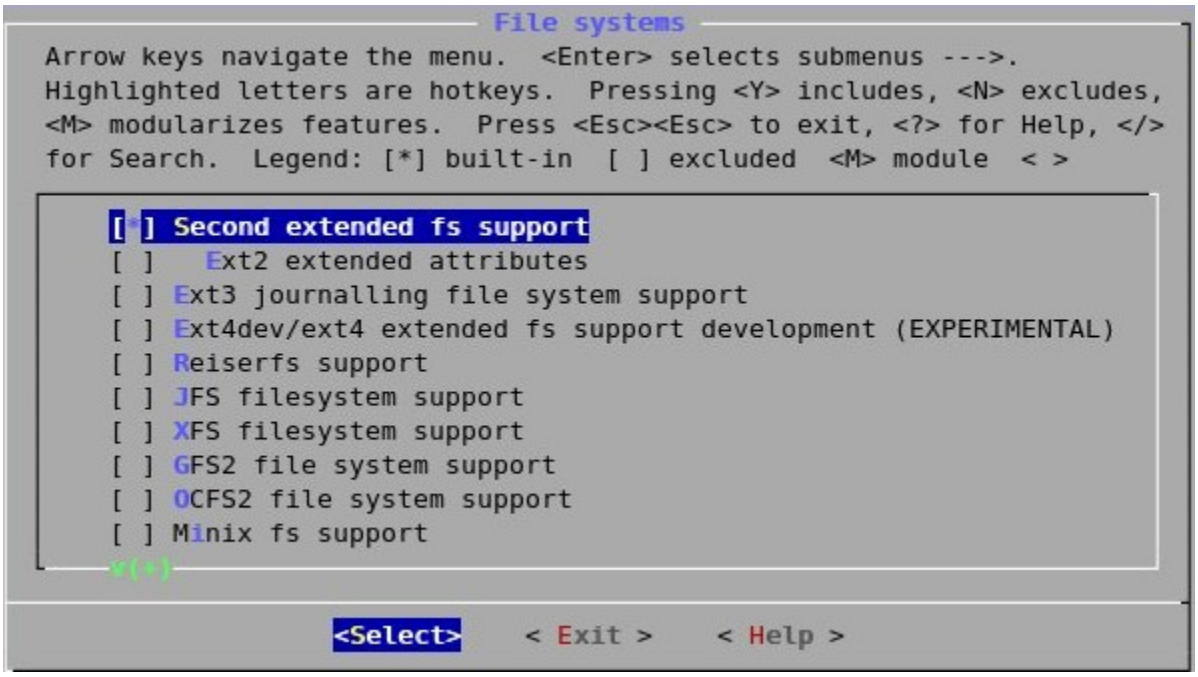
```
Linux Kernel Configuration ->
   Device Drivers ->
      Network device support ->
         Ethernet (10 or 100Mbit) ->
            Xilinx 10/100/1000 EMACLITE support.
```

- Exit from the kernel configuration, and **don't save any changes** (you shouldn't have made any!).

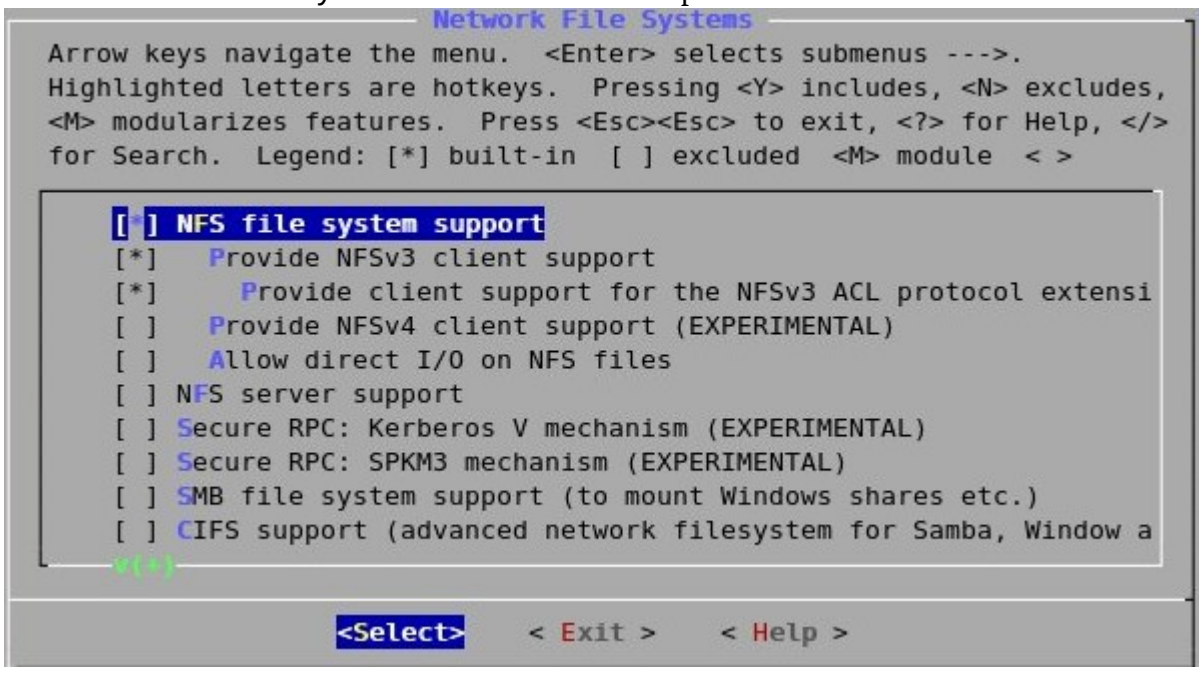
Embedded Linux Kernel Settings to Support NFS

As mentioned in the previous section "Embedded Linux Kernel Settings to Support Network", "`Packet socket`" is required in networking support configuration to support NFS. Besides, Linux kernel file system configuration is also required to configured to support NFS file system. Here are the instructions on Linux kernel file system configuration to support NFS:

- From the main kernel configuration menu ("`Linux Kernel Configuration`" menu), scroll down and select the "`File Systems`" sub-menu.
- The "`File Systems`" menu will show up. This is where you can configure which of the many supported file systems to build into your kernel:



- Scrolling down a few lines, choose the "`Network File Systems`" sub-menu and then the "`Network File Systems`" menu will show up:



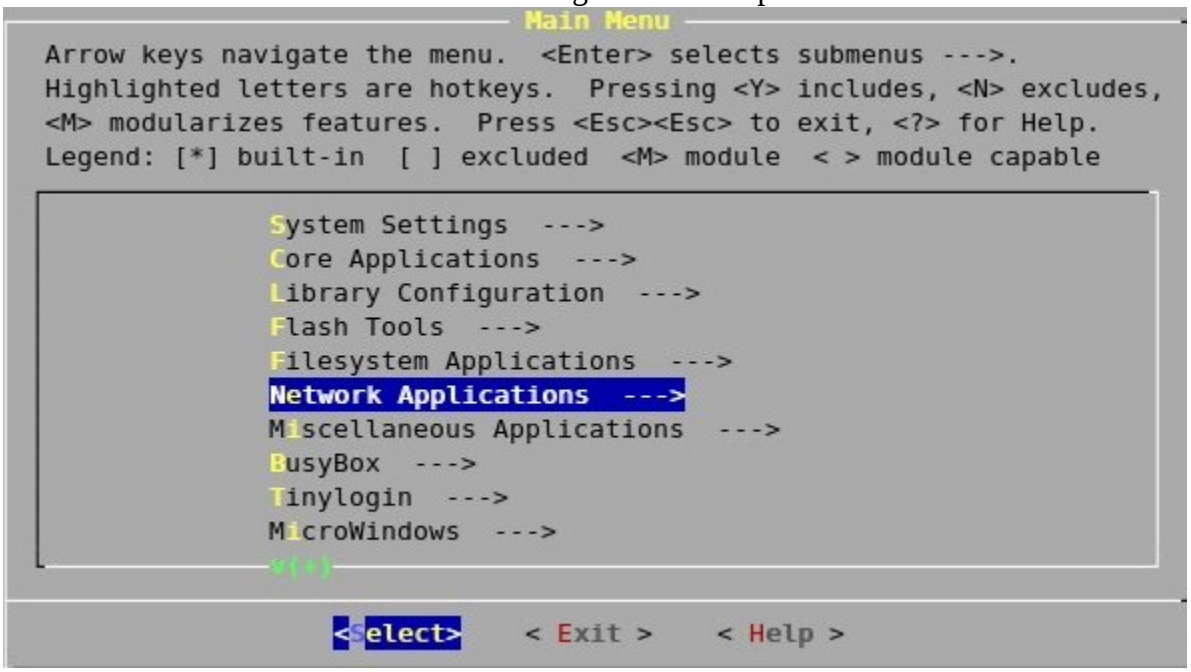
- In the "`Network File Systems`" menu, you will see the "`NFS file system support`" option. It should already be selected.

- Exit from the kernel configuration, and **don't save any changes** (you shouldn't have made any!).

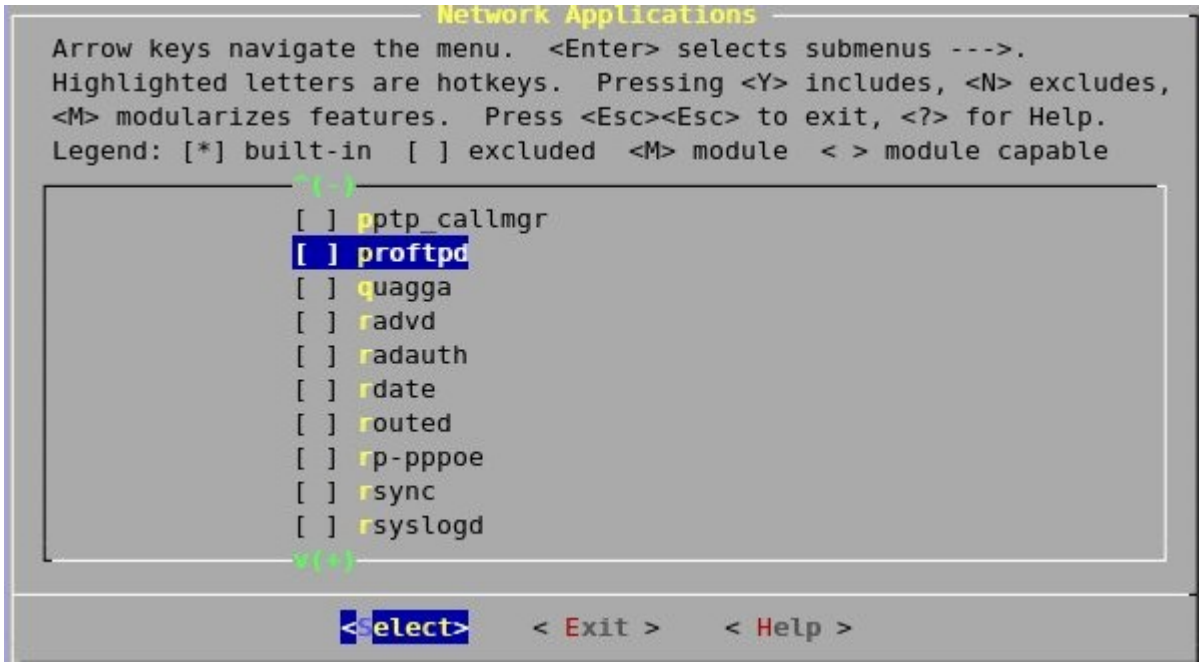
User Space Networking Applications Configuration

Telnet server, FTP server, NFS mount and web server are all user space applications. There are many more user space networking applications. This section tells you where the network applications are in `menuconfig` such that you can select to build them into the embedded Linux system. Let's start exploring the `menuconfig` to look for those network applications:

- Run `menuconfig` on the host by executing:
  ```
  [host] $ cd ~/petalinux/software/petalinux-dist
  [host] $ make menuconfig
  ```
- In the pop-up configuration window, select "`Kernel/Library/Defaults Selection`" --> "`Customize Vendor/User Settings`":
  ```
  [*] Customize Vendor/User Settings
  ```
- The "`Main Menu`" of Vendor/User Settings will show up:



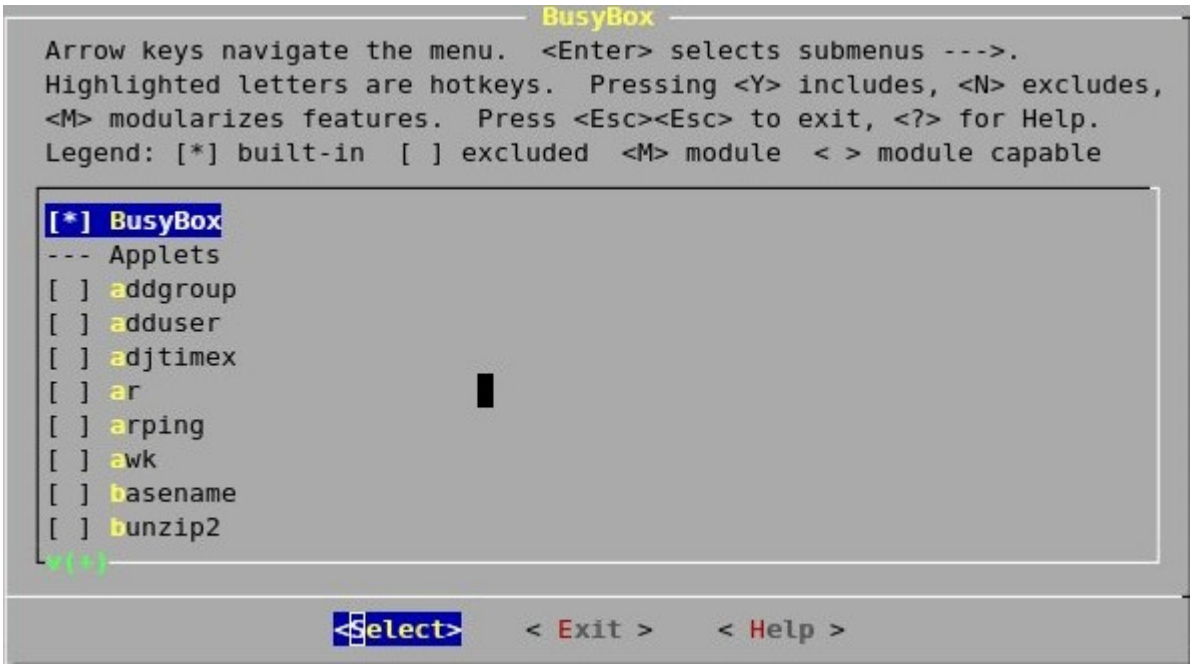
- To to the "`Network Applications`" option and select it, it will show the "`Networking Applications`" sub-menu. The user space network applications are here:



- Scroll the menu, you will find that the `telnetd` for telnet server, `ftpd` for FTP server and `fnord web server` for HTTP server applications are selected. That's why we can telnet and ftp to the MicroBlaze system and can open the web pages from MicroBlaze system.
- Go back to the "`Main Menu`" of "`Customize Vendor/User Settings`"

Besides, telnet server, FTP server and web server, we also use NFS mount in this lab. NFS mount is a feature of `mount` command. The `mount` command used on the MicroBlaze Linux system is from `busybox`. `busybox` combines tiny versions of many common UNIX utilities into a single small executable. It is commonly used in embedded Linux system. We can configure what commands to build into `busybox` with `menuconfig`. Here are the instructions on how to configure `mount` of `busybox` to support NFS:

- `busybox` configuration menu is a sub-menu of the "`Main menu`" of "`Customize Vendor/User Settings`". In the "`Main menu`", select "`BusyBox`" option. The "`BusyBox`" menu will show up:



- Scroll down the "`BusyBox`" menu, you will see "`mount`" and "`mount: support NFS mounts`" options are selected. That is the `mount` with NFS support is configured to be built into `busybox` in the embedded Linux system.
- Exit from the Vendor/User configuration, and **don't save any changes** (you shouldn't have made any!).

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Lab 1.5 – Your first kernel module

Rationale

A lot of Embedded Linux kernel device drivers are developed as kernel modules, such as the Ethernet adapter driver. If a kernel is configured to allow loadable modules, after the kernel boots we can load or unload a module at run time.

Objectives

- Create a simple kernel module using PetaLinux tools.
- Experience the load module command and unload module command

Introduction

If a kernel is configured to allow loadable modules, users are able to load kernel modules after the kernel is booted.

In this lab session, you will create your first very simple kernel module and learn how to load a module and unload a module in Linux.

Time

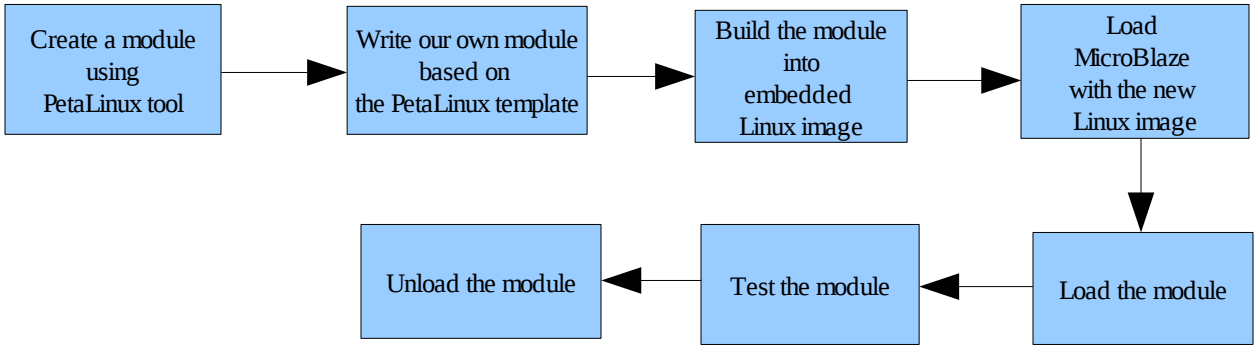
This session will run for approximately 45 minutes.

Preparation

If this is the first lab you are doing then please refer to sections "Before You Start" of Lab 1.1 document for necessary preparatory information on how to setup the hardware environment.

Lab overview

The following diagram is a high level overview of the steps taken in this Lab:



Create a Simple Kernel Module

The referenced platform we used has configured the Linux system to support loadable modules. If you are interested in how to configure the Linux system to support loadable modules, please refer to "Loadable Modules Support Configuration" section in the "Appendix" at the end of this document.

Now, lets create our own Kernel module. Here are the steps to do it using PetaLinux tools:

- Use PetaLinux tool to create a module called `mymodule` by executing the following command in any directory on the host machine:

```
[host] $ petalinux-new-module mymodule
```

This command creates a module called `mymodule`. It generates source files and Makefile from the PetaLinux templates and puts them into `~/petalinux/software/user-modules/mymodule` directory. You are encouraged to look into these files. Here is a description of these files:

File Name	Descriptions
`README`	Instructions on how to modify the template files and how to build the module.
`Makefile`	Makefile template for the created module
`mymodule.c`	Source template to define operations supported by the module.

In `mymodule.c`, module initialization and module exit functions have been defined, that is this module can be loaded and unloaded. But it can do nothing else because no other operations have been defined. In the following section, we will modify the file to support write/read operations.

Write a Simple Virtual Miscellaneous Device Driver

Now let's make the module capable of doing something.

Miscellaneous device is a type of character device. It can be accessed by specifying a device name through file system. To make the simplest workable miscellaneous device driver, we need to :

- Register the device;
- implement the the very basic file operations: open(), release(), read() and write().

The source files are already in `~/xup-materials/labs/lab1.5/resources/user-modules/mymodule` directory. Please copy those files to the `mymodule` directory you have created by executing (all in one line):

```
[host] $ cp ~/xup-materials/labs/lab1.5/resources/user-
modules/mymodule/* ~/petalinux/software/user-modules/mymodule/
```

You are encouraged to go through these source files and the Makefile.

Below is a description about the changes to the template files.

- `mymodule.c`
  - Module initialization function – Changed to initialize the device resources and register the devices. A device has to be registered to use.
  - Module exit function – Changed to unregister the devices and free resources.
  - Open function – This function will be called when the device file is opened.
  - Release function – This function will be called when the device file is closed.
  - Read function – Retrieve data from device.
  - Write function – Send data to device.

  Because the module is a fake device, a buffer acts as the data storage of the device.

- `Makefile`

  Because our Embedded Linux system is a read-only system, it is not allowed to make a node in `/dev` directory after the system is booted, the device file has to be added into the the system image during compilation. The modification in Makefile is on this purpose. Here is the line in Makefile to define a device file:

  ```
  DEVICES =  mymodule0,c,10,128
  ```

  Each "field" in the above definition is described as follows:
  - "`mymodule0`" is the device name
  - "`c`" indicates it is a character device
  - "`10`" is the major number of the device. Miscellaneous devices' major number is 10.
  - "`128`" is the minor number of the device which is used by the kernel to determine exactly which device is being referred to.

Target `romfs` in the template Makefile is to put the module file to the root file system. It has been changed to add the device file to the root file system as well. Here is the command defined in the `romfs` target in `mymodule/Makefile` to generate the device file to the root file system:

```
for i in $(DEVICES); do \
                touch $(ROMFSDIR)/dev/@$$i; \
done
```

The above command will add the device file to the `/dev` directory in the root file system.

Build the module

We have developed a simple virtual miscellaneous device driver. Now, let's build the driver. Here are the steps:

- Compile `mymodule` by executing:

  ```
  [host] $ cd ~/petalinux/software/user-modules/mymodule
  [host] $ make
  ```

  A module file `mymodule.ko` is generated.

- Add the module and its device file into the MicroBlaze root file system system and update the MicroBlaze Linux image by executing:

  ```
  [host] $ make image
  ```

Alternatively, you can compile the module, update the MicroBlaze root file system and the MicroBlaze Linux image in only one step by executing:

```
[host] $ make all image
```

Create a New User Application to Test the Module

After we developed a module, we need a test application to test it.

- In Lab 1.3, we have learned how to create a new application with PetaLinux tools. Now let's create a test application with what we have learned. Type the following command on the host:

  ```
  [host] $ petalinux-new-app testmymodule
  ```

  Directory `~/petalinux/software/user-apps/testmymodule` directory containing the template source file and Makefile will be created.

- The test application is already in `~/xup-materials/labs/lab1.5/resources/user-apps/testmymodule` directory. Copy it to your newly created `testmymodule` directory by executing:


```
[host] $ cd ~/petalinux/software/user-apps/testmymodule
[host] $ cp ~/xup-materials/labs/lab1.5/resources/user-apps/testmymodule/* ./
```

This test application takes the command parameter as an input string, writes that string to `/dev/mymodule0` device and then reads the string back from the device.

- Now, build the test application and update the MicroBlaze root file system and the MicroBlaze Linux image by executing:

  ```
  [host] $ make all image
  ```

Load and Unload a Module

So far, the MicroBlaze Linux image with our own module and the test application is ready, it is time to test our module. In this section, we will load our module, test the module and in the end, unload it.

Here are the steps:

- reboot the development board with the new MicroBlaze Linux image using TFTP as we have learned in the "Booting the New Image" section in Lab 1.2.
- Browse the `/dev` directory on the MicroBlaze system after we have logged in it by executing the following command on the `kermit` console:

  ```
  # ls -l /dev
  ```

  Here is the output from executing the command:

  ```
  crw-rw-r--    1 root     0      90,  15 Jan  1 00:00 mtdr7
  crw-rw-r--    1 root     0      90,  17 Jan  1 00:00 mtdr8
  crw-rw-r--    1 root     0      90,  19 Jan  1 00:00 mtdr9
  crw-rw-r--    1 root     0      10, 128 Jan  1 00:00 mymodule0
  ```

  Before the last modification time stamp of the device file is the major number following by the minor number of the device file.

- Browse the `/lib/modules/kernel/drivers/misc` directory on the MicroBlaze system by executing:

  ```
  # ls /lib/modules/kernel/drivers/misc/
  ```

  You will find your module--`mymodule.ko`--there.

- Load your module on the MicroBlaze system by executing:

  ```
  # insmod /lib/modules/kernel/drivers/misc/mymodule.ko
  ```

  Here is the output from loading the module:

```
Hello module world.
Module parameters is (2)
mymodule0 initialized
mymodule1 initialized
```

The output is from the module initialization function, because when loading a module, the module initialization function will be called.

Now module `mymodule` has been loaded into the kernel. By default, `mymodule` supports up to 2 `mymodule` devices. You can change the max allowed "module" devices by specifying it when you load the module. Here is how to do it:

- At first, unload your module by executing:

  ```
  # rmmod mymodule
  ```

- Reload the module using command line parameters by executing (all in one line):

  ```
  # insmod /lib/modules/kernel/drivers/misc/mymodule.ko
  mymaxdevices=1
  ```

  Here is the output from loading the module by specifying the module supports up to 1 device:

  ```
  Hello module world.
  Module parameters is (1)
  mymodule0 initialized
  ```

- See where the loaded module's information is in the system by executing:

  ```
  # ls /sys/module
  ```

  The modules have been loaded into the system can be found in `/sys/module`. Here is the output from this command:

  ```
  lockd      mymodule   printk     tcp_cubic
  ```

  The information about `mymodule` is in `/sys/module/mymodule` directory. Let's have a look at what is in the directory by executing:

  ```
  # ls -l /sys/module/mymodule
  ```

  Here is the output:

  ```
  drwxr-xr-x    2 root     0           0 Jan  1 04:05 drivers
  -r--r--r--    1 root     0        4096 Jan  1 04:05 initstate
  drwxr-xr-x    2 root     0           0 Jan  1 04:05 parameters
  -r--r--r--    1 root     0        4096 Jan  1 04:05 refcnt
  ```

Here is a brief description of these files/directories:

File/Directory Name	Description
`drivers`	The drivers belong to the module.
`initstate`	The state of the module initialization.
`parameters`	The value of the input parameters to load the module.
`refcnt`	The number of memory reference counters.

- Run the test application by executing:

  ```
  # testmymodule "welcome to the Xilinx and Petalogix workshop"
  ```

  This test application opens the `mymodule` device, writes the input string to the device, reads it back and then compares the original string and the one read from the device. If these two strings are the same, the test is considered as succeeded, otherwise, it is considered as failed.

  Here is the result of running the program:

  ```
  Hello, test the new module!
  open mymodule
  Open /dev/mymodule0 successfully
  Write 44(bytes) to /dev/mymodule0 successfully
  result: welcome to the Xilinx and Petalogix workshop
  mymodule test succeeded
  ```

  We have successfully written and read the `mymodule0` device!

- After the test, unload the module by executing:

  ```
  # rmmod mymodule
  ```

  This time, the module exit function is called, the function prints the following words on the `kermit` console:

  ```
  Goodbye module world.
  ```

- Now , have a look at the `/sys/module` again by executing:

  ```
  # ls /sys/module
  ```

  We can see that the `mymodule` has been removed from the directory.

Use Completed Resource

The completed Linux image for this lab is available in `~/xup_materials/labs/lab1.5/completed/`. If you are stuck in any problem in the lab, you are welcome to use the completed resource. Here is the instructions on how to use the completed resource:

- Copy the completed user applications and user modules to PetaLinux tree and the Linux images to `/tftpboot` directory by executing the following command on the host:

  ```
  [host] $ ~/xup_materials/complete_lab 1.5
  ```

- Boot the board with tftp as usual. You may now complete the on-board activities of this lab worksheet.

Outcomes

At the completion of this lab you should know

- how to configure the kernel to support loadable modules
- how to create a simple module
- how to add a device node in romfs system.
- how to load and unload a module
- where to find the module information

Appendix

Loadable Modules Support Configuration

The MicroBlaze Linux system has been configured to support loadable modules in this workshop. This section is to show you where these configurations are in the `menuconfig` such that you know how to configure Linux to support loadable in future when you configure your own embedded Linux with PetaLinux tools.

! Please don't change anything in **`menuconfig`**, navigate only!

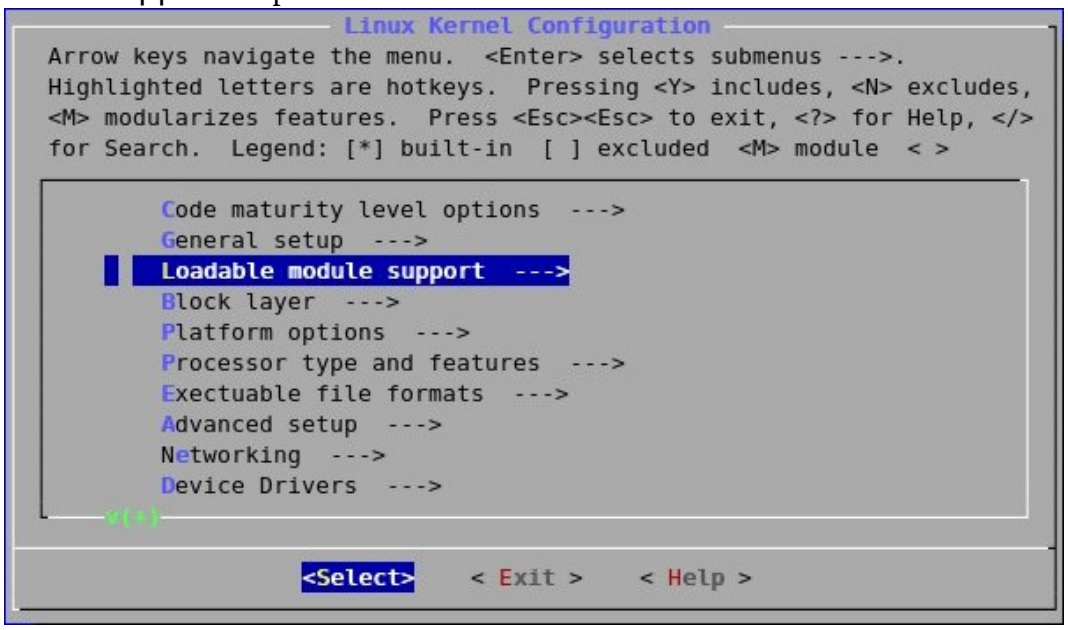
To support loadable modules, both the Linux kernel settings and the user space application settings are required to be configured properly to support it.

In this section, we will look at how to configure the Linux kernel to support loadable modules and then look at what user space applications should be configured to load and unload modules.

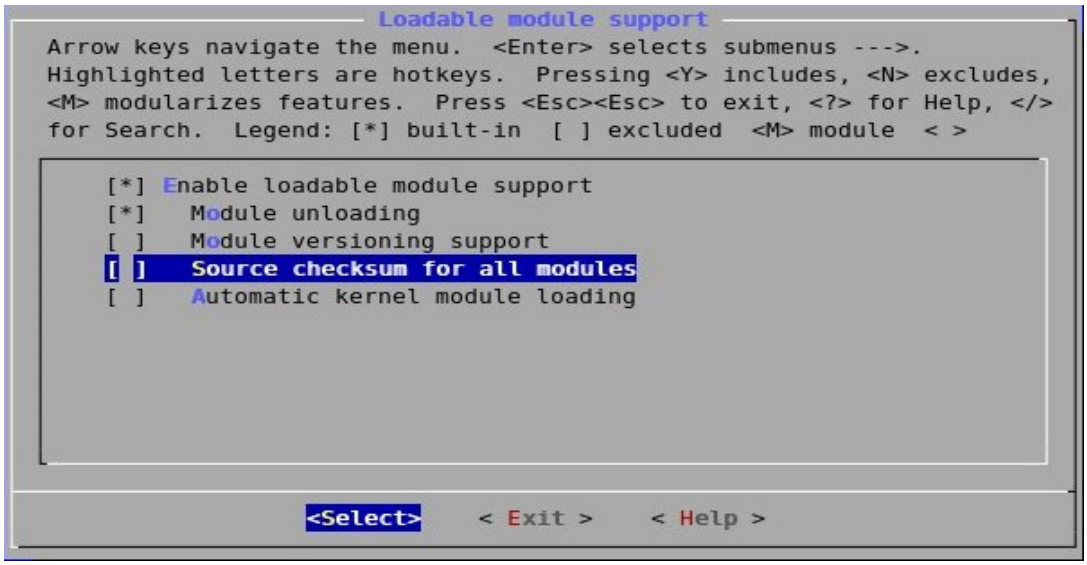
Kernel Settings for Supporting Loadable Modules

We will navigate the configuration of the referenced platform used in this lab to learn how to configure the Linux Kernel to support loadable modules:

- Run `menuconfig` on the host by executing:
  ```
  [host] $ cd ~/petalinux/software/petalinux-dist
  [host] $ make menuconfig
  ```
- In the pop-up configuration window, select "`Kernel/Library/Defaults Selection`" --> "`Customize Kernel Settings`":
  ```
  [*] Customize Kernel Settings
  ```
- Exit the menu and select "`Yes`" to "`save your new kernel configuration`", the "`Linux Kernel Configuration`" menu window will pop up.
- In the "`Linux Kernel Configuration`" menu, go down to select the "`Loadable module support`" option:



- The "`Loadable module support`" sub-menu shows up. The following options have been selected to support loadable modules:
  ```
  [*]  Enable loadable module support
  [*]  Module unloading
  ```

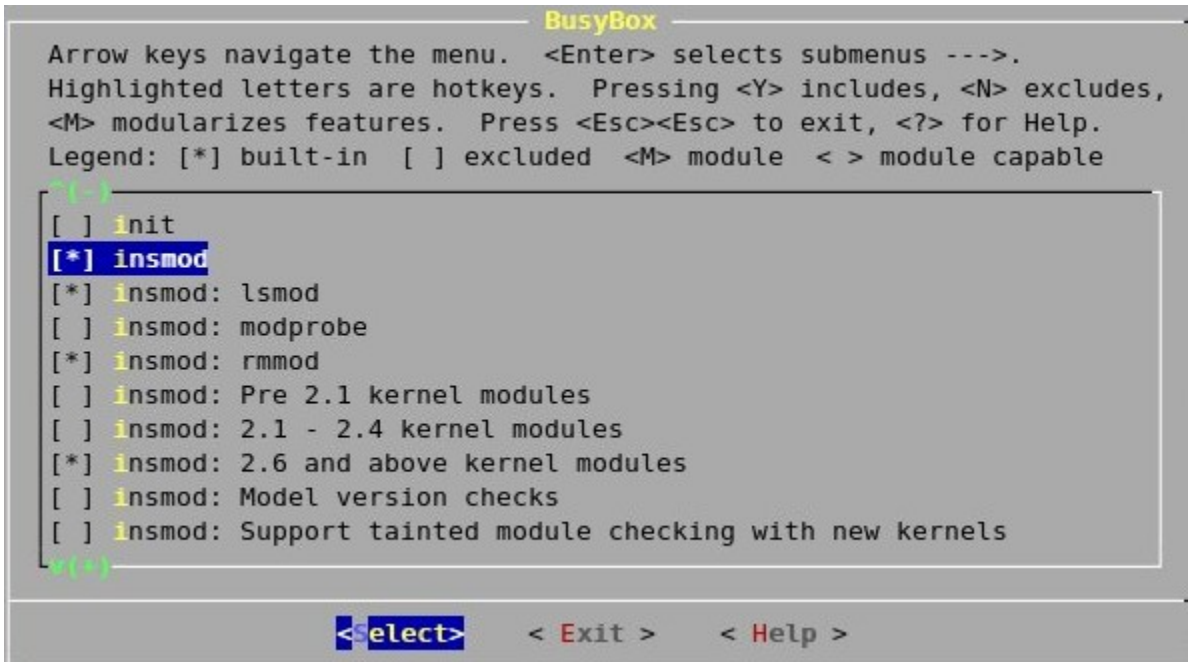


- Exit without saving any changes. (No changes should be made to `menuconfig`. Just browse.)

Vendors/User Settings for Supporting Loadable Modules

`insmod` and `rmmod` are commands of `busybox`, let's see how to configure the `busybox` to support loading and unloading modules:

- Run `menuconfig` on the host by executing:
  ```
  [host] $ cd ~/petalinux/software/petalinux-dist
  [host] $ make menuconfig
  ```
- In the pop-up configuration window, select "`Kernel/Library/Defaults Selection`" --> "`Customize Vendor/User Settings`":
  ```
  [*] Customize Vendor/User Settings
  ```
- The "`Main Menu`" of Vendor/User Settings will pop up.
- Select the "`BusyBox`" option in the "`Main Menu`" to show the "`BusyBox`" sub-menu.
- Scroll down to the "`insmod`" option in the "`BusyBox`" menu to see the module related commands configuration.



From the menu, we can see that:

- `insmod` is selected: this is the command to load a module.
- "`insmod: 2.6 and above kernel modules`", since we are using 2.6 Linux kernel, we should select this option to compile the `insmod` to support the 2.6 and above kernel.
- `lsmod` is selected: this is the command to see what are the currently loaded modules in the the Linux system.
- `rmmod` is selected: this is the command to unload a module.

- Exit without saving any changes. (No changes should be made to `menuconfig`. Just browse.)

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Lab 1.6 – MMU build and boot

Rationale

Memory Management Unit (MMU) is a computer hardware component responsible for handling memory access. Its functions include translation of virtual address to physical address, memory protection and so on. If the processor is configured to have MMU and the Embedded Linux is configured to support MMU, memory management will protect processes from accessing the other's memory space; otherwise, all the processes including those in user space can access the whole memory.

Objectives

- Build Embedded Linux with MMU support
- Compare the system with MMU support and that without MMU support

Introduction

The previous labs are all about uCLinux (Embedded Linux without MMU support). In this lab, we will build an Embedded Linux system with MMU support. We will then compare this system with uCLinux to see the effect of introducing MMU support.

Time

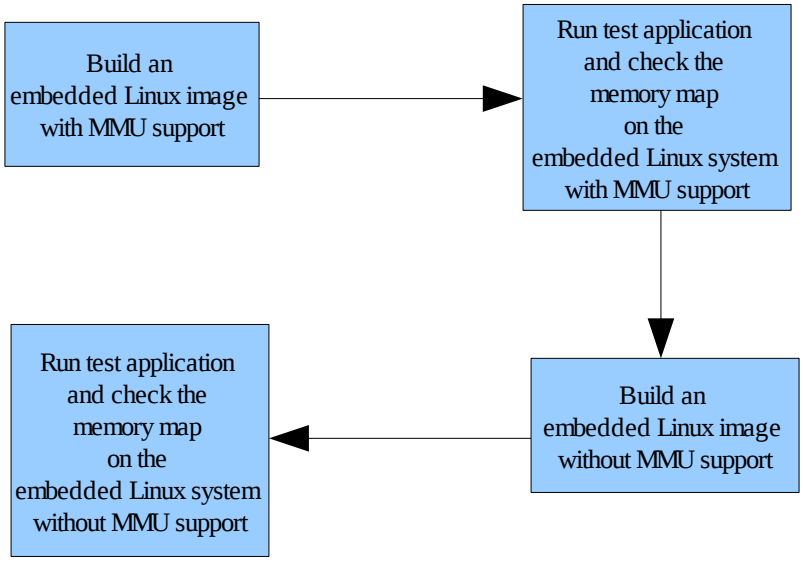
This session will run for approximately 45 minutes.

Preparation

If this is the first lab you are doing then please refer to sections "Before You Start" of Lab 1.1 document for necessary preparatory information on how to setup the hardware environment.

Lab overview

The following diagram is a high level overview of the steps taken in this Lab:

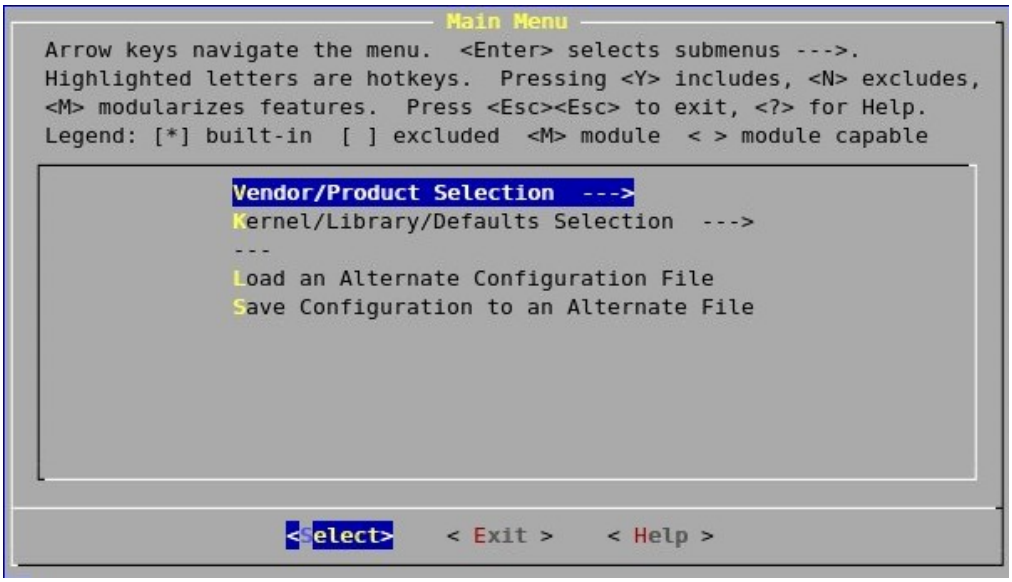


Build Embedded Linux with MMU Support

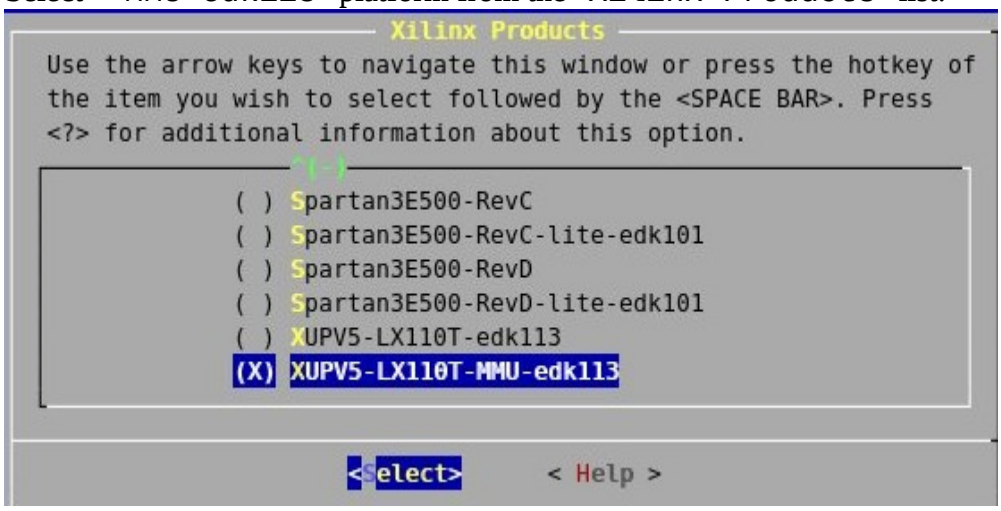
The reference platform used so far in the lab doesn't include the MMU support. We will change to use another reference platform which supports MMU for the board. Here we go:

- Run `menuconfig` on the host by executing:

```
[host] $ cd ~/petalinux/software/petalinux-dist
[host] $ make menuconfig
```



- Select "`Vendor/Product Selection`" from the "`Main menu`". And then select "`Xilinx Products`" sub-menu to show the "`Xilinx Products`" sub-menu.
- Select "`-MMU-edk113`" platform from the "`Xilinx Products`" list:



- Exit `menuconfig` and save the configuration changes.

We have configure the embedded Linux settings to support MMU. Let's rebuild the embedded Linux for the board by executing:

```
[host] $ cd ~/petalinux/software/petalinux-dist
[host] $ make
```

Create a User Application to Test MMU

What's the difference between a Linux system supporting MMU and and the one not supporting MMU? Let's create a simple user application to check it. In the application, we will write some garbage to memory randomly. Here are the steps to create such an test application:

- Use PetaLinux tool to create a new user application by executing:

```
[host] $ petalinux-new-app memwalk
```

  This command will create a `memwalk` directory containing source code template and Makefile in the `~/petalinux/software/user-apps` directory.

- There is a complete application in `~/xup-materials/labs/lab1.6/resources/user-apps/memwalk`; Please copy the files in that directory to the `memwalk` directory you have just created by executing (all in one line):

```
[host] $ cp ~/xup-materials/labs/lab1.6/resources/user-apps/memwalk/* ~/petalinux/software/user-apps/memwalk/
```

- Please take some time to look at the contents of `memwalk.c` file.
- Build the `memwalk` application and update the MicroBlaze Linux image by executing:

```
[host] $ cd ~/petalinux/software/user-apps/memwalk
[host] $ make all image
```

Check the MMU Effect

Why is MMU useful? Let's check the MMU effect by running the `memwalk` program on both the MMU embedded Linux system and the non-MMU embedded Linux system.

Run Test Application on Embedded Linux with MMU Support

- Reboot the development board with the new embedded Linux image with MMU support using TFTP as we have learned in the "Booting the New Image" section in Lab 1.2.
- Run our test application `memwalk` after log into the MicroBlaze Linux system by executing the following command on the `kermit` console:

```
# memwalk
```

  This application will write garbage to a randomly generated memory address. Here is the output on the `kermit` console after running the program:

```
.SIGSEGV
#
```

  The application will be terminated and the system is still running. The MMU support protects the process from accessing memory which doesn't belong to it.

- Have a look at the memory mapping of the processes running on the MicroBlaze Linux system by executing:

```
# cat /proc/self/maps
```

`/proc` directory holds the information of existing processes in the system. `self` is the current running process. You should see something similar to the following shown on the `kermit` window:

```
10000000-10001000 r-xp 00000000 00:01 90   /bin/cat
10001000-10002000 rw-p 00000000 00:01 90   /bin/cat
10002000-10003000 rwxp 10002000 00:00 0    [heap]
48000000-4801b000 r-xp 00000000 00:01 142  /lib/ld-2.3.3.so
4801b000-4801d000 rw-p 0001a000 00:01 142  /lib/ld-2.3.3.so
4801d000-48172000 r-xp 00000000 00:01 160  /lib/libc-2.3.3.so
48172000-48175000 r--p 00154000 00:01 160  /lib/libc-2.3.3.so
48175000-48177000 rw-p 00157000 00:01 160  /lib/libc-2.3.3.so
48177000-4817a000 rw-p 48177000 00:00 0
bf89b000-bf8b0000 rwxp bf89b000 00:00 0    [stack]
```

The fields in each line are:

```
start-end permission offset major:minor inode image
```

The line with "`x`" permission indicates executable code segment.

You can check the process memory mapping of some other processes. E.g., check the memory mapping of process "1" by executing:

```
# cat /proc/1/maps
```

You sill see a similar output as below on the `kermit` console:

```
10000000-10003000 r-xp 00000000 00:01 88  /bin/init
10003000-10004000 rw-p 00002000 00:01 88  /bin/init
10004000-10025000 rwxp 10004000 00:00 0   [heap]
48000000-4801b000 r-xp 00000000 00:01 142 /lib/ld-2.3.3.so
4801b000-4801d000 rw-p 0001a000 00:01 142 /lib/ld-2.3.3.so
4801d000-48025000 r-xp 00000000 00:01 167 /lib/libcrypt-2.3.3.so
48025000-48027000 rw-p 00007000 00:01 167 /lib/libcrypt-2.3.3.so
48027000-4804e000 rw-p 48027000 00:00 0
4804e000-481a3000 r-xp 00000000 00:01 160 /lib/libc-2.3.3.so
481a3000-481a6000 r--p 00154000 00:01 160 /lib/libc-2.3.3.so
481a6000-481a8000 rw-p 00157000 00:01 160 /lib/libc-2.3.3.so
481a8000-481ac000 rw-p 481a8000 00:00 0
bfb8b000-bfba0000 rwxp bfb8b000 00:00 0   [stack]
```

The highlighted lines on the above shows the processes are able to share the same segments. That is if more than one process uses the same executable code, there is only one copy of it stored in memory.

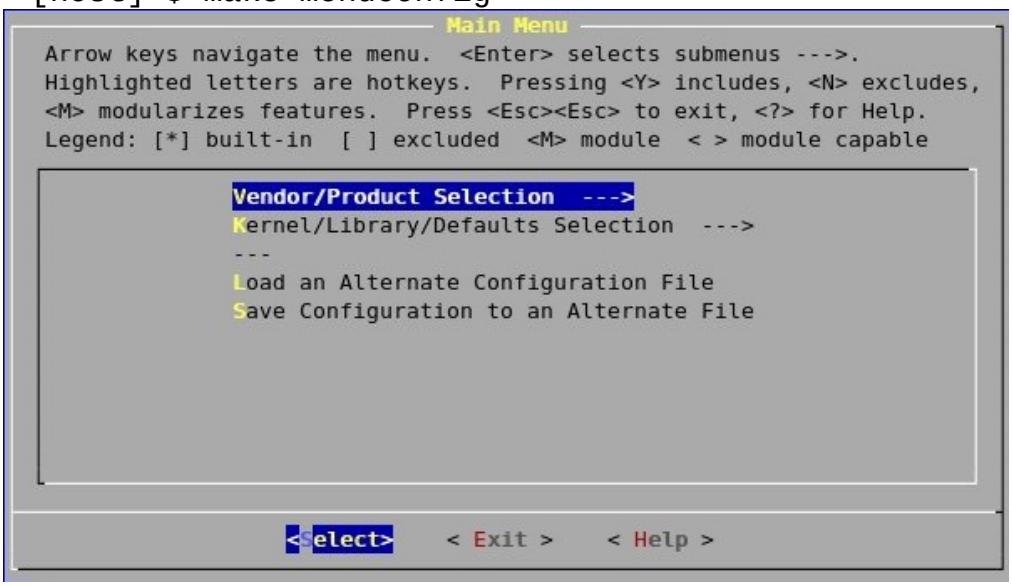
Run Test Application on Embedded Linux without MMU Support

After running the test application and checking the memory mapping on the embedded Linux with MMU support system. Now, we are going to do these on uCLinux (the embedded Linux without MMU support).

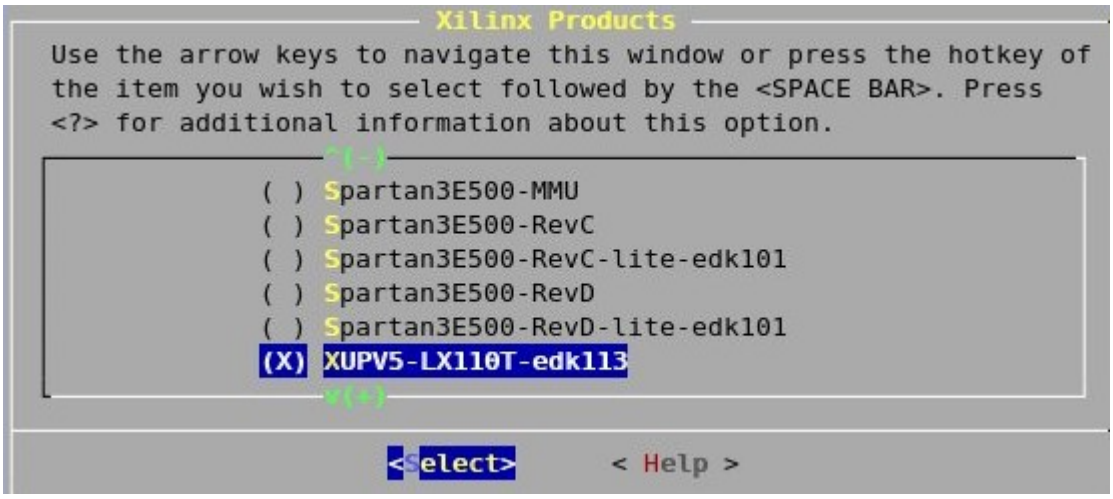
At first, build the MicroBlaze uCLinux following these steps:

- Change back to use the reference platform without MMU support on the host machine:
  - Run `menuconfig` in `~/petalinux/software/petalinux-dist` by executing:

```
[host] $ cd ~/petalinux/software/petalinux-dist
[host] $ make menuconfig
```



  - Select "`Vendor/Product Selection`" from the "`Main menu`". And then select "`Xilinx Products`" to show the "`Xilinx Products`" sub-menu.
  - Select "`-edk113`" platform from the "`Xilinx Products`" list:



  - Exit `menuconfig` and save the configuration changes.

- Build the MicroBlaze uCLinux image by executing:

```
[host] $ cd ~/petalinux/software/petalinux-dist
[host] $ make
```

- Build the `memwalk` application into the MicroBlaze uCLinux image by executing:

```
[host] $ cd ~/petalinux/software/user-apps/memwalk
[host] $ make clean
[host] $ make all image
```

The MicroBlaze uCLinux image is ready, we can run the test application and check the memory mapping with this image now. Here are the steps to do it:

- Power off the development board and then power it on again and boot it with the new uCLinux image using TFTP as we have learned in the "Booting the New Image" section in Lab 1.2.
- Check the memory map of process `self` by executing the following command on the `kermit` console:

```
# cat /proc/self/maps
```

The output from the command will be similar to the following:

```
8fdc8000-8fdcc000 rwxp 00000000 00:00 0
```

Check the memory map of process "1" by executing the following command:

```
# cat /proc/1/maps
```

The output from the command will be similar to the following:

```
881da000-881da870 rw-p 00000000 00:00 0
881db1e0-881db1fa rw-p 00000000 00:00 0
881db6c0-881db6d0 rw-p 00000000 00:00 0
```



```
881dbec0-881dbecc rw-p 00000000 00:00 0
881dbf80-881dbf88 rw-p 00000000 00:00 0
881dbfc0-881dbfda rw-p 00000000 00:00 0
884af698-884af6c1 rw-p 00000000 00:00 0
884af6d8-884af701 rw-p 00000000 00:00 0
884af718-884af73f rw-p 00000000 00:00 0
884af758-884af77f rw-p 00000000 00:00 0
884e0000-88500000 rwxp 00000000 00:00 0
```

Check the memory mapping of the other processes. The output will be similar to the above. For every process, all its executable code is kept in the one segment. No sharable executable code will be in a system without MMU support.

- Run our `memwalk` application by executing:

```
# memwalk
```

The system hangs after the program printing some dots:

```
..........................................................
```

The system crashes because every process can access the whole memory if the Linux system has no MMU support.

Use Completed Resource

The completed Linux image for this lab is available in `~/xup_materials/labs/lab1.6/completed/`. If you are stuck in any problem in the lab, you are welcome to use the completed resource. Here is the instructions on how to use the completed resource:

- Copy the completed user applications to `PetaLinux` tree and the Linux images to `/tftpboot` directory by executing the following command on the host:

```
[host] $ ~/xup_materials/complete_lab 1.6
```

The Linux image with MMU support is `~/tftpboot/image.ub`.

The Linux image without MMU support is `~/tftpboot/image.ub.nommu`

- Hit any key to stop auto boot when you see

```
Hit any key to stop autoboot: 5
```

on the `kermit` console.

- Boot the board with Linux image with MMU support using tftp by executing the following command on the `kermit` console:

```
U-Boot> tftp $(netstart) image.ub; bootm
```

- Boot the board with Linux image without MMU support using tftp by executing the following command on the `kermit` console:

```
U-Boot> tftp $(netstart) image.ub.nommu; bootm
```

Outcomes

At the completion of this lab you should

- know how to configure the system with MMU support
- understand some important differences between MicroBlaze Linux systems configure with and without hardware MMU support.

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Date: 2010-01-21

Lab 2.1 – Base System Builder and Board Bring up

Rationale

The real power of Linux on an FPGA platform comes when the custom logic resources of the FPGA are combined with the usability and software infrastructure of the operating system. Xilinx provides a powerful tool to ease FPGA design. The purpose of this lab session is to go through the Xilinx Base System Builder (BSB) and learn how to use PetaLogix tools to configure Embedded Linux system for a new platform.

Objectives

- Use BSB and EDK to create a simple Linux-capable design
- Use PetaLinux to create a new Embedded Linux target for the hardware platform
- Build and boot the new Embedded Linux system

Introduction

In previous labs, we have learned how to configure and build Embedded Linux systems. Embedded Linux always runs on a certain hardware platform. In this lab session, you will create a Linux capable FPGA platform from scratch.

Time

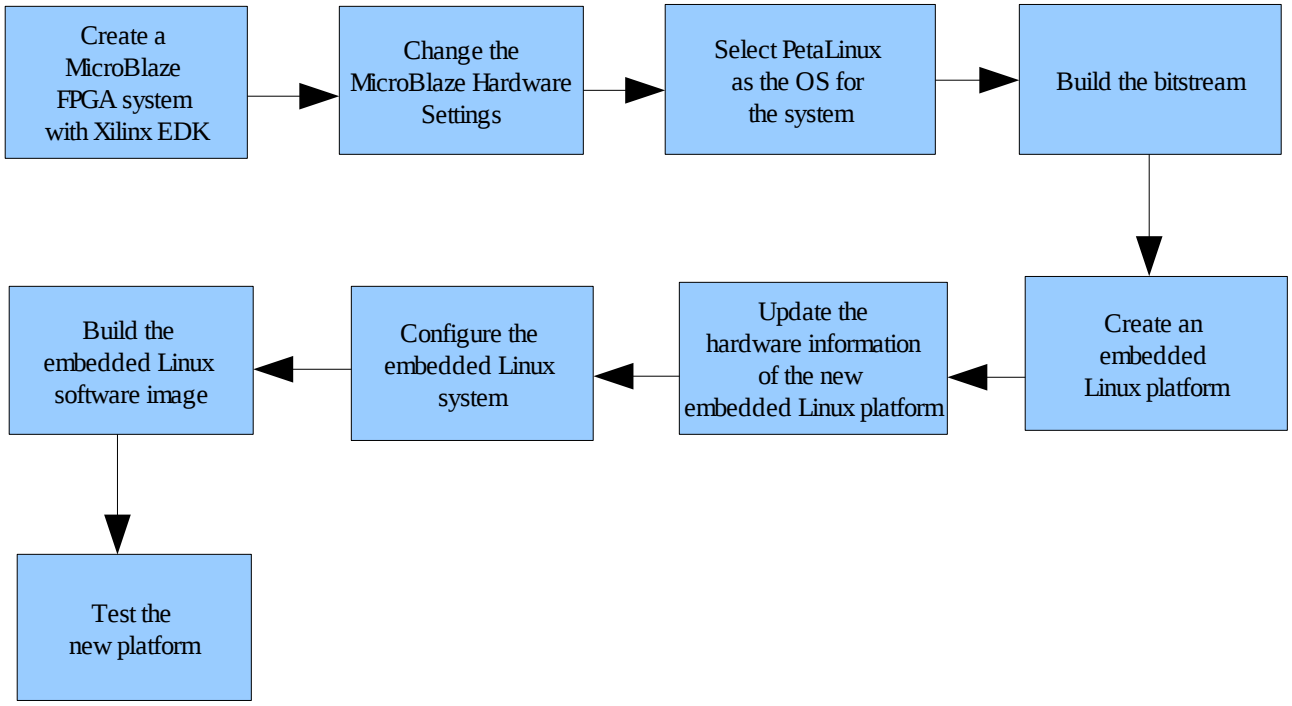
This session will run for approximately 70 minutes.

Preparation

If this is the first lab you are doing then please refer to sections "Before You Start" of Lab 1.1 document for necessary preparatory information on how to setup the hardware environment.

Lab overview

The following diagram is a high level overview of the steps taken in this Lab:



Use Xilinx EDK BSB to Create a FPGA System

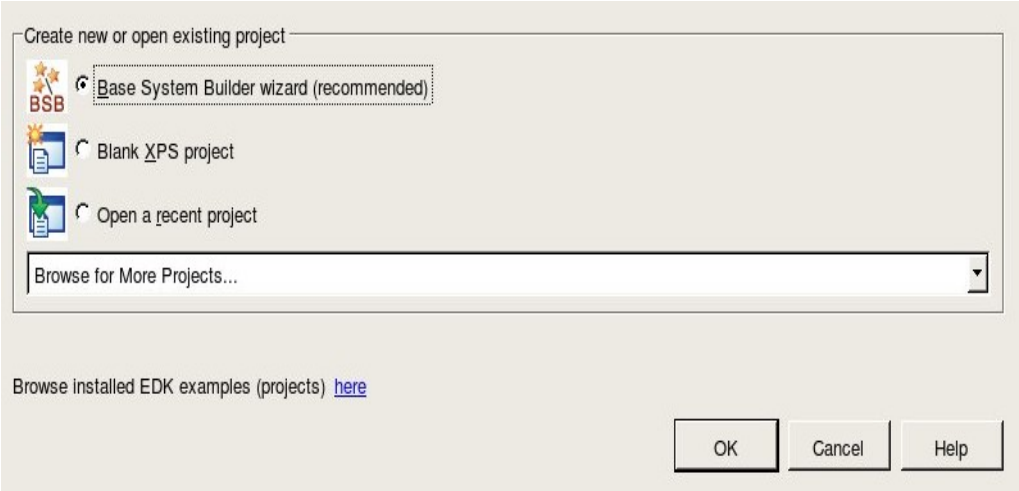
Xilinx EDK provides a tool called "`Base System Builder(BSB)`" to help the users to build a basic FPGA system. In this section, we will learn how to build a MicroBlaze FPGA system with Xilinx EDK BSB. The instructions are described as below:

(Note: depending on the resolution/size of the screen, some BSB GUI pages may display slightly differently to the pages shown in this document.)

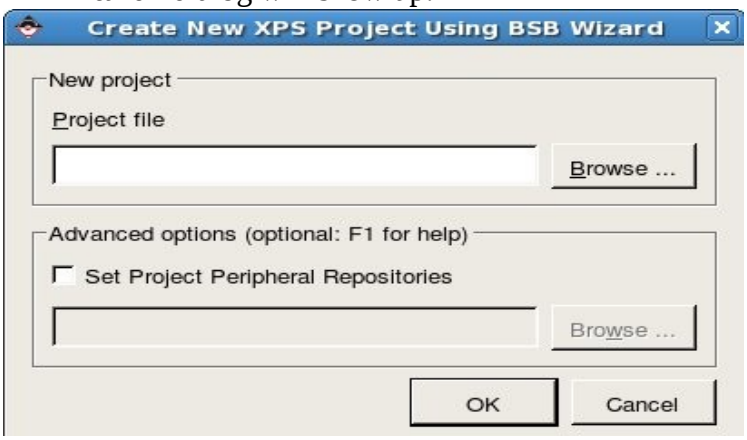
- Start Xilinx Platform Studio (XPS) by executing the following command on the host machine:

  ```
  [host] $ xps
  ```

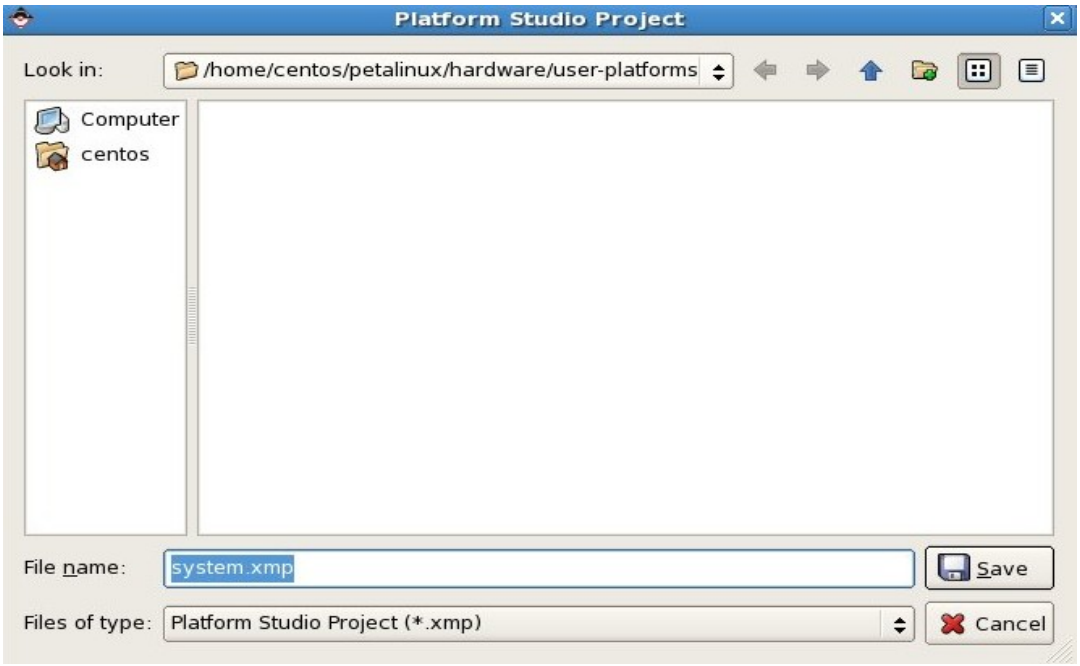
  The XPS GUI will pop up:



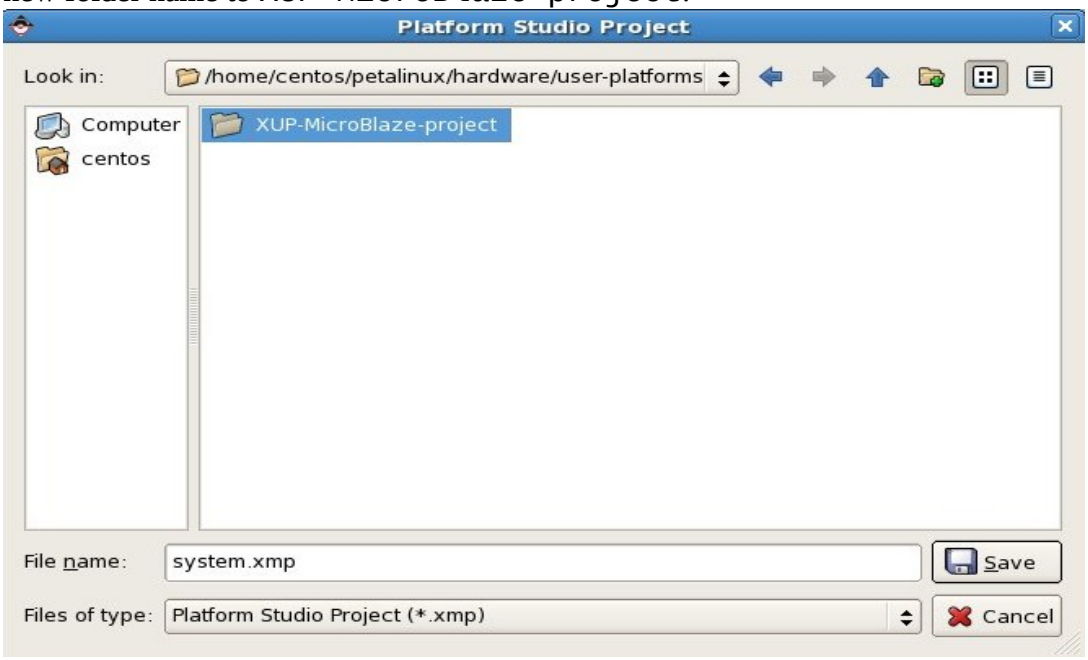
- Select "`Base System Builder wizard(recommended)`" in the "`Create or open existing project`" dialog and click "`OK`" button. The "`Create New XPS Project BSB Wizard`" dialog will show up:



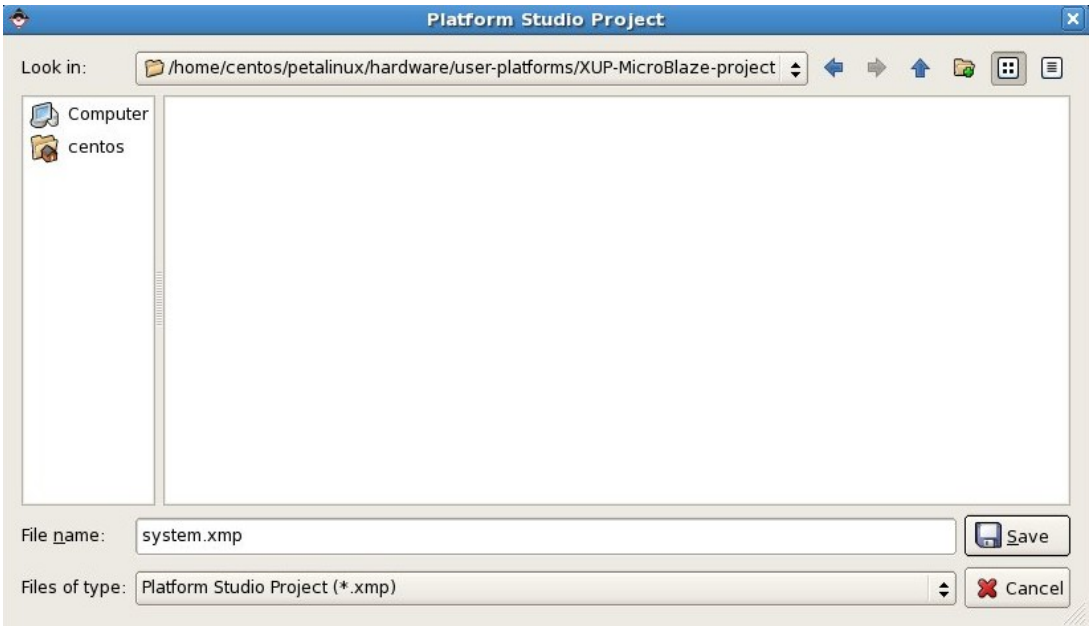
- Click "`Browse...`" button to select a directory to hold the project:



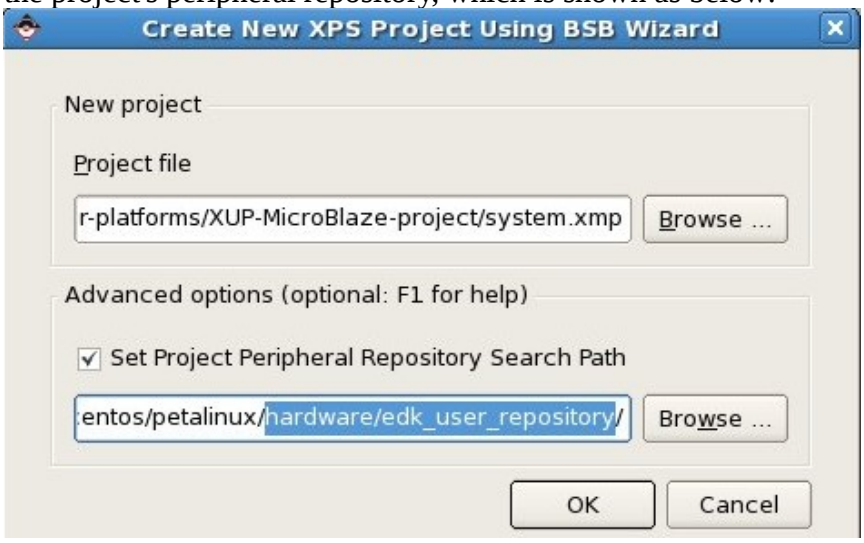
- Let's create a directory called `XUP-MicroBlaze-project` in `~/petalinux/hardware/user-platform` directory to hold the project file `system.xmp` by clicking the new folder icon at the right side of the panel and changing the new folder name to `XUP-MicroBlaze-project`:



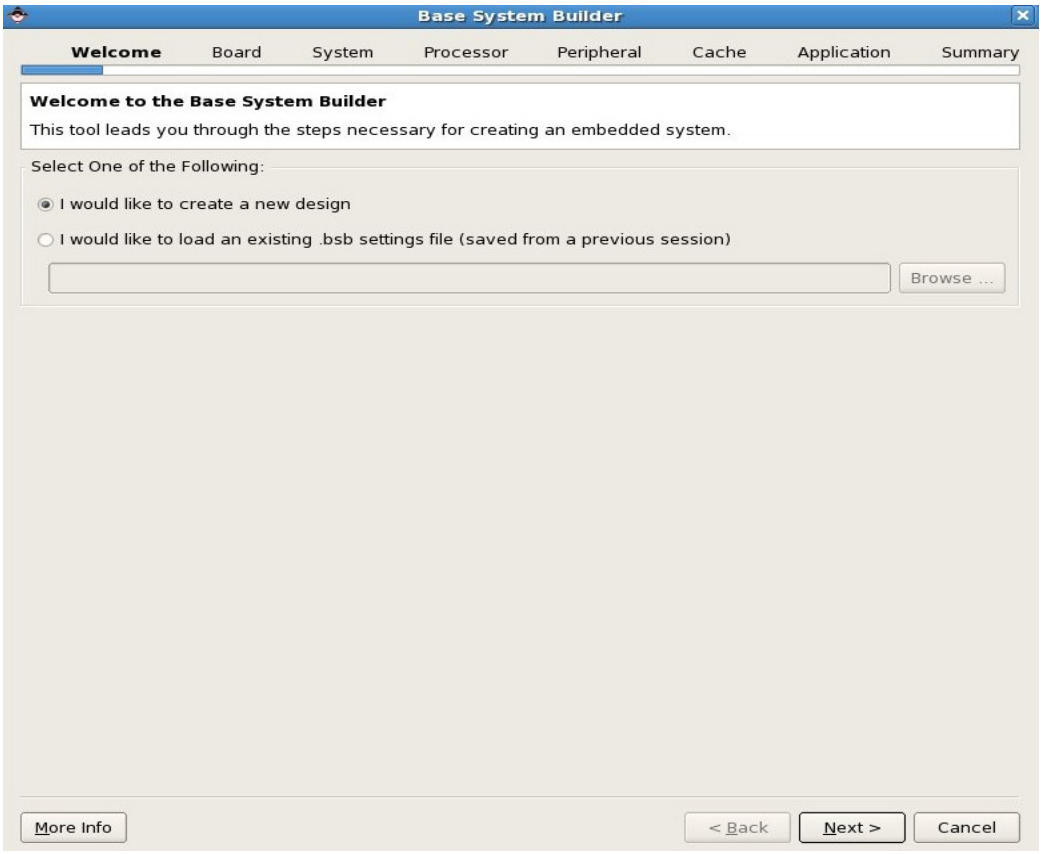
- Click into the `XUP-MicroBlaze-project`:



- Click the "`Save`" button to go back to "`Create New XPS Project Using BSB Wizard`" dialog.
- Select "`Set Project Peripheral Repositories`" and browse to the "`/home/centos/petalinux/hardware/edk_user_repository`" and select it as the project's peripheral repository, which is shown as below:



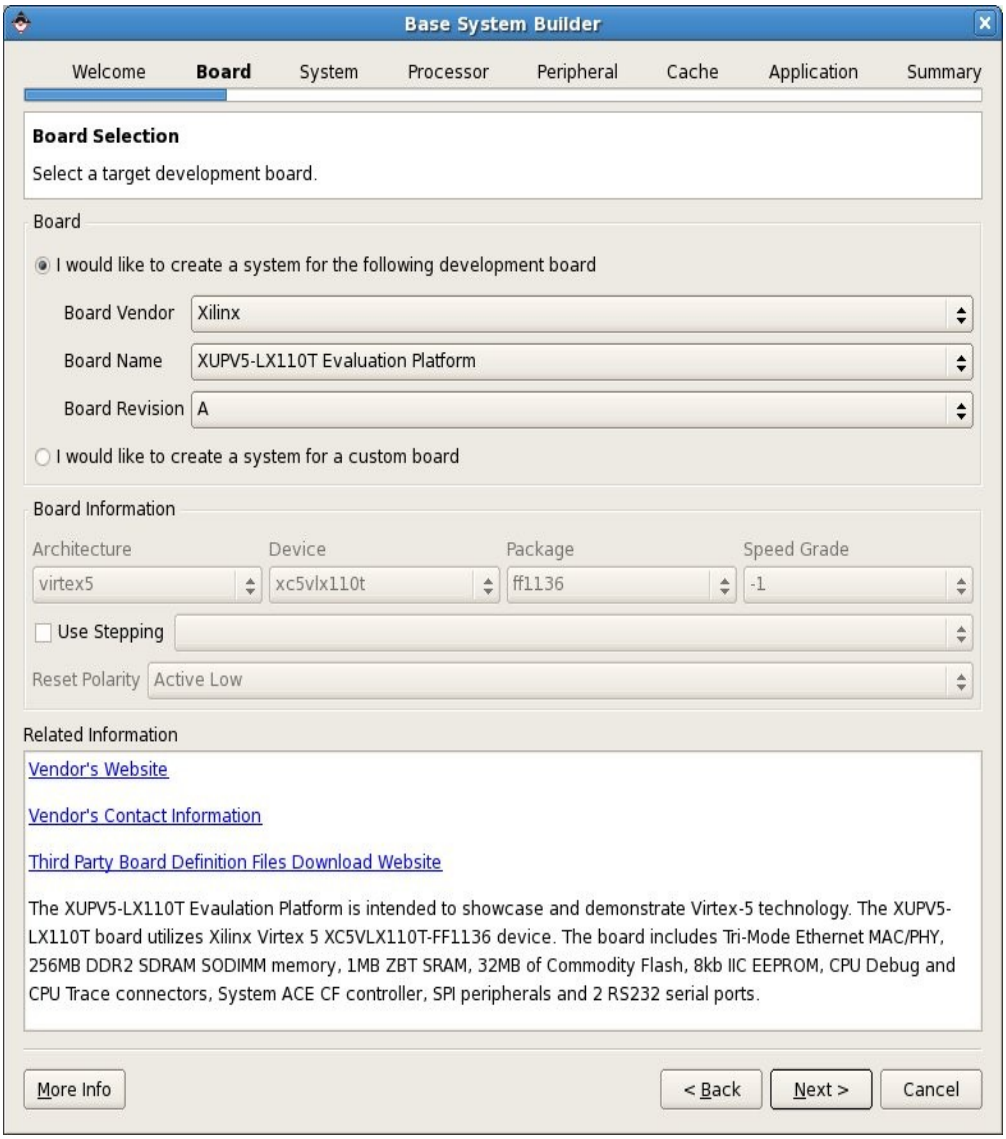
- Click "`OK`" button to go forward. The "`Base System Builder`" welcome window will pop up:



- Select "`I would like to create a new design`" on the "`Base System Builder`" welcome window and then click "`next`" button to move on.

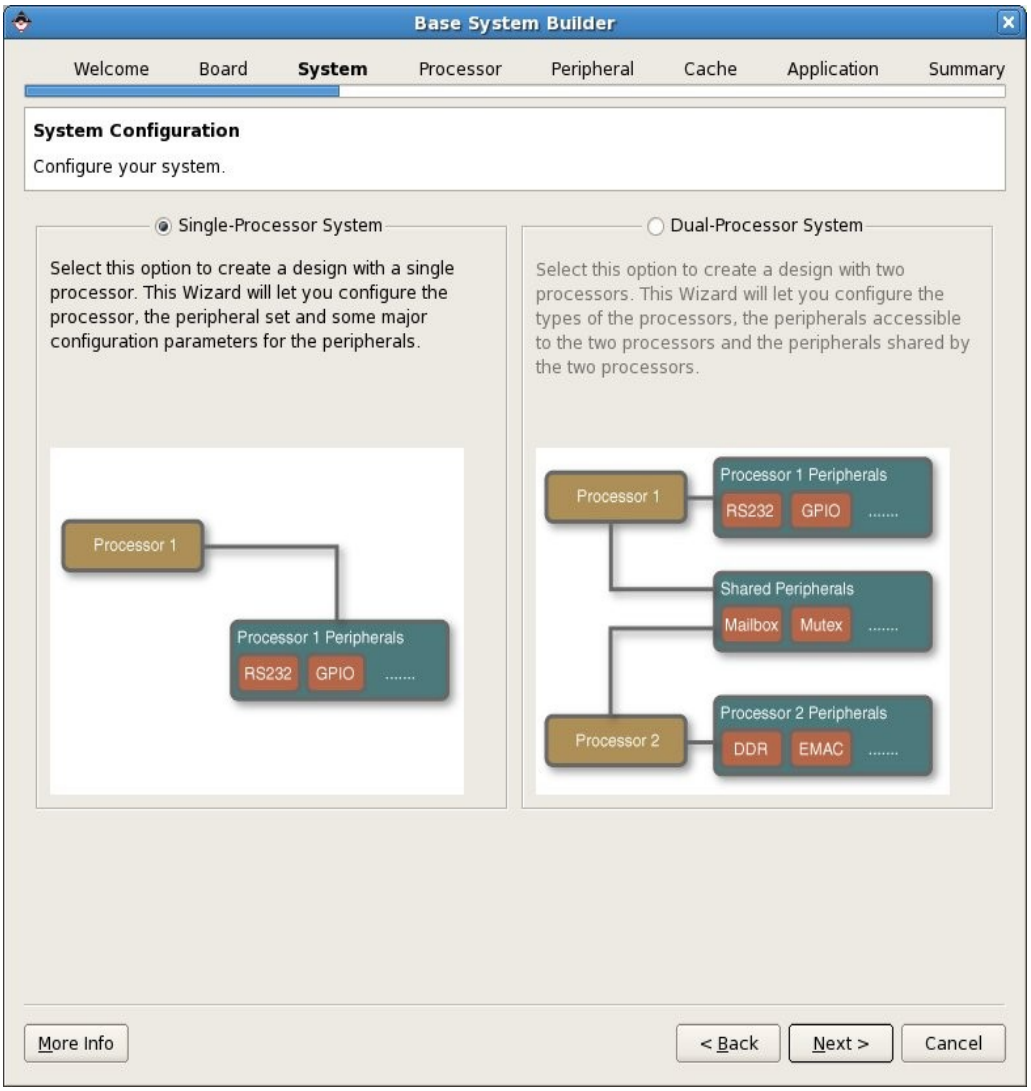
  In the following steps, we will go through the wizard to select a target board and configure peripherals.

- ***Step 1: Select a target board:***
  In the "`Base System Builder - Board`" window,
  - Select "`Xilinx`" as the board vendor
  - Select "`XUPV5-LX110T Evaluation Platform`" as the board name
    (This is shown in the diagram on the next page.)



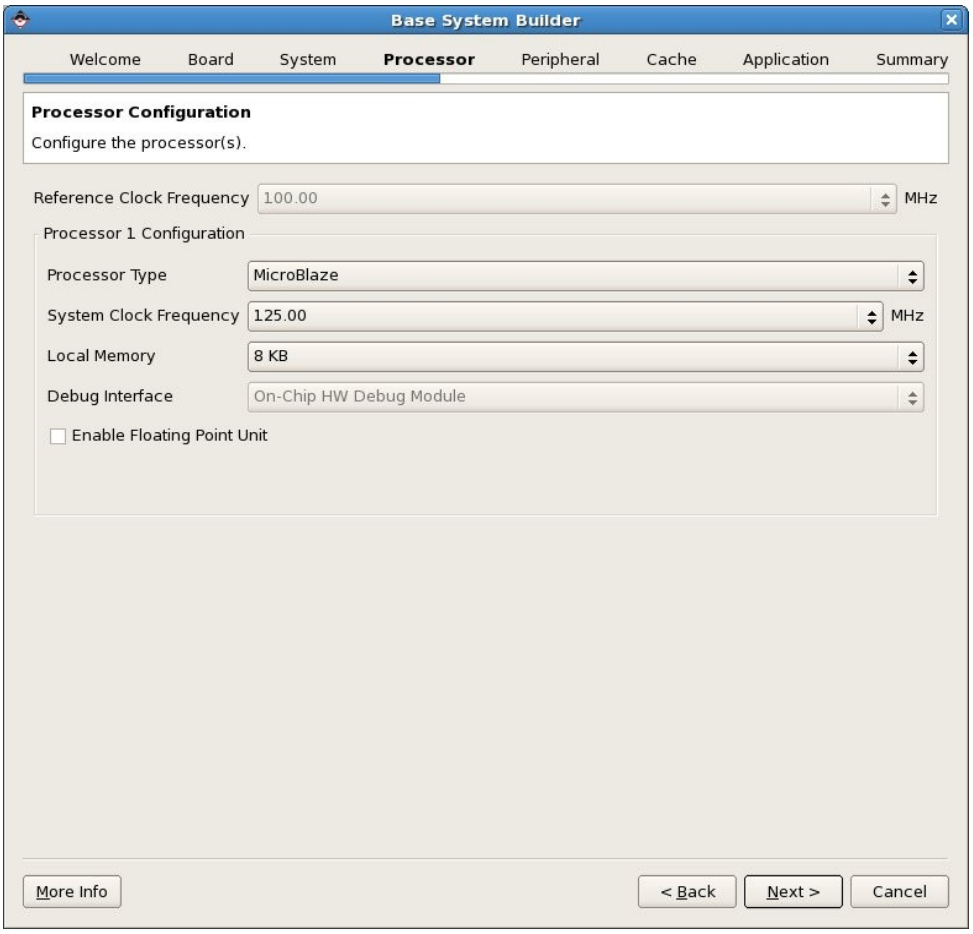
- Click "`Next`" to move forward.

- ***Step 2: Configure System:***
  By default, "`Single-Processor System`" is selected in the "`Base System Builder System`" window:



- Click "`Next`" button without any changes.

- ***Step 3: Configure Processor:***
  In the "`Base System Builder - Processor`" window:
  - Processor Type: select `MicroBlaze`
  - Processor-Bus clock frequency: select `125.00 MHz`
  - Local memory: select `8 KB`



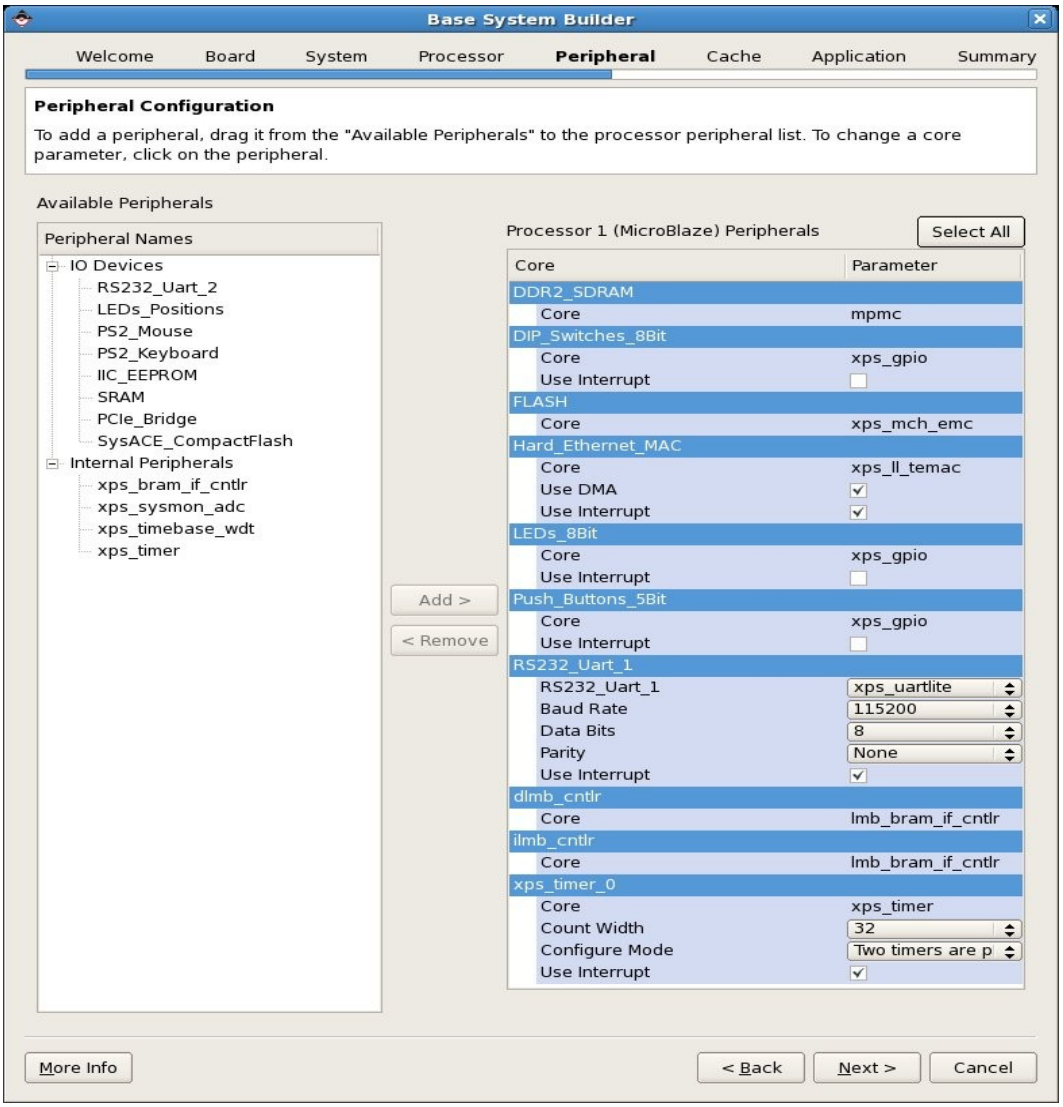
  - Click "Next".

- ***Step 4: Configure Peripherals:***
  In the "Base System Builder Peripheral" window:
  - Remove the following unused Peripherals in this tutorial from the "Processor 1 (MicroBlaze) Peripherals" table by selecting each of them and then clicking "<Remove" button in the middle of the window:
    - IIC_EEPROM
    - LEDs_Positions
    - PCIe_Bridge
    - PS2_Keyboard
    - PS2_Mouse
    - RS232_Uart_2
    - SRAM
    - SysACE_CompactFlash
  - Select "FLASH" from the "IO Devices" list in the "Available Peripherals" table, and then click "Add>" button in the middle of the window to add "FLASH" to the

processor's peripherals. Now, you should see "FLASH" listed in the "Processor 1 (MicroBlaze) Peripherals" table.

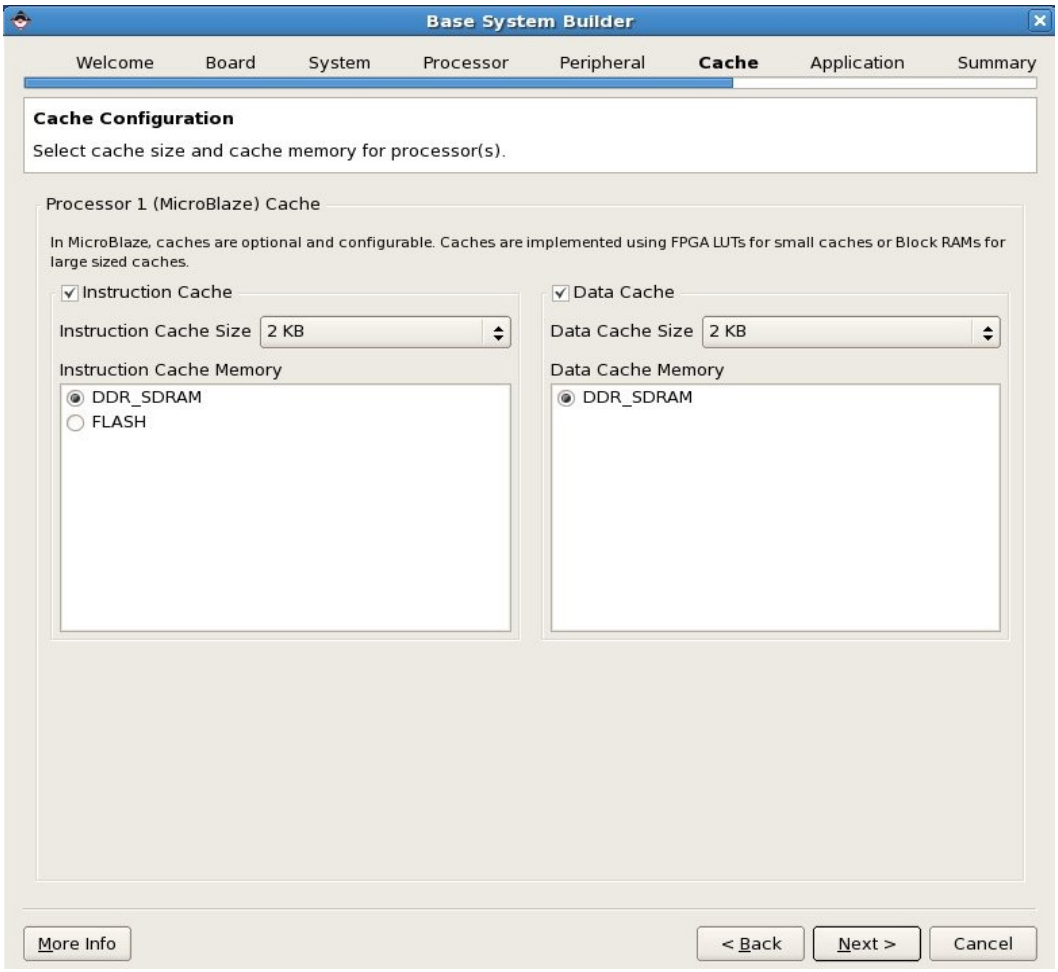
- Click "Select All" button which is just above the peripheral list on the right of the window. This operation will select all the peripherals and expand their settings.
- Change "Hard_Ethernet_MAC" settings:
  - Tick "Use DMA" and "Use Interrupt"
- Change "RS232_UART_1" settings:
  - Baud Rate: Select 115200
  - Tick "Use Interrupt"
- Because Linux relies on timer ticks and the timer is not configured by default, we add a timer peripheral by following these steps:
  - Click "xps_timer" on the "Internal Peripherals" list on the "Available Peripherals" list to select it.
  - Click "Add>" button in the middle of the window to add a timer to the peripherals list on the right of the window. The xps_timer_0 is automatically selected when it is added.
  - Tick "Use Interrupt" of timer "xps_timer_0"

  The Peripherals settings are shown in the diagram on the next page (Please make sure your peripheral settings are the same as those in the following diagram



- Click "`Next`".

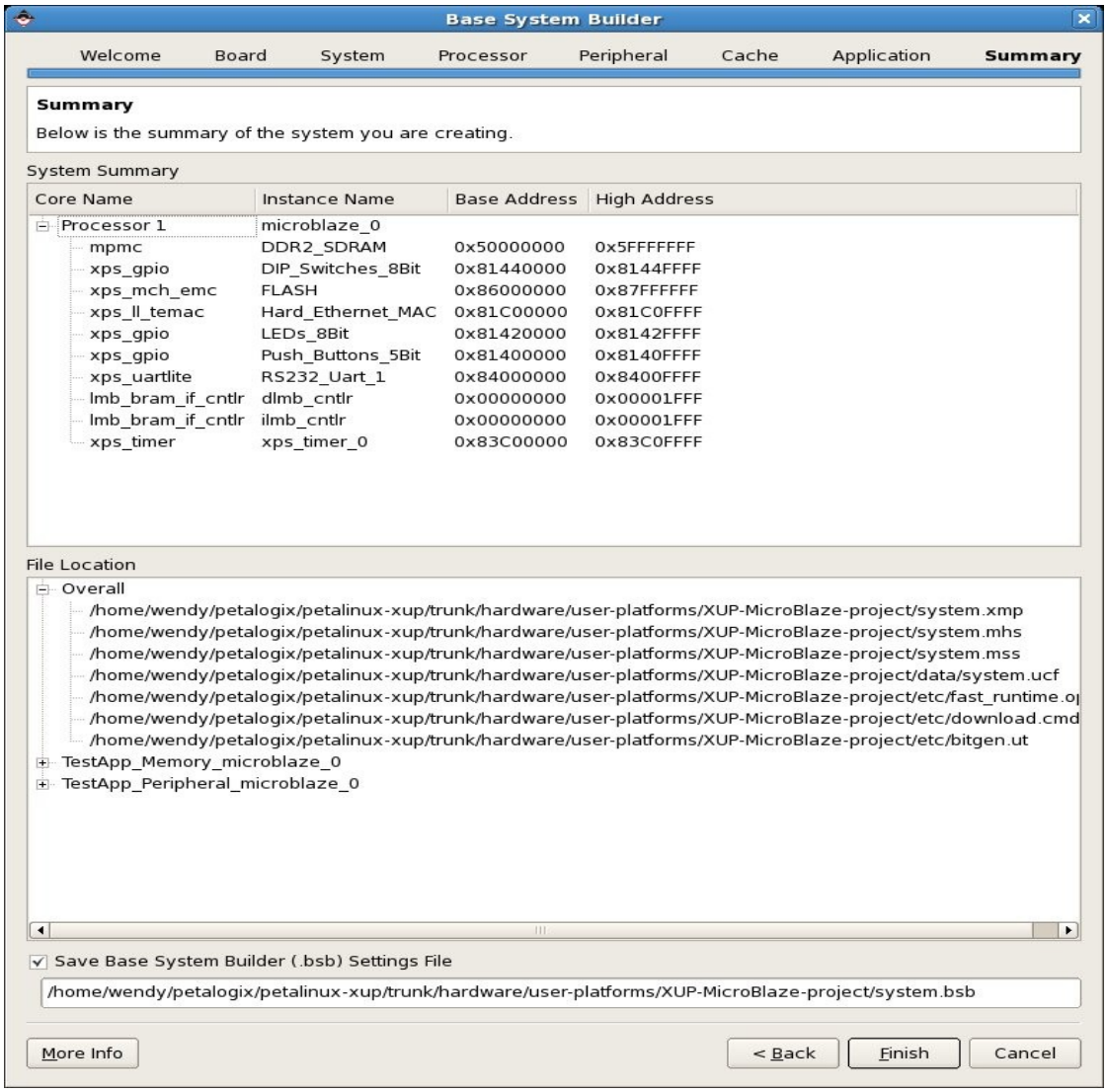
- ***Step 5: Cache Setup:***
  In the "Base System Builder" cache configuration window:
  - Instruction Cache: `tick`
  - Instruction Cache Size: select `2 KB`
  - Instruction Cache Memory: Select `DDR_SDRAM`
  - Data Cache: `tick`
  - Data Cache Size: select `2 KB`
  - Data Cache Memory: select `DDR_SDRAM`:
    Please make sure your cache settings are the same as those shown in the following diagram:



  - Click "`Next`" button

- Click "`Next`" button without changing anything in the "`Base System Builder`" application window.

- The last window of "`Base System Builder`" is the summary window. This window will show you the summary of the system we have just configured and the location of project files. The below diagram shows an example of the `Base System Builder` summary:



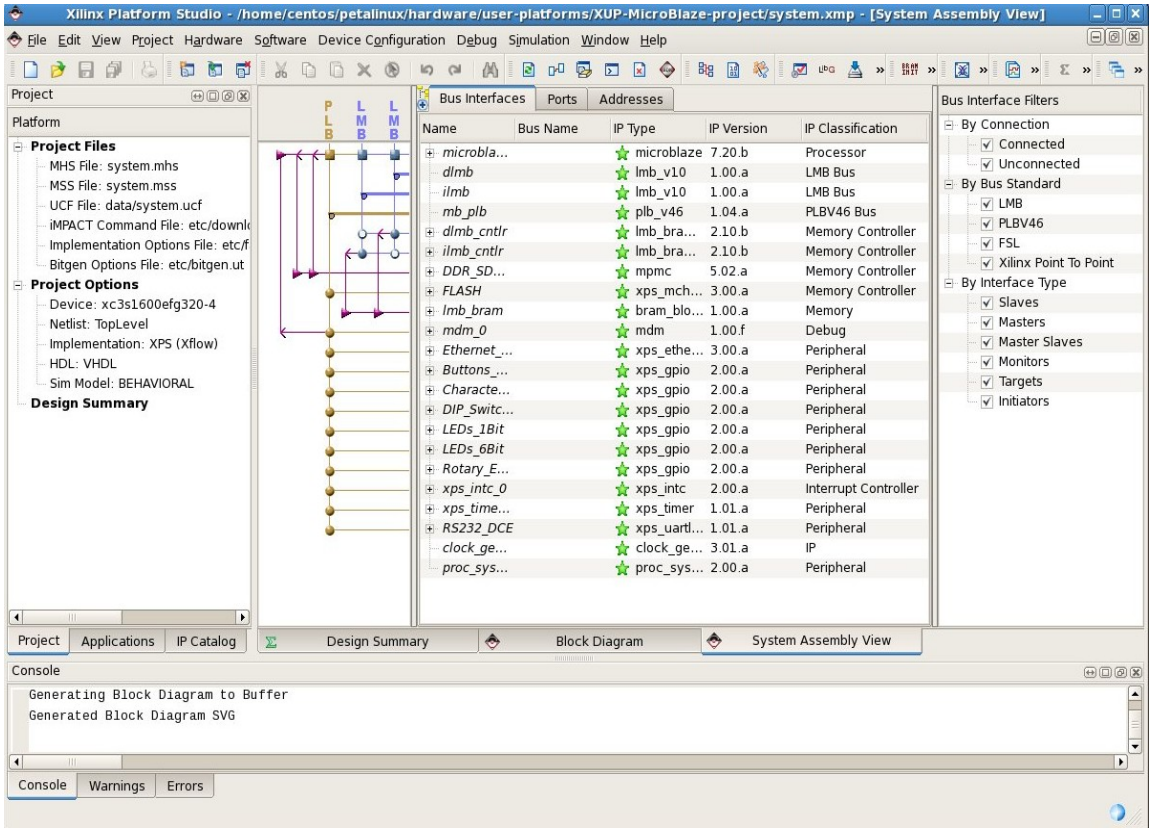
  - Have a look at the contents of the summary window and then click "`Finish`" button to finish the base system building.

- Click "`OK`" button to start using platform studio in "`The Next Step`" pop up window:

Brief Introduction to XPS GUI

Now we have successfully created a MicroBlaze based FPGA platform. Let's start to use Platform Studio.

First of all, have a look at what the EDK GUI tells us:



There are 3 window ranges on the GUI. The above image is just an example, you may see different contents in the EDK GUI.

- The upper left most window range is the `Project Information Adrea`. It has "`Project`", "`Application`", and "`IP Catalog`" tabs.
  - The "`Project`" tab lists the following project information:
    - Project files: It includes Microprocessor Hardware Specification(MHS) file, Microprocessor Software Specification(MSS) file, User Constraint File (UCF), iMPACT command file, implementation Options file and bitgen options file.
    - Project options: It includes all project specific options.
    - Design summary: Double click to open design summary which provides quick access to various report files.
  - The "`Application`" tab lists source files, header files and the settings of each software project.
  - The "`IP Catalog`" tab lists all the EDK IP Cores and custom IP Cores available to choose to configure the system.
- The middle window region has "`Design Summary`", "`Block Diagram`" and "`System Assembly View`" windows.
  - As mentioned in the above, the "`Design Summary`" provides quick access to the report files.
  - The "`Block Diagram`" shows the whole platform's architecture.
  - The "`System Assembly View`" has "`Bus Interfaces`", "`Ports`" and "`Addresses`" tabs.
    - "`Bus Interfaces`" tab displays which component connects to which bus and which bus has which components connected to it. This tab has 3 panels: the connectivity panel on the left, the main panel in the middle and the filter panel on the right.
      - The connectivity panel is a graphical representation of the bus connectivity of the hardware platform.
      - The filter panel defines what will be shown in the connectivity panel.
    - "`Ports`" tab displays the ports configuration of each component.
    - "`Addresses`" tab displays the address mapping of each component.
- The windows at the bottom are output consoles to show the information and results of the XPS and the other tools invoked by XPS.
  - "`Output`" tab is the console to display all the output messages including warnings and errors;

- "`Warning`" tab is the console to display the warning messages;
- "`Error`" tab is the console to display the error messages.

Major Project Files Introduction

As mentioned previously in this lab, BSB generates a complete hardware system. The hardware system is described by the following files:

- `system.mhs` – Microprocessor Hardware Specification file. This file describes the hardware structure of the system. It describes the bus connection, ports connection, address mappings and other configuration settings of each of the cores in the system. If you add or delete a Core or change its configuration through the GUI, this file will be changed too(and vice versa).
- `system.mss` – Microprocessor Software Specification file. This file describes the software settings about OS and drivers of the system but not applications.

  The PetaLinux tools read the `system.mss` file to know what cores are used in the system.
- `data/system.ucf` – User constraint file. Describes IO standard constraints, location constraints, timing constraints and etc.
- `system.xmp` – XPS project file. This file describes project options of the system and the software applications settings.

Configure the MicroBlaze to Enable Barrel Shifter

So far, we have configured a basic MicroBlaze FPGA system. In this section we will change the MicroBlaze hardware settings to enable Barrel Shifter to learn how to change the settings of a hardware core using XPS.

At first, let's have a general idea on Barrel shifter. A Barrel shifter can shift a data word by a specified number of bits in one clock cycle. Including Barrel shifter will dramatically improve the performance but will increase the size of the processor.

Now, we will change the MicroBlaze configuration to include Barrel Shifter on XPS GUI and see the change done by XPS automatically to `system.mhs` file.

We can change system through "`System Assembly View`" or modify the `system.mhs` file directly.

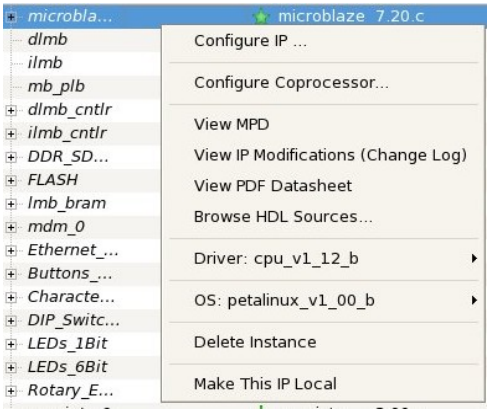
- Before we do any changes, have a look at the MicroBlaze settings in the `system.mhs` file. Open the `system.mhs` file by double clicking the `system.mhs` item from "`Project`" tab. And then read the settings of `microblaze` component. Here is the MicroBlaze settings defined in the `system.mhs` file:

```
BEGIN microblaze
```

```
 PARAMETER INSTANCE = microblaze_0
 PARAMETER C_AREA_OPTIMIZED = 1
 PARAMETER C_INTERCONNECT = 1
 PARAMETER C_DEBUG_ENABLED = 1
 PARAMETER C_ICACHE_BASEADDR = 0x44000000
 PARAMETER C_ICACHE_HIGHADDR = 0x47ffffff
 PARAMETER C_CACHE_BYTE_SIZE = 2048
 PARAMETER C_ICACHE_ALWAYS_USED = 1
 PARAMETER C_DCACHE_BASEADDR = 0x44000000
 PARAMETER C_DCACHE_HIGHADDR = 0x47ffffff
 PARAMETER C_DCACHE_BYTE_SIZE = 2048
 PARAMETER C_DCACHE_ALWAYS_USED = 1
 PARAMETER HW_VER = 7.20.c
 PARAMETER C_USE_ICACHE = 1
 PARAMETER C_USE_DCACHE = 1
 BUS_INTERFACE DLMB = dlmb
 BUS_INTERFACE ILMB = ilmb
 BUS_INTERFACE DPLB = mb_plb
 BUS_INTERFACE IPLB = mb_plb
 BUS_INTERFACE DXCL = microblaze_0_DXCL
 BUS_INTERFACE IXCL = microblaze_0_IXCL
 BUS_INTERFACE DEBUG = microblaze_0_mdm_bus
 PORT MB_RESET = mb_reset
 PORT INTERRUPT = microblaze_0_Interrupt
END
```

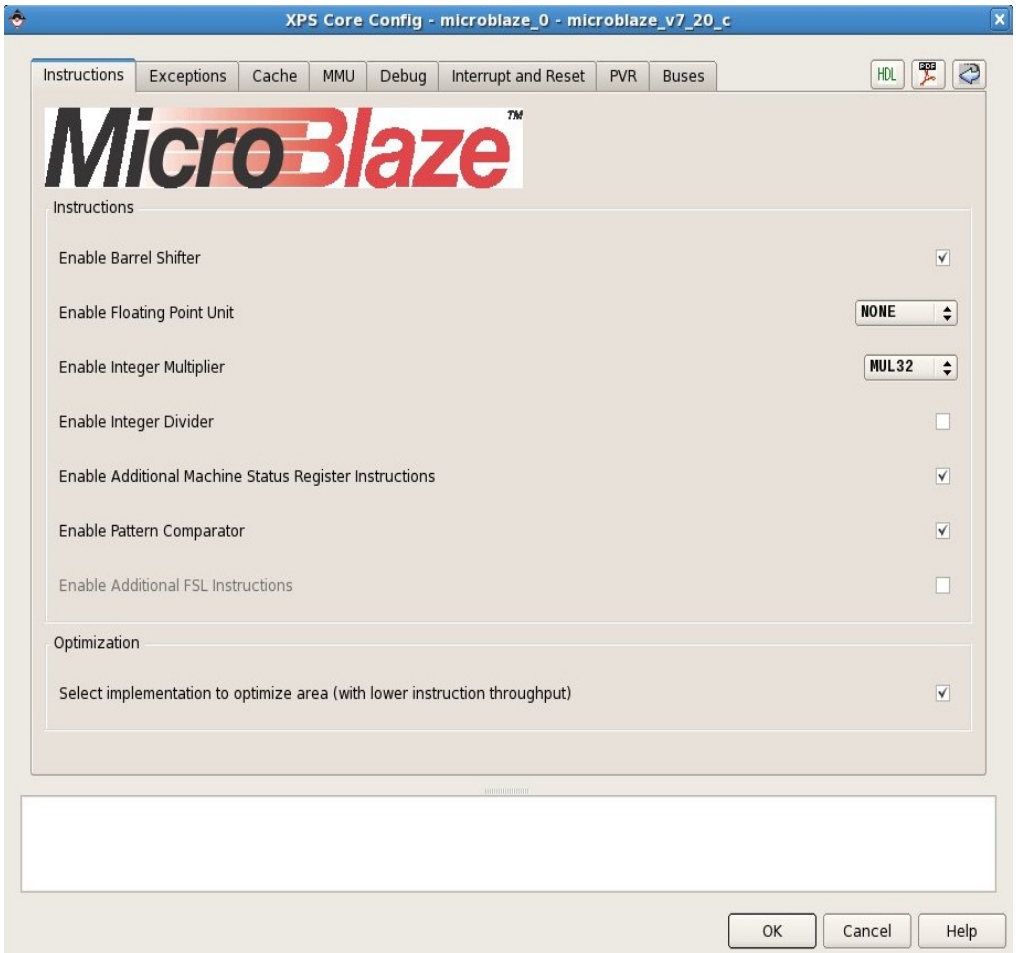
Please note that the MicroBlaze settings shown as above is just an example, the details such as CACHE address can be different depending on the development board and the Xilinx version you used.

- We start to change the MicroBlaze settings using XPS GUI. In the "`Bus Interfaces`" tab of "`System Assembly View`", right click `microblaze_0` and select "`Configure IP ...`" from the menu:



And then the MicroBlaze configuration window will pop up.

- Change the settings to enable Barrel Shifter:
  - Tick "`Enable Barrel Shifter`" on "`Instructions`" tab in the MicroBlaze configuration window as shown in the following diagram



- Click "OK" button to apply the change.

- Open the `system.mhs` file again to see the change in `system.mhs` file. Since the `system.mhs` file has been updated by XPS automatically, a dialog box will be shown to ask whether you want to reload the it if you have open the file on XPS GUI before. If you see such a box, just click the "Yes" button.

  We can see "`PARAMETER C_USE_BARREL = 1`" is added to the `system.mhs` file:

```
BEGIN microblaze
 PARAMETER INSTANCE = microblaze_0
 PARAMETER C_AREA_OPTIMIZED = 1
 PARAMETER C_INTERCONNECT = 1
 PARAMETER C_DEBUG_ENABLED = 1
 PARAMETER C_ICACHE_BASEADDR = 0x44000000
 PARAMETER C_ICACHE_HIGHADDR = 0x47ffffff
 PARAMETER C_CACHE_BYTE_SIZE = 2048
 PARAMETER C_ICACHE_ALWAYS_USED = 1
 PARAMETER C_DCACHE_BASEADDR = 0x44000000
 PARAMETER C_DCACHE_HIGHADDR = 0x47ffffff
 PARAMETER C_DCACHE_BYTE_SIZE = 2048
 PARAMETER C_DCACHE_ALWAYS_USED = 1
 PARAMETER HW_VER = 7.20.c
 PARAMETER C_USE_ICACHE = 1
 PARAMETER C_USE_DCACHE = 1
 PARAMETER C_USE_BARREL = 1
 BUS_INTERFACE DPLB = mb_plb
 BUS_INTERFACE IPLB = mb_plb
 BUS_INTERFACE DXCL = microblaze_0_DXCL
 BUS_INTERFACE IXCL = microblaze_0_IXCL
 BUS_INTERFACE DEBUG = microblaze_0_mdm_bus
 BUS_INTERFACE DLMB = dlmb
 BUS_INTERFACE ILMB = ilmb
 PORT MB_RESET = mb_reset
 PORT INTERRUPT = microblaze_0_Interrupt
END
```

  Please note that the MicroBlaze settings shown as above is just an example, the details such as CACHE address can be different depending on the development board and the Xilinx version

you used.

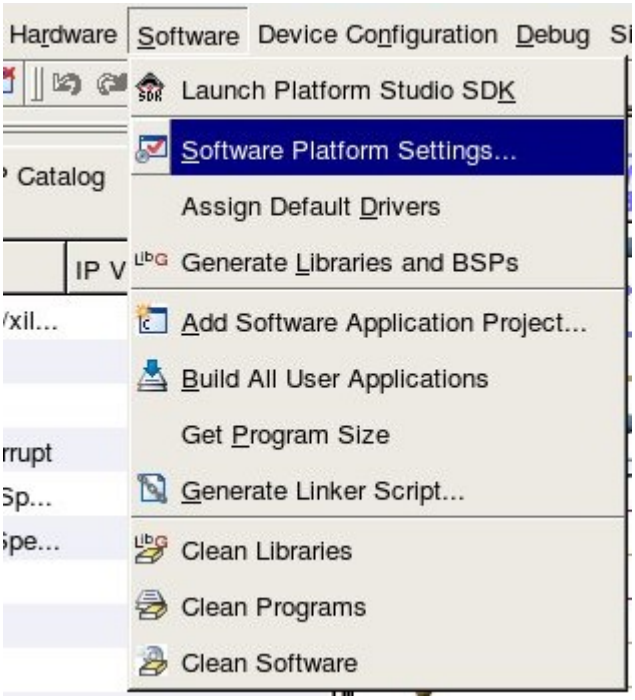
Modify the Software Specification to Target Embedded Linux

By default, the OS running on MicroBlaze is `standalone`. We will change the OS to `PetaLinux`. We will make the modification through GUI and watch the changes to `system.mss` file.

- At first, have a look at the OS settings and processor settings in `system.mss` file before we do any changes.
  - Double click "`MSS File: system.mss`" from "`Project Files`" list in "`Project`" tab to open the `system.mss` file. Below is the OS and processor default settings in `system.mss` file.

```
BEGIN OS
 PARAMETER OS_NAME = standalone
 PARAMETER OS_VER = 2.00.a
 PARAMETER PROC_INSTANCE = microblaze_0
 PARAMETER STDIN = RS232_Uart_1
 PARAMETER STDOUT = RS232_Uart_1
END
```

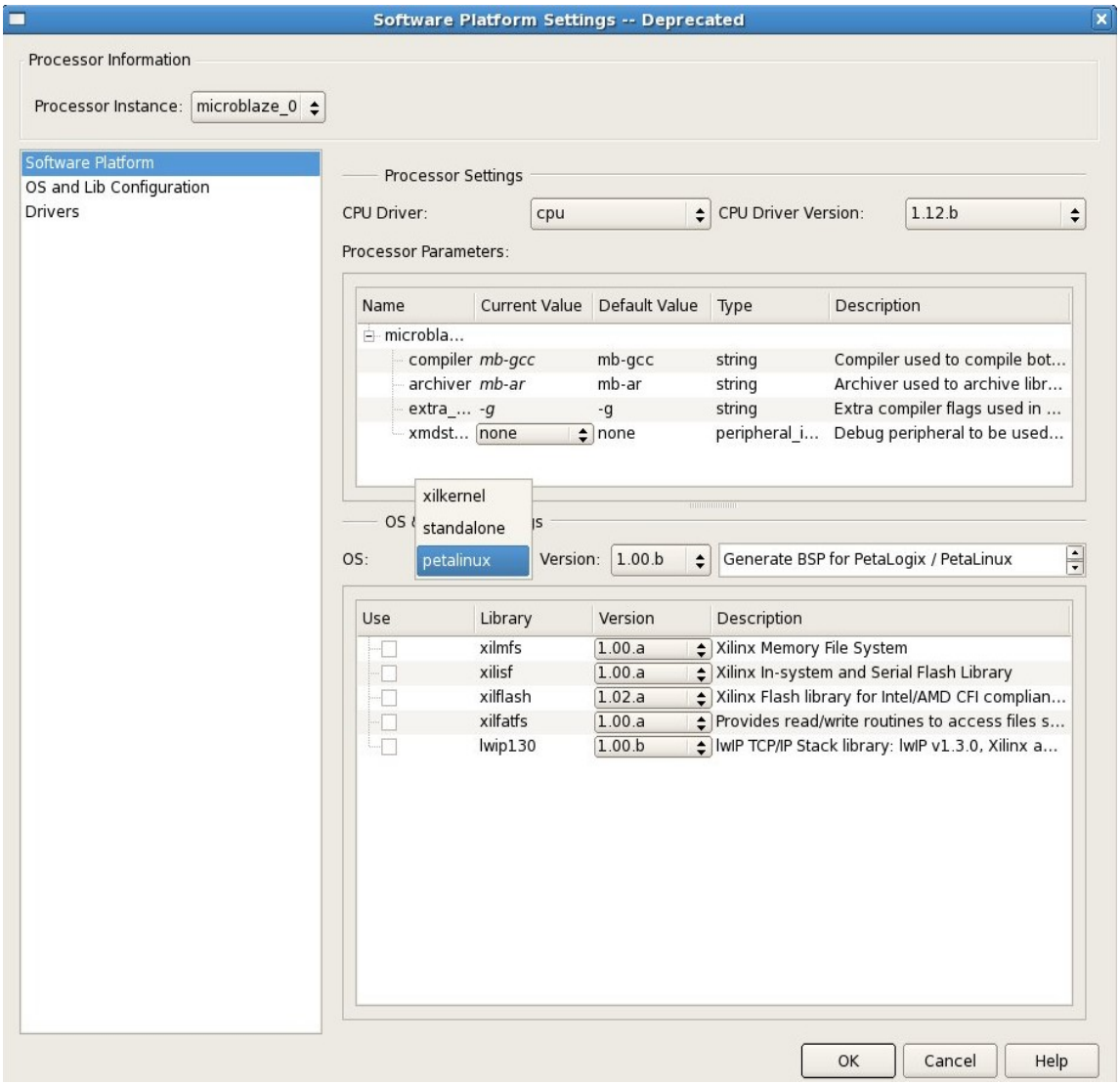
- Change the software platform settings to use `PetaLinux` by:
  - Open "`System Software Settings`" by selecting "`Software --> Software Platform Settings`" on menu bar:



This operation will open "`Software Platform Settings`" window.

There will be a "`Software Features Deprecated`" window pop up when you click the "`Software Platform Settings`". Click "OK" button of this window; and then the "`Software Platform Settings`" window will pop up.

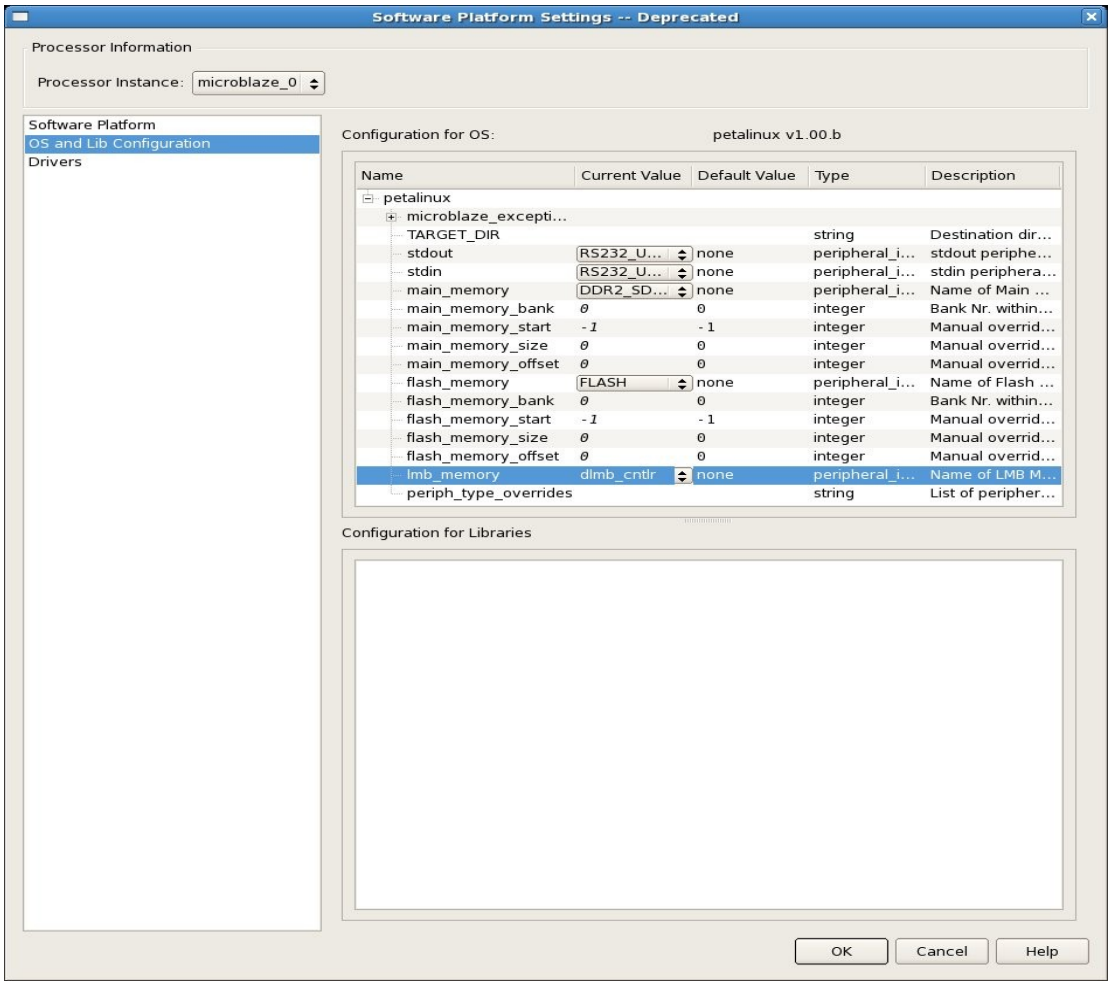
- Set OS to "`petalinux`" in "`Software Platform`" tab:



- Select "`OS and Libraries`" tab and configure software settings for `petalinux`:
  - Click the "`+`" sign on the left of the "`petalinux`" in the "`Name`" column of the "`Configuration for OS`" table to expand the list of settings of PetaLinux OS.
  - Adjust the size of the "`Name`" column to see the whole names of each element by putting your cursor on the border of the column "`Name`", clicking your mouse and dragging it right or left.
  - Do the following settings:
    - stdin: select `RS232_Uart_1`
    - stdout: select `RS232_Uart_1`

- main_memory: select `DDR2_SDRAM`
- flash_memory: select `FLASH`
- lmb_memory: select `dlmb_cntlr`

The following diagram shows an example of the "`Software Platform Settings`":



- Click "`OK`" button to apply the "`Software Platform Settings`" change.
- Check the changes in `system.mss` file:

```
BEGIN OS
 PARAMETER OS_NAME = petalinux
 PARAMETER OS_VER = 1.00.b
 PARAMETER PROC_INSTANCE = microblaze_0
 PARAMETER stdin = RS232_Uart_1
```

```
 PARAMETER stdout = RS232_Uart_1
 PARAMETER main_memory = DDR2_SDRAM
 PARAMETER flash_memory = FLASH
 PARAMETER lmb_memory = dlmb_cntlr
 PARAMETER microblaze_exception_vectors = ((XEXC_NONE,...
END
```

Build the Hardware Bitstream

Now, we are ready to build the hardware. Here is the steps to build the bitstream using XPS GUI:

- Select "`Device Configuration`" --> "`Update Bitstream`" on menu bar to build the bitstream. Or click the "`Update Bitstream`" icon  on the "`Device Configuration`" toolbar directly.

  This operation includes:

  - Generate Netlist: "`Hardware`" --> "`Generate Netlist`"
  - Generate Bitstream: "`Hardware`" --> "`Generate Bitstream`"
  - Generate Libraries and BSPs: "`Software`" --> "`Generate Libraries and BSPs`"
  - Update Bitstream with application to initialize BRAM: "`Device Configuration`" --> "`Update Bitstream`"

Add a New Platform in PetaLinux Configuration Options

Because we are going to run Embedded Linux on the hardware platform, as mentioned in Lab 1.2, we need platform files to tell Linux compilation tools the underlined hardware system and what to build into the Linux image. We can use existing PetaLinux reference platform to build the system, but it is a good chance to learn how to create an Embedded Linux platform. So, we are going to create an Linux platform using PetaLinux tools in this section. Here are the steps:

- Use PetaLinux tool to create a new Embedded Linux platform by executing the following commands on the host machine:

```
[host] $ petalinux-new-platform -v Xilinx -p XUP-MicroBlaze-project -k 2.6
```

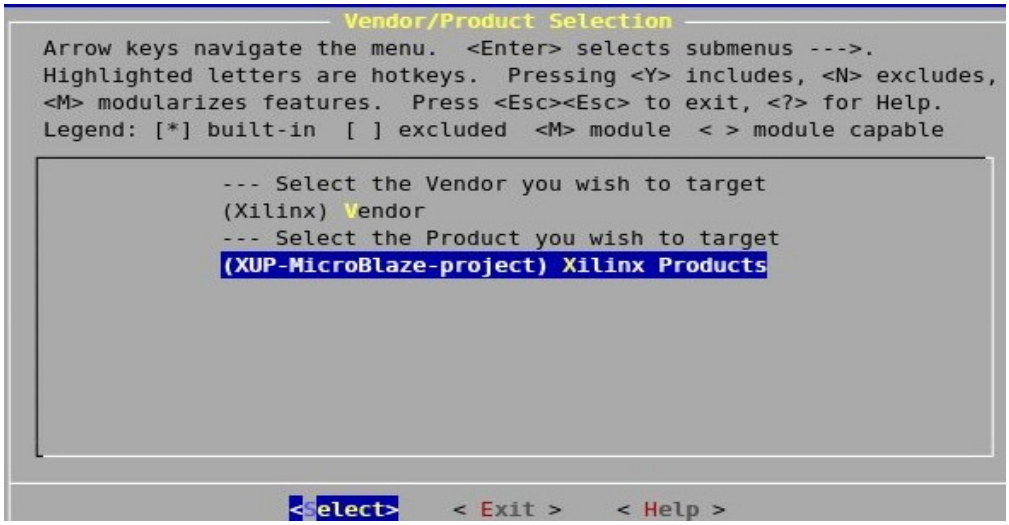
The above command will create a new platform called `XUP-MicroBlaze-project` whose vendor is Xilinx and its Linux kernel version is 2.6.

The default Linux settings of the new platform are in `~/petalinux/software/petalinux-dist/vendors/Xilinx/XUP-`

`MicroBlaze-project` directory.

The default hardware information file for the new platform is in `~/petalinux/software/linux-2.6.x-petalogix/arch/microblaze/platform/Xilinx-XUP-MicroBlaze-project` directory.

- Run `menuconfig` in `~/petalinux/software/petalinux-dist` to select the new platform as we have learned in Lab 1.2:



Exit `menuconfig` and save the configuration change.

- After the bitstream has successfully built, copy hardware settings to `PetaLinux` by executing:

```
[host] $ cd ~/petalinux/hardware/user-platforms/XUP-MicroBlaze-project
[host] $ petalinux-copy-autoconfig
```

Build the MicroBlaze Linux System

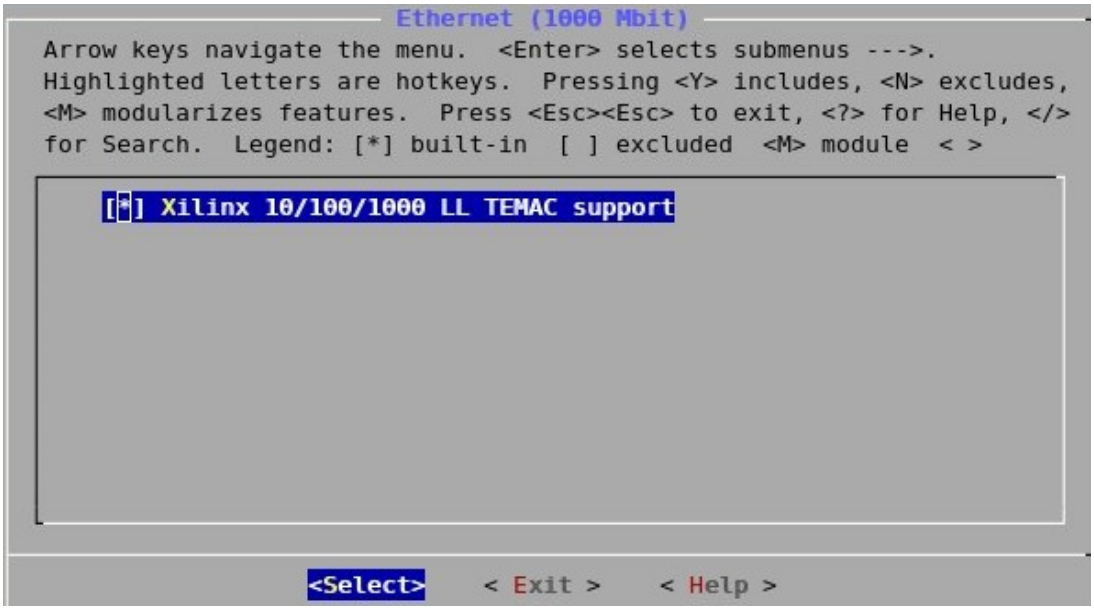
We have to check or change the default configuration to make sure the embedded system we are going to build can work on the hardware platform.

- Run "`make menuconfig`" in "`~/petalinux/software/petalinux-dist`" directory
- Select "`Kernel/Library/Defaults Selection --->`" in the "`Main Menu`". And then select:

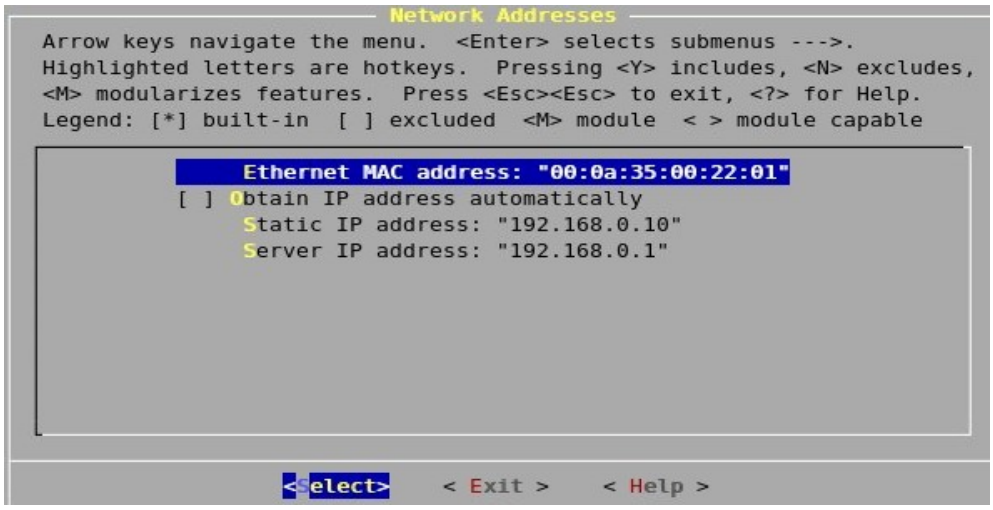
```
[*] Customize Kernel Settings
[*] Customize Vendor/User Settings
```

in the "`Kernel/Library/Defaults Selection`" menu.

- Exit and save configuration changes. The "`Linux Kernel Configuration`" menu window will pop up.
- Pick the right network device driver to support networking:
  - Scroll down to "`Device Drivers`" sub-menu in "`Linux Kernel Configuration`" menu and select it.
  - Scroll down to "`Network Device Support`" sub-menu in "`Linux Kernel Configuration`" menu and select it.
  - Scroll down to `Ethernet (1000 Mbit)` sub-menu in "`Network Device Support`" menu and select it.
  - Select `Xilinx 10/100/1000 EMACLITE support` as the network device driver:



- Exit and save kernel configuration. And then the user settings window pops up.
- Go into "`System Settings`" sub-menu of the "`Main Menu`".
- Select "`Network Addresses`" sub-menu and make sure the IP addresses are correctly set. Here is the network address settings we use in this lab:



- Exit and save configuration changes.
- Build the MicroBlaze Linux with the new Linux platform by executing:

  ```
  [host] $ cd ~/petalinux/software/petalinux-dist
  [host] $ make
  ```

  This will build the entire embedded Linux software package.

Program the FPGA

Both the bitstream and the MicroBlaze Linux image are ready. We can boot the board now. First of all we need to program the FPGA with the newly built bitstream. Here are the steps to configure the FPGA:

- Go back to the Xilinx EDK GUI in which our hardware project is opened to program the FPGA with our bitstream:
  - Select "`Device Configuration`" --> "`Download Bitstream`" from menu bar of the XPS GUI.

  This operation will trigger iMPACT to use the bitstream in the hardware project to program the FPGA on the board. The "`output`" console at the bottom of XPS GUI shows the information the process. If the board is successfully programed by the bitstream, messages similar to the following will be shown on the console.

  ```
  INFO:iMPACT:2219 - Status register values:
  INFO:iMPACT - 0011 1111 1101 1100
  INFO:iMPACT:579 - '1': Completed downloading bit file to device.
  INFO:iMPACT - '1': Checking done pin....done.
  '1': Programmed successfully.
  ```

```
Elapsed time =      3 sec.
Done!
```

- In the `kermit` window, we should see some outputs from the application used to initialized the BRAM. In this lab, `TestApp_Memroy` application is configured by default by the Xilnx EDK `Base System Builder` as the program to initialize BRAM.

  If you choose different application to initialize BRAM, the output in the `kermit` window will be different. E.g., the PetaLinux hardware reference designs use `fs-boot` to initialize BRAM. If you create your hardware system based on the PetaLinux hardware reference designs as you will learn in the coming labs, the output in the `kermit` window will be from the `fs-boot` application after the FPGA is programed by your bitstream.

Boot PetaLinux with JTAG

The FGPA has been programed, now, we can boot PetaLinux on it. Here are the steps to do it:

- Use PetaLinux tool to download the new kernel image to the board on JTAG by executing the following command on the host machine:

```
[host] $ petalinux-jtag-boot -t 0 -a 0x50000000 -i /tftpboot/image.bin
```

  The "`0x50000000`" is the base address of the main system memory, if your main memory address is different, please change it to the right one. You can find the address map of the system in the "`Address`" tab of "`System Assembly View`" of "`Xilinx Platform Studio`".

- When the login prompt comes up in the `kermit` window. Log in and try command such as "`gpio-test`", "`ping`" and "`ifconfig`".

Use Completed Resource

The completed Linux image for this lab is available in

```
~/xup_materials/labs/lab2.1/completed/
```

If you are stuck in any problem in the lab, you are welcome to use the completed resource. Here is the instruction on how to use the completed resource:

- Copy the completed hardware project to `PetaLinux` tree and the Linux images to `/tftpboot` directory by executing the following command on the host machine:

  ```
  [host] $ ~/xup_materials/complete_lab 2.1
  ```

- Download the bitstream to the board by executing:

  ```
  [host] $ cd ~/petalinux/hardware/user-platforms/XUP-MicroBlaze-
  ```

```
project
[host] $ impact -batch etc/download.cmd
```

This command will download the bitstream `implementation/download.bit` to the board. (iMPACT is an Xilinx device configuration tool.)

- Boot the board using `` `petalinux-jtag-boot` `` by executing:

```
[host] $ petalinux-jtag-boot -t 0 -a 0x50000000 -i /tftpboot/image.bin
```

Outcomes

At the completion of this lab you should

- know how to use XPS BSB to create a hardware plartform
- know how to build bitstream with PetaLinux support
- know how to create new Embedded Linux platform
- know how to build Embedded Linux for a hardware platform.

Document Version

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Date: 2010-01-21

Lab 2.2.a – Custom Hardware Development – PLB PWM

Rationale

Xilinx provides commonly used bus interfaces for customized IP Core to talk to the rest of the on-chip system. It also provides a customized IP Core creation tool to automatically add the specified bus interface to our IP Core when we use it to create our customized hardware.

The purpose of this lab session is to go through XPS Create and Import Peripheral Wizard and experience one of the commonly used buses, Processor Local Bus (PLB).

Objectives

- Design a IP Core in VHDL
- Use XPS Create and Import Peripheral Wizard to create customized IP Core
- Integrate a IP Core with PLB interface
- Use XMD to debug the hardware

Introduction

In the previous lab, we have learned how to create a hardware platform with BSB. In this lab, we are going to create our PWM core with PLB interface with XPS Create and Import Peripheral Wizard.

Pulse Width Modulation (PWM) is a method of generating analog-like signals from purely digital circuits. By varying the duty cycle of a square wave signal from 0 to 100 percent, and filtering the output through a low-pass filter, analog outputs may be simulated.

We will use multichannel PWM to vary the brightness of 4 User LEDs on the development board. Varying the duty cycle of the LED control signal, and with your eye providing the low pass filtering, you can vary the apparent brightness of the LED from all-off to all-on.

Time

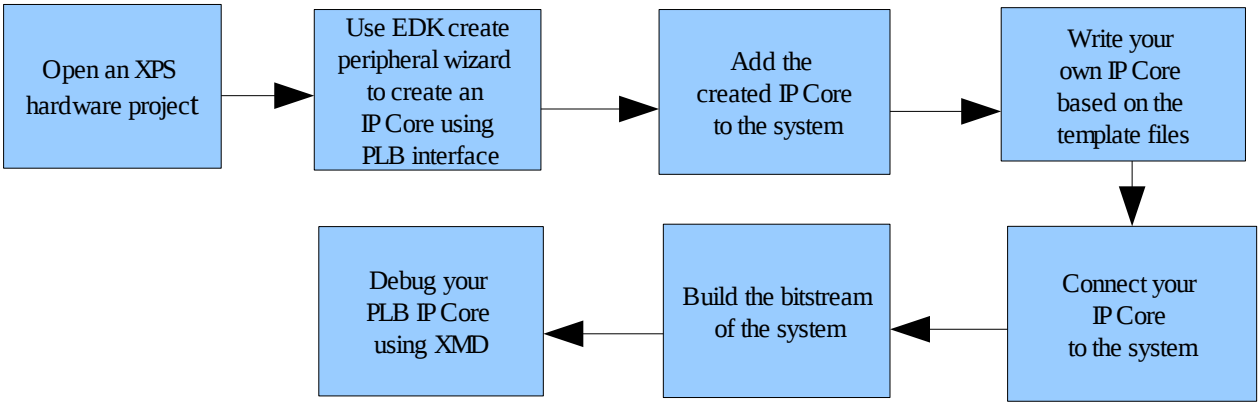
This session will run for approximately 75 minutes.

Preparation

If this is the first lab you are doing then please refer to sections "Before You Start" of Lab 1.1 document for necessary preparatory information on how to setup the hardware environment.

Lab overview

The following diagram is a high level overview of the steps taken in this Lab:



Create a XPS project for PWM

- Create a PWM project directory in `~/petalinux/hardware/user-platforms/` by executing the following commands on the host machine:

```
[host] $ cd  ~/petalinux/hardware/user-platforms/
[host] $ mkdir XUP-pwm-plb-project
```

- Copy the contents from the reference design to the new `XUP-pwm-pld-project` directory by executing:

```
[host] $ cd XUP-pwm-plb-project
[host] $ cp -r ~/petalinux/hardware/reference-
designs/Xilinx--edk113/* ./
```

  Because we use the same development board as the reference design, we can make our hardware platform by modifying the reference design to save time.

- Run XPS to open the project by executing the following command in the `XUP-pwm-plb-project` directory:

```
[host] $ xps system.xmp
```

At this point, Version Management wizard might appear if the Xilinx version you used is newer than the one used to generate the reference design. If it is the case, click "`Next`" as required, and then "`Finish`" to upgrade the project files.

Browse PWM VHDL design

There is a ready-to-use PWM entity in the lab materials, before we move forward, let's have a look at

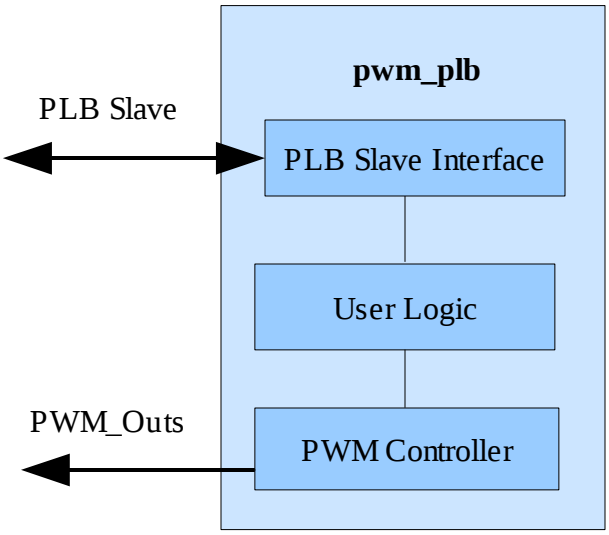
the file.

Open the `pwm_controller.vhd` file in `~/xup-materials/labs/lab2.2a/resources/pcores/pwm_plb_v1_00_a/hdl/vhdl` directory and have a look at the file.

This file describes a very simple 4-channel PWM controller. Each channel has a 8-bit PWM counter. The input `PWM_Value0` to `PWM_Value3` represent the duty cycle of PWMs<0> to PWMs<3> respectively. Each PWM channel has a value range from 0 to 255.

We will create a PLB interface to control the core.

Below are architecture diagrams of PWM IP Core with PLB interface.



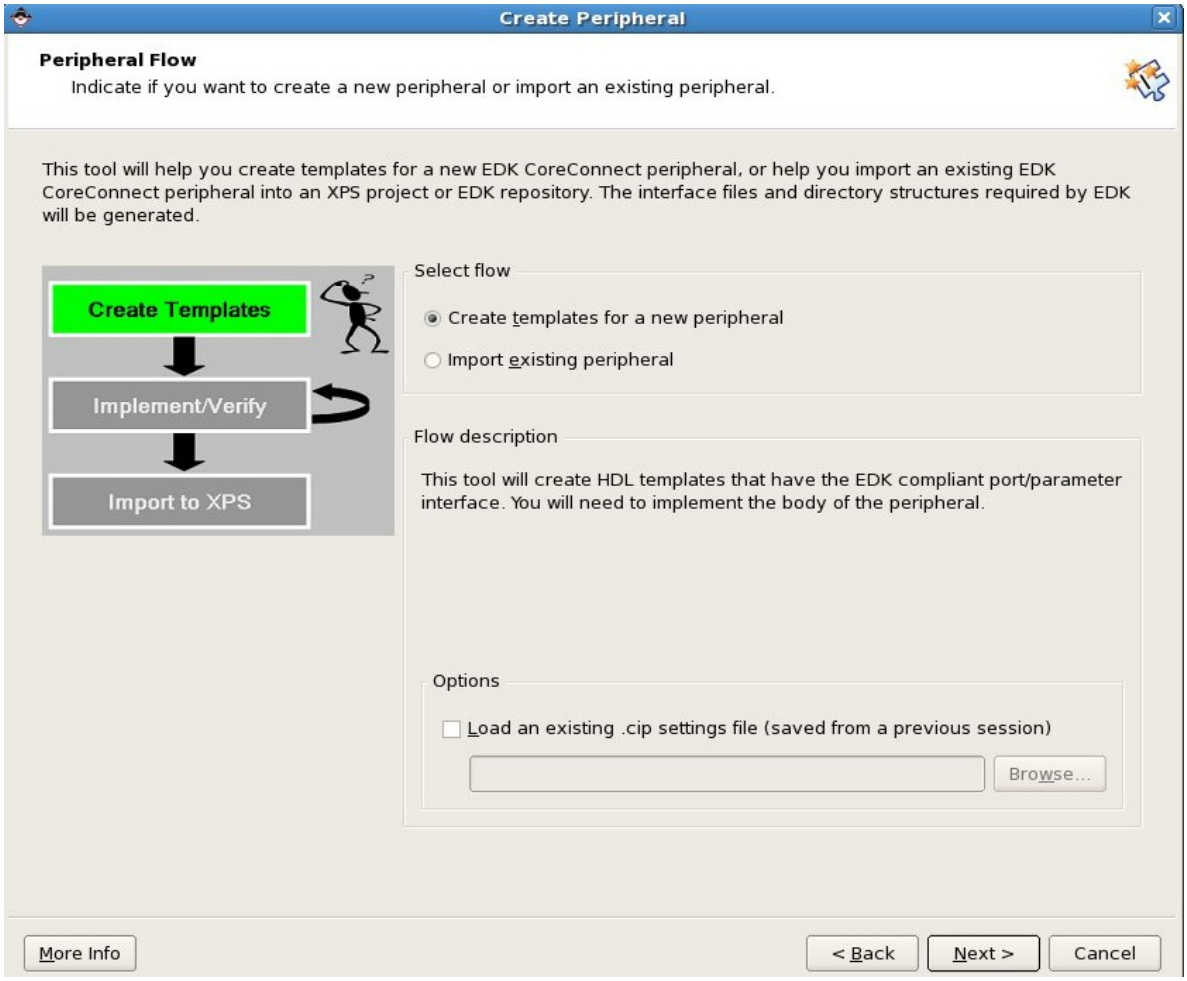
- PWM controller with PLB interface architecture is shown in the upper diagram.
  - `pwm_plb` – Top level wrapper. It contains 3 components, PLB Slave interface, User Logic and PWM Controller.
  - `PLB Slave Interface` – Interface to slave side of PLB bus.
  - `User Logic` – Set the PWM duty cycle values based on the data got from PLB Slave Interface.
  - `PWM Controller` – the PWM controls the 4 PWM channels' output, it outputs '1' in the duty cycle and '0' in the non-duty cycle.

We will create a PWM controller with PLB interface and will build a hardware platform with it in the following sections.

Create a PWM Controller with PLB Interface

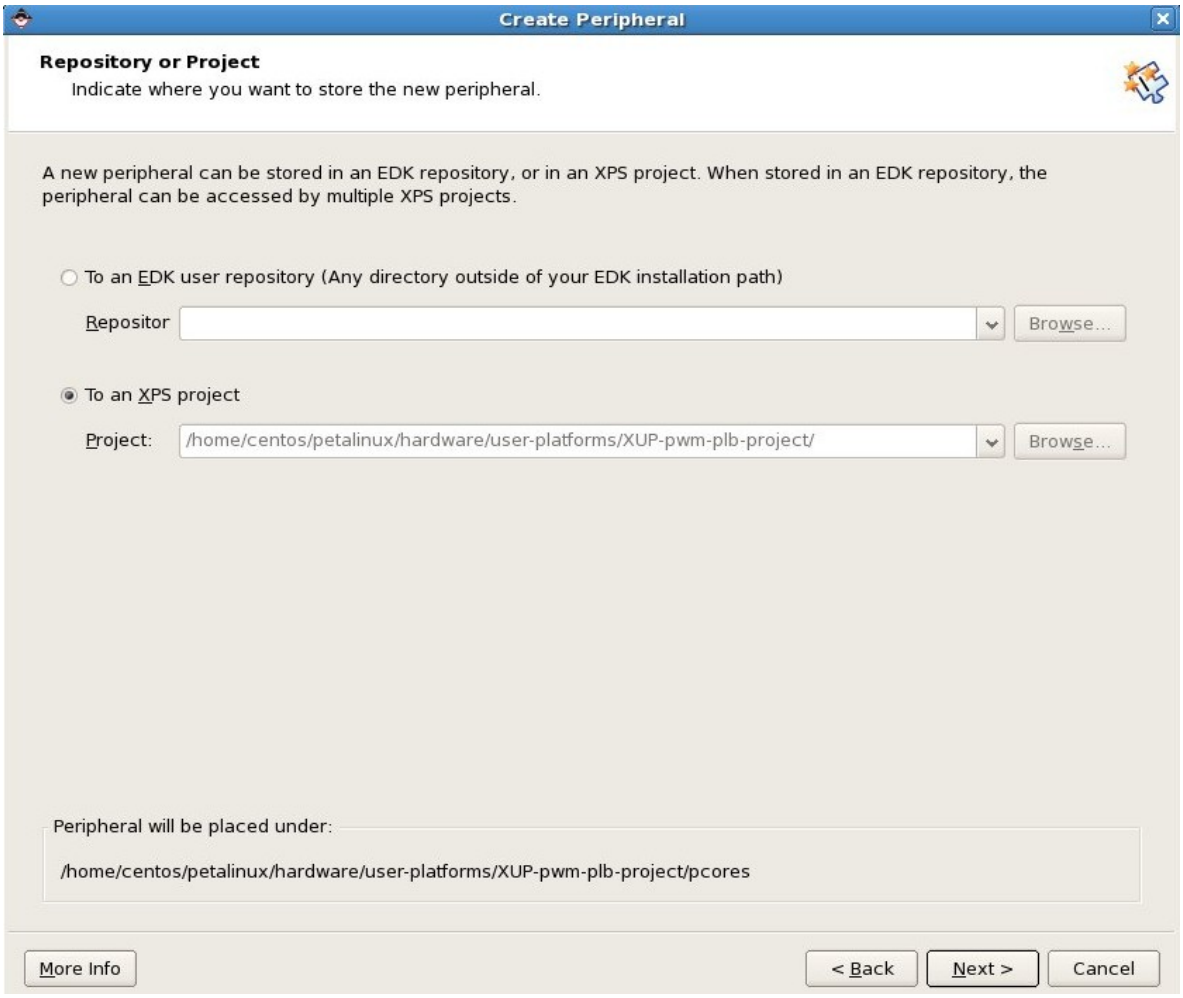
To use the PWM controller, we need to connect it to the rest of the system. In this section, we will create a PWM controller with PLB interface with XPS "Create and Import Peripheral Wizard". Here are the steps:

- Select "`Hardware`"-> "`Create or Import Peripherals`" from menu bar to run Create and Import Peripheral Wizard.
- Click "`Next`" in the welcome window
- Select "`Create templates for a new peripheral`" in the "`Peripheral flow`" window:

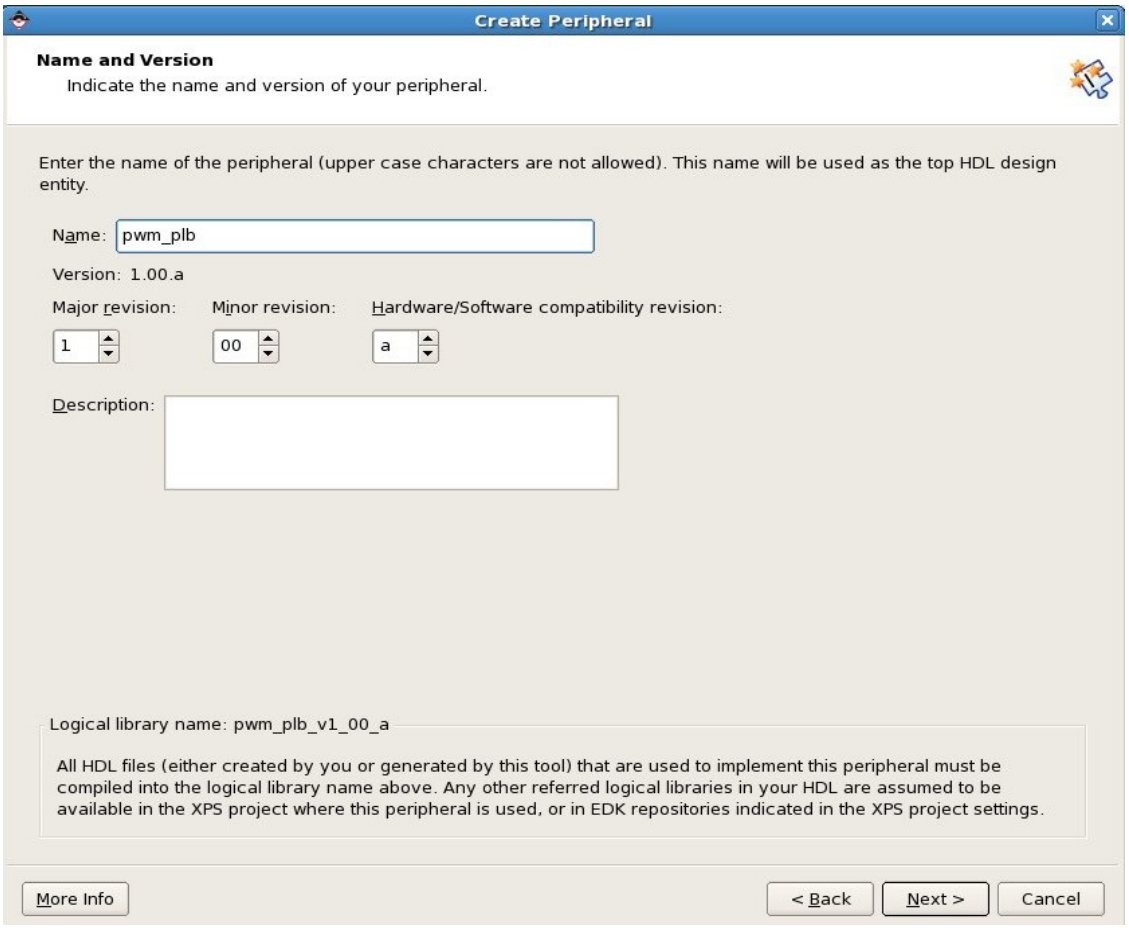


Click "`Next`".

- Click "`Next`" in the "`Create Peripheral - Repository or Project`" window with the default setting to save the new IP Core in this XPS project:

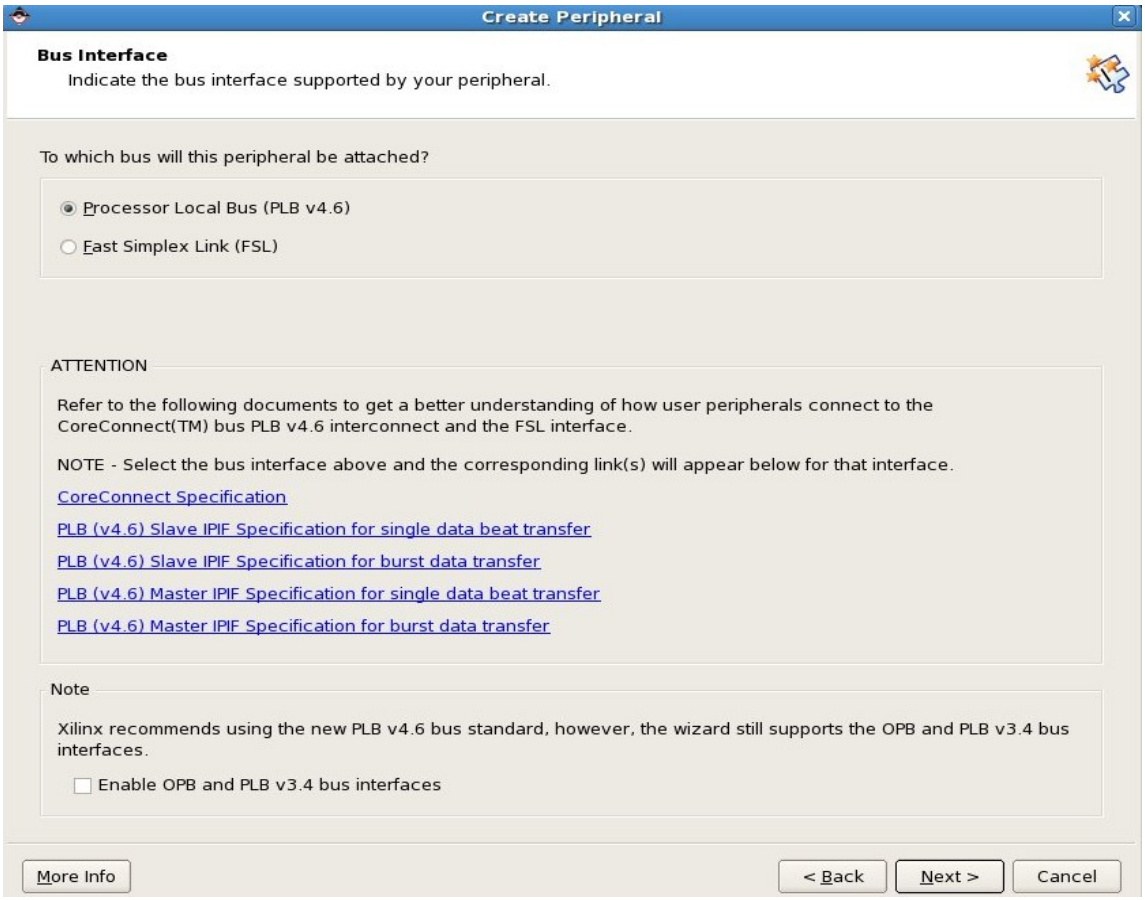


- In the "`Name and Version`" window, type "`pwm_plb`" in the peripheral name text box:

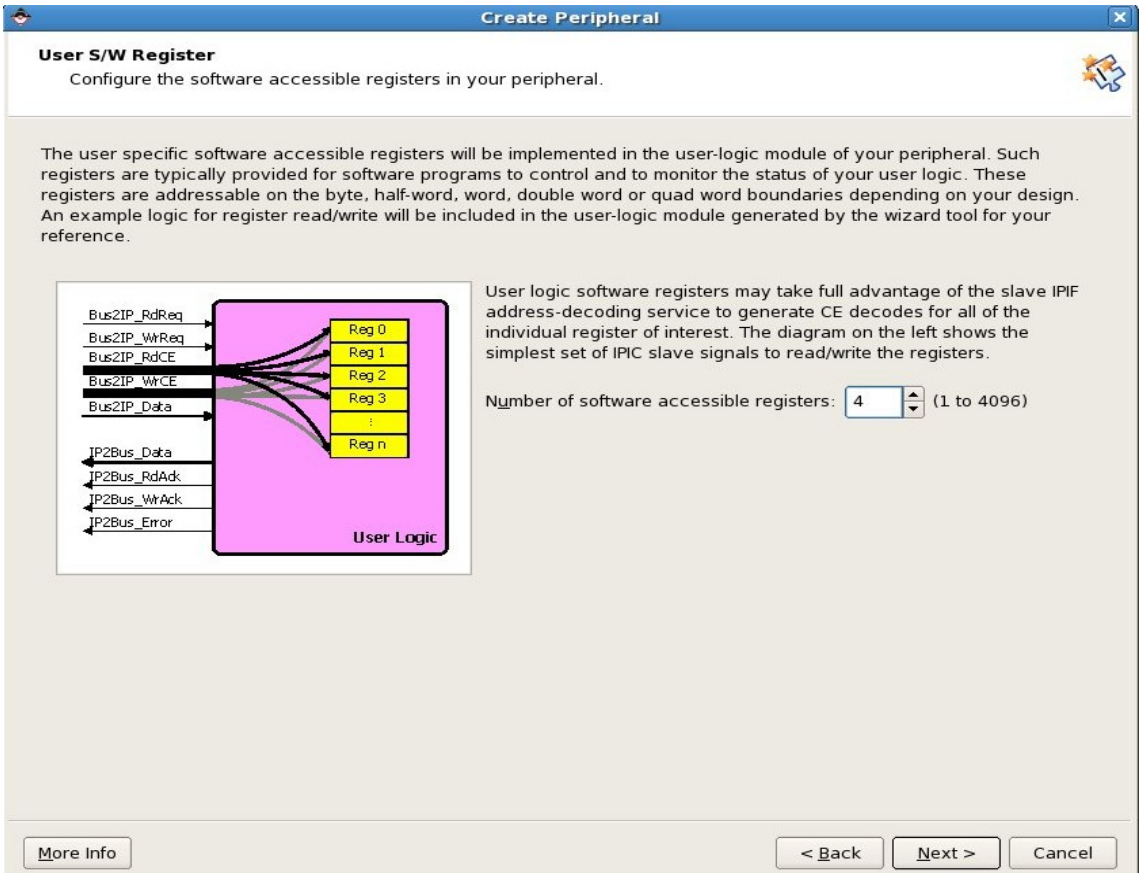


Click "`Next`".

- In the "`Bus Interface`" window, select "`Processor Local Bus (PLB v4.6)`":

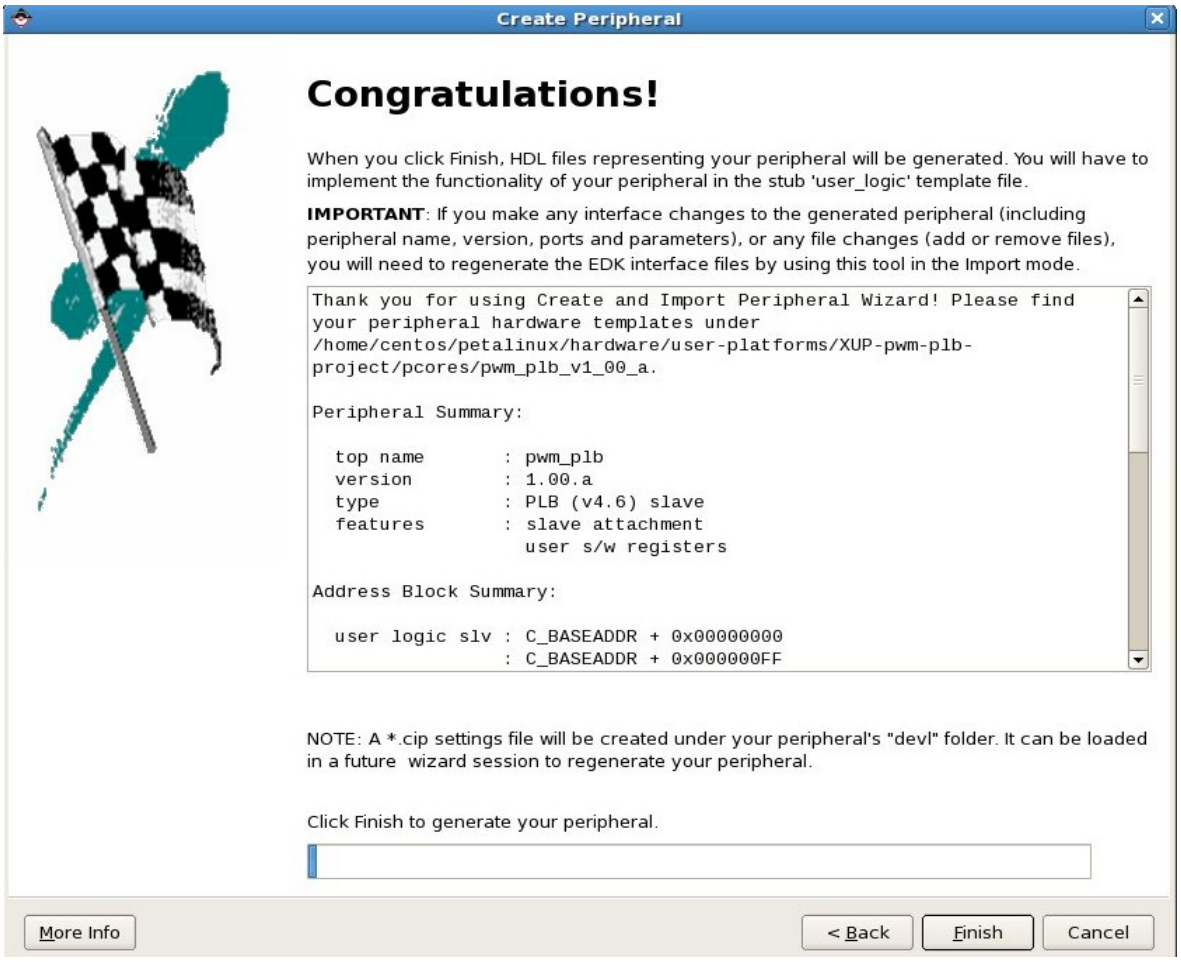


- Click "`Next`" with default settings until you reach the "`User S/W Register`" window.
- In the "`User S/W Register`" window, set the number of software accessible registers to 4 because we have 4 PWM channels. Each register corresponds to one PWM channel:



Click "`Next`".

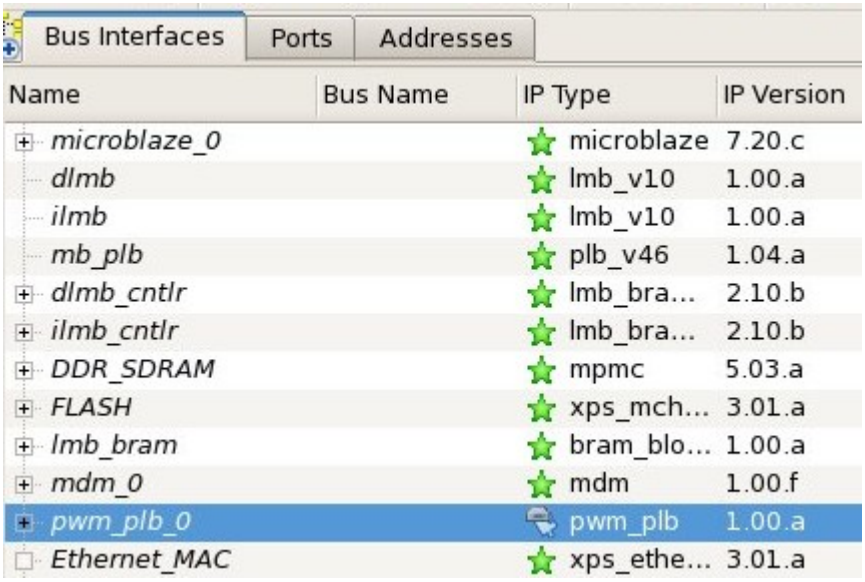
- Click "`Next`" with default settings until you get to the "`Congratulations`" window:



There is a summary of the new IP Core and a list of template files will be created for the IP Core in this window. You can have a look at the summary and click "`Finish`" to finish creating the core.

- Now, the new IP Core is listed in the "`IP Catalog`" panel:

- Double click the "`pwm_plb`" core listed in the "`IP Catalog`" to add the core to the system. Click "`Yes`" button in the pop up window which asks whether you are sure to add the IP. " The newly added `pwm_plb_0` instance will be shown in the "`System Assembly View`":



Please note that the details shown in the "`Bus Interfaces`" tab of "`System Assembly View`" can be different from the above figure. It depends on the development board and the Xilinx tool you use.

Modify the Auto Created PWM_PLB to Implement PWM

We have created a new PWM_PLB IP Core. It is just the top level interfacing to the PLB bus but can not do any PWM controlling work.

The auto generated files of the newly created PWM PLB Core are located in `~/petalinux/hardware/user-platforms/XUP-pwm-plb-project/pcores/pwm_plb_v1_00_a/` directory.

There are three directories in this folder:

- `data`
  - `*.mpd` – Microprocessor Peripheral Definition. Describes the parameters and ports of the IP Core which is used by XPS tools to know the IP Core's interface.
  - `*.pao` – Peripheral Analyze Order. Describes the sources needs analyzing when building the IP Core.
- `devl` – The ISE and XST project files for this IP Core.
- `hdl` – Contain Hardware Description Language files

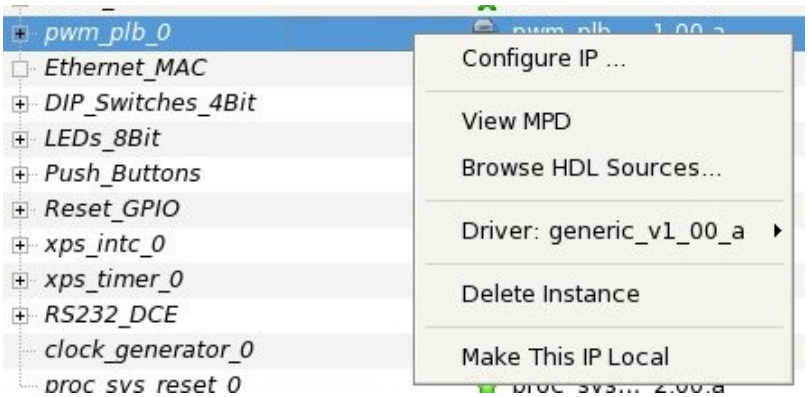
Let's change the IP core to a true PLB PWM controller.

- Copy the `pwm_controller.vhd` file from the lab materials into the IP Core's directory by executing:

```
[host] $ cp ~/xup-materials/labs/lab2.2a/resources/pcores/pwm_plb_v1_00_a/hdl/vhdl/pwm_controller.vhd ~/petalinux/hardware/user-platforms/XUP-pwm-plb-project/pcores/pwm_plb_v1_00_a/hdl/vhdl/
```

- Browse the `pwm_plb_0` HDL Sources:

  Select the `pwm_plb_0` instance in the "`System Assembly View`" window, and right click and select "`Browse HDL Sources`".



And then in the pop up files selection dialog, you can see the HDL files of the IP Core.

- `pwm_plb.vhd` – the top level entity of the core, which acts as a wrapper.
- `user_logic.vhd` – the entity works in response to the requests from PLB interface.
- `pwm_controller.vhd` – the PWM controller/generator.

- Change the `pwm_plb.vhd` and `user_logic.vhd` files to use `pwm_controller` and output PWM signals:
  - Change `user_logic.vhd` file to use `pwm_controller` component:
    - Add `PWM`*`N`*`_Value` ports to the `user_logic` entity by adding the highlighted lines shown as follows to the `user_logic.vhd` file:

      (**! Please note that the left-most column is the line numbers, don't type line numbers in the file.**)

```
84            entity user_logic is
85            generic
86            (
      ......
96            );
97            port
98            (
99              -- PWMs Value pports
100             PWM0_Value               : out std_logic_vector(0 to 7);
101             PWM1_Value               : out std_logic_vector(0 to 7);
102             PWM2_Value               : out std_logic_vector(0 to 7);
103             PWM3_Value               : out std_logic_vector(0 to 7);
104
105             -- DO NOT EDIT BELOW THIS LINE ---------------------
106             -- Bus protocol ports, do not add to or delete
107             Bus2IP_Clk               : in  std_logic;
```

      These signals will communicate each channels' PWM value from the PLB interface to the controller core.

    - Assign slave registers' lowest byte value to `PWM`*`N`*`_Value` port by adding the highlighted lines shown as follows to the `user_logic.vhd` file:

      (**! Please note that the left-most column is the line numbers, don't type line numbers in the file.**)

```
239           IP2Bus_Error <= '0';
240
241           -- Assign the lowest byte of slave registers to PWMs Value
242           PWM0_Value   <= slv_reg0(24 to 31);
243           PWM1_Value   <= slv_reg1(24 to 31);
244           PWM2_Value   <= slv_reg2(24 to 31);
245           PWM3_Value   <= slv_reg3(24 to 31);
246
247           end IMP;
```

The slave registers can be written/read through PLB. Each slave register is of 32-bit. The lowest byte of a register corresponds to a PWM value. Writing a slave register can change its related PWM value.

- Change the `pwm_plb.vhd` file:
  - Add `PWMs_out` port to the entity by adding the highlighted line shown as follows to the `pwm_plb.vhd` file:

```
138          entity pwm_plb is
139            generic
140            (
      ......
161            );
162            port
163            (
164              -- PWM outputs
165              PWMs_out                  : out std_logic_vector(0 to 3);
166
167              -- DO NOT EDIT BELOW THIS LINE ---------------------
168              -- Bus protocol ports, do not add to or delete
161              SPLB_Clk                  : in  std_logic;
```

  - Add `pwm`*N*`_value` signals and `pwm_controller` component to the architecture of the entity by adding the highlighted line shown as follows to the `pwm_plb.vhd` file:

```
224          architecture IMP of pwm_plb is
 ......
293            signal user_IP2Bus_Error        : std_logic;
294
295            -- PWMs values
296            signal pwm0_value               : std_logic_vector(0 to 7);
297            signal pwm1_value               : std_logic_vector(0 to 7);
298            signal pwm2_value               : std_logic_vector(0 to 7);
299            signal pwm3_value               : std_logic_vector(0 to 7);
300
301            component pwm_controller
302              port (
303                Clk        : in  std_logic;
304                Rst        : in  std_logic;
305                PWM0_Value : in  std_logic_vector(0 to 7);
306                PWM1_Value : in  std_logic_vector(0 to 7);
307                PWM2_Value : in  std_logic_vector(0 to 7);
308                PWM3_Value : in  std_logic_vector(0 to 7);
309                PWMs_out   : out std_logic_vector(0 to 3)
310              );
311            end component;
312
313          begin
```

- Change `user_logic` entity instantiation to include `pwmN_value` ports by adding the highlighted line shown as follows to the `pwm_plb.vhd` file:

```
395            USER_LOGIC_I : entity pwm_plb_v1_00_a.user_logic
396              generic map
397              (
     ... ...
404              )
405              port map
406              (
407                PWM0_Value                     => pwm0_value,
408                PWM1_Value                     => pwm1_value,
409                PWM2_Value                     => pwm2_value,
410                PWM3_Value                     => pwm3_value,
411
412                Bus2IP_Clk                     => ipif_Bus2IP_Clk,
```

- Add `pwm_controller` instantiation to the implement of the architecture by adding the highlighted line shown as follows to the `pwm_plb.vhd` file:

  (**! Please note that the left-most column is the line numbers, don't type line numbers in the file.**)

```
424            PWM_I: pwm_controller
425              port map(
426                Clk        => ipif_Bus2IP_Clk,
427                Rst        => ipif_Bus2IP_Reset,
428                PWM0_Value => pwm0_value,
429                PWM1_Value => pwm1_value,
430                PWM2_Value => pwm2_value,
431                PWM3_Value => pwm3_value,
432                PWMs_out   => PWMs_out
433              );
434
435              ----------------------------------------
436              -- connect internal signals
437              ----------------------------------------
438              ipif_IP2Bus_Data <= user_IP2Bus_Data;
```

- Because the interface of the PWM_PLB has been changed to included new PWM ports, the `*.mpd` file should be changed, otherwise, the XPS tools cannot see the updated PWM interface.

  Add the `PWMN` ports into `pwm_plb_v2_1_0.mpd` file:

  (**! Please note that the left-most column is the line numbers, don't type line numbers in the file.**)

```
37           ## Ports
```

```
38            PORT PWMs_out = "", DIR = O, VEC = [0 : 3]
39            PORT SPLB_Clk = "", DIR = I, SIGIS = CLK, BUS = SPLB
40            PORT SPLB_Rst = SPLB_Rst, DIR = I, SIGIS = RST, BUS = SPLB
```

- Make sure "`OPTION ARCH_SUPPORT_MAP = (OTHERS=DEVELOPMENT)`" option to the `*.mpd` file such that running XPS generation tools will reanalyze the IP Core whenever there is change to the IP Core:

```
11            ## Peripheral Options
12            OPTION IPTYPE = PERIPHERAL
13            OPTION IMP_NETLIST = TRUE
14            OPTION HDL = VHDL
15            OPTION ARCH_SUPPORT_MAP = (OTHERS=DEVELOPMENT)
16            OPTION IP_GROUP = MICROBLAZE:PPC:USER
17            OPTION DESC = PWM_PLB
```

  If it's not in the `pwm_plb_v2_1_0.mpd` file, add it.

  This is helpful because when the hardware project including this IP Core is rebuilt, it will build this IP Core.

- PAO file of an IP Core tells the Xilinx synthesis tool which HDL file(s) should be analyzed when synthesizing the IP Core. Because `pwm_controller.vhd` has been added to the IP Core, the `*.pao` file has to be changed to include PWM_PLB IP Core.

  Add `pwm_controller` to the `pwm_plb_v2_1_0.pao` file:

  (**! Please note that the left-most column is the line numbers, don't type line numbers in the file.**)

```
16            lib plbv46_slave_single_v1_00_a plbv46_slave_single vhdl
17            lib pwm_plb_v1_00_a pwm_controller vhdl
18            lib pwm_plb_v1_00_a user_logic vhdl
19            lib pwm_plb_v1_00_a pwm_plb vhdl
```

PWM_PLB Bus and Ports Connection

Although we have added the `PWM_PLB` to the system, but it hasn't connected to any bus or ports yet. Now, we will connect it to the PLB bus and the LED ports.

- Because we have updated the `PWM_PLB` core's ports, we should ask the Xilinx EDK to rescan the user repositories directory to reflect the interface changes on GUI. We do this by selecting "`Project`" -> "`Rescan User Repositories`" from menu bar. Do this now.
- Connect the `PWM_PLB` to PLB bus:

Go to the "Bus Interface" panel of "System Assembly View". Click the "+" sign on the left to pwm_plb_0 instance to expend the bus interface of the IP Core. Select mb_plb in the bus connection selection list of pwm_plb_0:

- Go to the "Ports" panel in "System Assembly View". Expand the ports list of pwm_plb_0 by clicking the "+" sign on the left of the pwm_plb_0. We should be able to see the new PWM ports added to PWM_PLB.
- Select port PWMs_out from the pwm_plb_0 port list in "Ports" panel in "System Assembly View". Select "Make External" from the list in "Net" column to make PWMs_out as and external port.

  If you expand the "External Ports" which is located at the top of the "Ports" panel, you can see the pwm_plb_0_PWMs_out_pin port.

  If you open the project's system.mhs file, you can see the new PWM ports are added to the external ports list which is at the top of the file following the version definition.
- Remove LED GPIO from the system because the PWM module will use the LEDs and it is impossible for two IP Cores to access the same PINs:

  In the "System Assembly View", select instance LEDs_8Bit, right click and select "Delete Instance".

  In the "Delete IP Instance" options list, select "Delete instance and its ports(both internal and external)" and then click "OK" to delete the instance.
- Assign address to the new pwm_plb core:

  Go to "Addresses" panel of "System Assembly View" and expand the "Unmapped Addresses" by clicking the "+" sign on the left. You will see pwm_plb_0 is on the "Unmapped Addresses" list with unknown size.

  Do nothing but click "Generate Addresses" at the right top corner. XPS will assign address to the IP Core for you.

  Expand the "microblaze_0's Address Map" by clicking the "+" sign on the left, you will find the pwm_plb_0's address map on the list.
- Change the project's user constraint file to let the PWM_PLB core to access the user LEDs pins:

  Because the it is now the pwm_plb_0 instance to access the user LEDs pins rather than the LED GPIO module, the user constraint file has to be changed to reflect this system modification.

  Open the system.ucf file by double clicking it from "Project Files" list in

"`Project`" panel.

Replace the LED GPIO Net mappings with the PWMs mappings:

Replace:

```
1           #  XUPV5-LX110T Evaluation Platform
2           Net fpga_0_RS232_Uart_1_RX_pin LOC = AG15  |  IOSTANDARD=LVCMOS33;
3           Net fpga_0_RS232_Uart_1_TX_pin LOC = AG20  |  IOSTANDARD=LVCMOS33;
4           Net fpga_0_LEDs_8Bit_GPIO_IO_pin<0> LOC = AE24  |  IOSTANDARD=LVCMOS18  |
            PULLDOWN  |  SLEW=SLOW  |  DRIVE=2;
5           Net fpga_0_LEDs_8Bit_GPIO_IO_pin<1> LOC = AD24  |  IOSTANDARD=LVCMOS18  |
            PULLDOWN  |  SLEW=SLOW  |  DRIVE=2;
6           Net fpga_0_LEDs_8Bit_GPIO_IO_pin<2> LOC = AD25  |  IOSTANDARD=LVCMOS18  |
            PULLDOWN  |  SLEW=SLOW  |  DRIVE=2;
7           Net fpga_0_LEDs_8Bit_GPIO_IO_pin<3> LOC = G16  |  IOSTANDARD=LVCMOS25  |
            PULLDOWN  |  SLEW=SLOW  |  DRIVE=2;
8           Net fpga_0_LEDs_8Bit_GPIO_IO_pin<4> LOC = AD26  |  IOSTANDARD=LVCMOS18  |
            PULLDOWN  |  SLEW=SLOW  |  DRIVE=2;
9           Net fpga_0_LEDs_8Bit_GPIO_IO_pin<5> LOC = G15  |  IOSTANDARD=LVCMOS25  |
            PULLDOWN  |  SLEW=SLOW  |  DRIVE=2;
10          Net fpga_0_LEDs_8Bit_GPIO_IO_pin<6> LOC = L18  |  IOSTANDARD=LVCMOS25  |
            PULLDOWN  |  SLEW=SLOW  |  DRIVE=2;
11          Net fpga_0_LEDs_8Bit_GPIO_IO_pin<7> LOC = H18  |  IOSTANDARD=LVCMOS25  |
            PULLDOWN  |  SLEW=SLOW  |  DRIVE=2;
12          Net fpga_0_Push_Buttons_5Bit_GPIO_IO_pin<0> LOC = AJ6  |
            IOSTANDARD=LVCMOS33  |  PULLDOWN  |  SLEW=SLOW  |  DRIVE=2;
13          Net fpga_0_Push_Buttons_5Bit_GPIO_IO_pin<1> LOC = AJ7  |
            IOSTANDARD=LVCMOS33  |  PULLDOWN  |  SLEW=SLOW  |  DRIVE=2;
```

With:

```
3           Net fpga_0_RS232_Uart_1_TX_pin LOC = AG20  |  IOSTANDARD=LVCMOS33;
4           Net pwm_plb_0_PWMs_out_pin<0> LOC = AE24  |  IOSTANDARD=LVCMOS18  |
            PULLDOWN  |  SLEW=SLOW  |  DRIVE=2;
5           Net pwm_plb_0_PWMs_out_pin<1> LOC = AD24  |  IOSTANDARD=LVCMOS18  |
            PULLDOWN  |  SLEW=SLOW  |  DRIVE=2;
6           Net pwm_plb_0_PWMs_out_pin<2> LOC = AD25  |  IOSTANDARD=LVCMOS18  |
            PULLDOWN  |  SLEW=SLOW  |  DRIVE=2;
7           Net pwm_plb_0_PWMs_out_pin<3> LOC = G16  |  IOSTANDARD=LVCMOS25  |
```

```
                PULLDOWN  |  SLEW=SLOW  |  DRIVE=2;
8               Net fpga_0_Push_Buttons_5Bit_GPIO_IO_pin<0> LOC = AJ6  |
                IOSTANDARD=LVCMOS33  |  PULLDOWN  |  SLEW=SLOW  |  DRIVE=2;
```

Build Bitstream

Build the bitstream with Xilinx EDK GUI as we have learned in Lab 2.1. If it is your first lab, please refer to section "Build the Hardware Bitstream" section in the Lab 2.1 manual.

Download Bitstream to the Board

Now, we can program the FPGA with the newly built bitstream as we have learned in section "Program the FPGA" in the Lab 2.1 manual.

Debug the PWM with PLB IP Core With XMD

Low level hardware debug is useful when testing new Hardware IP Core, otherwise, if we combine the hardware test, driver test and application test together, it is hard to tell whether it is a hardware problem or a software problem if there is a problem.

Xilinx Microprocessor Debugger(XMD) allows us directly write PLB registers. In this section, we will use XMD to debug our PWM with PLB IP Core. The XMD provides powerful debug functions, please refer to Xilinx documents or XPS help for more information.

Let's start debugging our PWM PLB core using XMD:

- Run XMD from command line in the working directory from the host machine by executing:

  ```
  [host] $ xmd
  ```

- After the XMD started, connect XMD to the target by executing the following XMD command in the XMD console on the host machine:

  ```
  XMD% connect mb mdm
  ```

- Stop the running application on MicroBlaze:

  Because the board is boot up with application to initialize BRAM and we cannot access registers when application is running on MicroBlaze, before accessing PWM PLB registers, we have to stop the running application. Here is the XMD command to stop the running application:

  ```
  XMD% stop
  ```

- Test our PWM PLB core by writing duty cycle values (0 ~ 255) to the PWM PLB registers, watch the LED status change on the board and read the PWM PLB core registers value back.

Here are the instructions to test the PWM PLB core:

We can get the PWM PLB registers address from "`Addresses`" panel of "`System Assembly View`":

As mentioned previously in this lab. The PWM with PLB IP Core has 4 registers corresponding to 4 PWM channels. The registers addresses start from the base address of the IP Core. The address of each 32-bit register is the previous one plus 4.

e.g. Slv-reg0 : 0xc9c00000

Slv-reg1 : 0xc9c00004

Slv-reg2 : 0xc9c00008

Slv-reg3: 0xc9c0000C

- Write values to PWM with PLB registers by executing this XMD command:

  ```
  XMD% mwr <register address> <value>
  ```

  e.g.

  ```
  XMD% mwr 0xc9c00000 100
  ```

  The GPIO LED 7 will be on.

  PWM with PLB registers 0 ~ 3 corresponds to GPIO LED 7 ~ 4.

- Try writing different values to different PWM with PLB registers. You should be able to see the LED brightness is changed from low to high if you write value to its register from 0 to 255.

- You can try read the value from registers in PWM with PLB. Here is the XMD command to read registers:

  ```
  mrd <register address> [num of continuous read]
  ```

  You should be able to see the value you have written to the them.

  e.g.
  ```
  XMD% mrd 0xc9c00000
     C9C00000:   00000064
     XMD% mrd 0xc9c00000 4
     C9C00000:   00000064
     C9C00004:   00000064
     C9C00008:   00000032
     C9C0000C:   000000FF
  ```

- Exit xmd by typing XMD `exit` command:

```
XMD% exit
```

Use Completed Resource

The completed Linux image for this lab is available in `~/xup_materials/labs/lab2.2a/completed/`. If you are stuck in any problem in the lab, you are welcome to use the completed resource. Here is the instruction on how to use the completed resource:

- Copy the completed hardware project to `PetaLinux` tree by executing:

```
[host] $ ~/xup_materials/complete_lab 2.2a
```

- Download the bitstream to the board by executing:

```
[host] $ cd ~/petalinux/hardware/user-platforms/XUP-pwm-plb-project
[host] $ impact -batch etc/download.cmd
```

  This command will download the bitstream `implementation/download.bit` to the board. (iMPACT is the Xilinx device configuration tool.)

Outcomes

At the completion of this lab you should

- know how to create a custom hardware IP Core with XPS tool
- know how to build bitstream from XPS GUI
- know the common bus interface -- PLB
- know how to use XMD to access software accessible PLB registers.

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Lab 2.2.b – Custom Hardware Development

-- FSL PWM

Rationale

Xilinx provides commonly used bus interfaces for customized IP Core to talk to the rest of the on-chip system. It also provides a customized IP Core creation tool to automatically add the specified bus interface to our IP Core when we use it to create our customized hardware.

The purpose of this lab session is to go through XPS Create and Import Peripheral Wizard and experience one of the commonly used bus, Fast Simplex Link(FSL).

Objectives

- Design a IP Core in VHDL
- Use XPS Create and Import Peripheral Wizard to create customized IP Core
- Integrate a IP Core with FSL interface

Introduction

In the previous lab, we have learned how to create a hardware platform with BSB. In this lab, we are going to create our PWM core with FSL interface with XPS Create and Import Peripheral Wizard.

Pulse Width Modulation (PWM) is a method of generating analog-like signals from purely digital circuits. By varying the duty cycle of a square wave signal from 0 to 100 percent, and filtering the output through a low-pass filter, analog outputs may be simulated.

We will use multichannel PWM to vary the brightness of 4 User LEDs on the development board. Varying the duty cycle of the LED control signal, and with your eye providing the low pass filtering, you can vary the apparent brightness of the LED from all-off to all-on.

Time

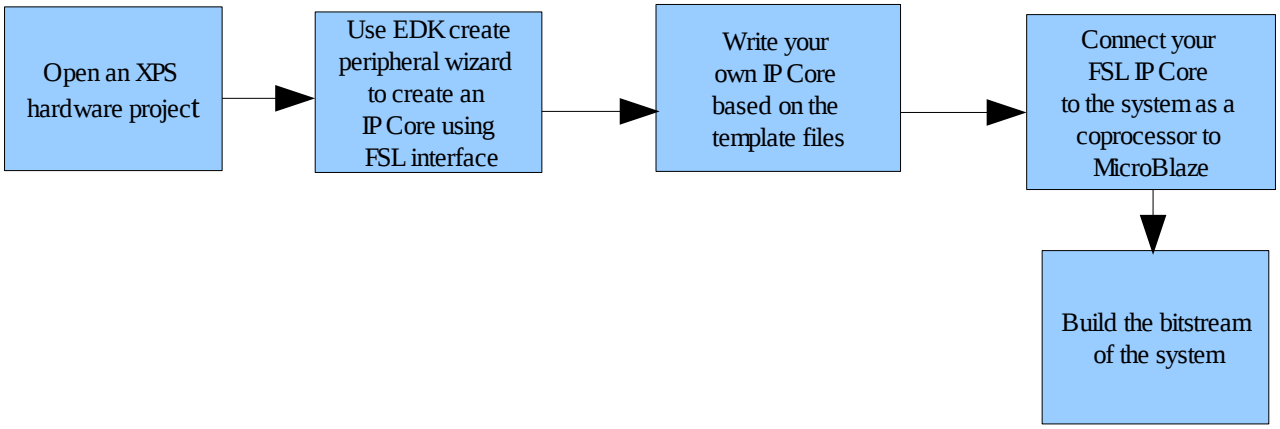
This session will run for approximately 75 minutes.

Preparation

If this is the first lab you are doing then please refer to sections "Before You Start" of Lab 1.1 document for necessary preparatory information on how to setup the hardware environment.

Lab overview

The following diagram is a high level overview of the steps taken in this Lab:



Create a XPS project for PWM

- Create a PWM project directory in `~/petalinux/hardware/user-platforms/` by executing the following commands on the host machine:

```
[host] $ cd  ~/petalinux/hardware/user-platforms/
[host] $ mkdir XUP-pwm-fsl-project
```

- Copy the contents from the reference design to the new `XUP-pwm-fsl-project` directory by executing:

```
[host] $ cd XUP-pwm-fsl-project
[host] $ cp -r ~/petalinux/hardware/reference-
designs/Xilinx--edk113/* ./
```

  Because we use the same development board as the reference design, we can make our hardware platform by modifying the reference design to save time.

- Run XPS to open the project by executing the following command in the `XUP-pwm-fsl-project` directory:

```
[host] $ xps system.xmp
```

At this point, Version Management wizard might appear if the Xilinx version you used is newer than the one used to generate the reference design. If it is the case, click "`Next`" as required, and then "`Finish`" to upgrade the project files.

Browse PWM VHDL design

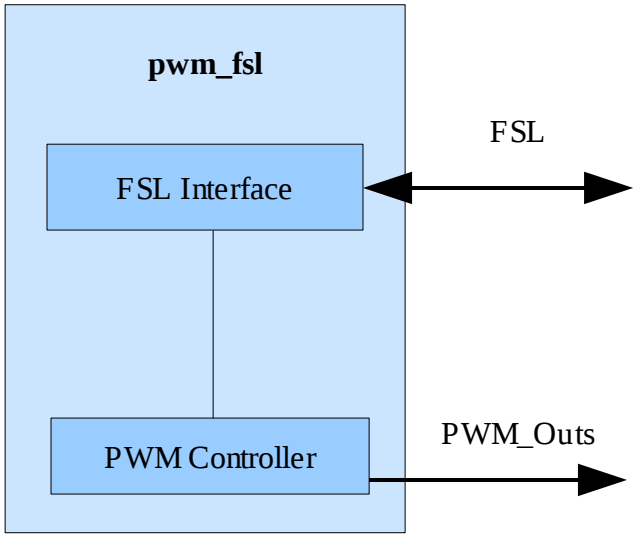
There is a ready-to-use PWM entity in the lab materials, before we move forward, let's have a look at

the file.

Open the `pwm_controller.vhd` file in `~/xup-materials/labs/lab2.2b/resources/pcores/pwm_fsl_v1_00_a/hdl/vhdl` directory and have a look at the file.

This file describes a very simple 4-channel PWM controller. Each channel has a 8-bit PWM counter. The input PWM_Value0 to PWM_Value3 represent the duty cycle of PWMs<0> to PWMs<3> respectively. Each PWM channel has a value range from 0 to 255.

We will create a FSL interface to control the core.



- PWM controller with FSL interface architecture is shown in the upper diagram
  - `pwm_fsl` – Top level wrapper. It contains 2 components, FSL interface and PWM Controller.
  - `FSL Interface` – Interface to FSL.
  - `PWM Controller` – PWM control the 4 PWM channels' output, it outputs '1' in the duty cycle and '0' in the non-duty cycle.

We will create a PWM controller with FSL interface and will build a hardware platform with it in the following sections.

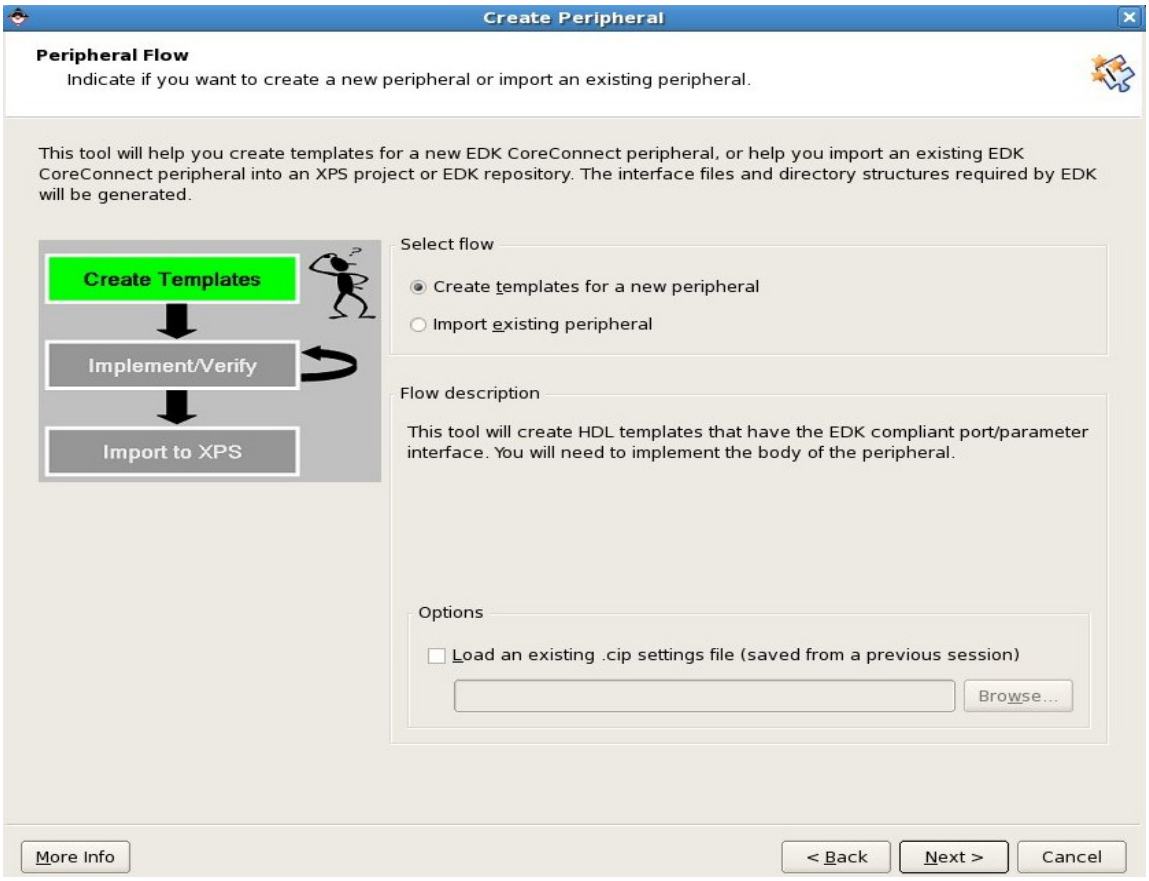
Create a PWM Controller with FSL Interface

To use the PWM controller, we need to connect it to the rest of the system. In this section, we will create a PWM controller with FSL interface with the XPS "Create and Import Peripheral Wizard". Here are the steps:

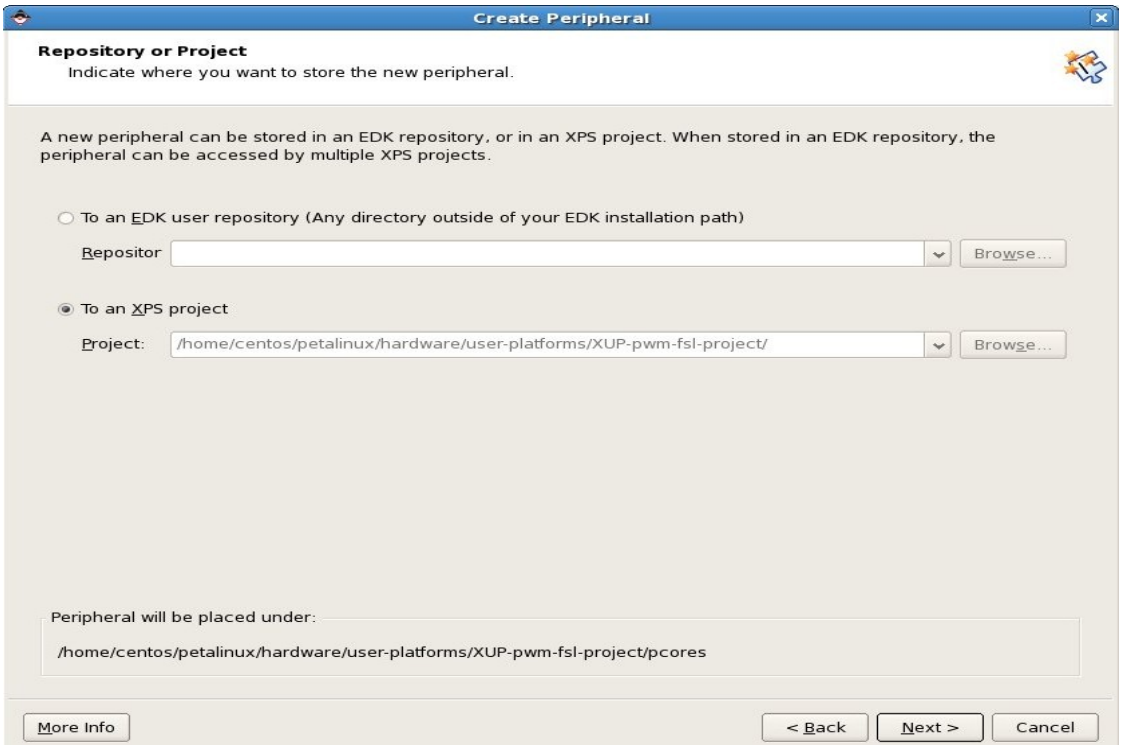
- Select "`Hardware`"-> "`Create or Import Peripherals`" from menu bar to run

"Create and Import Peripheral Wizard".

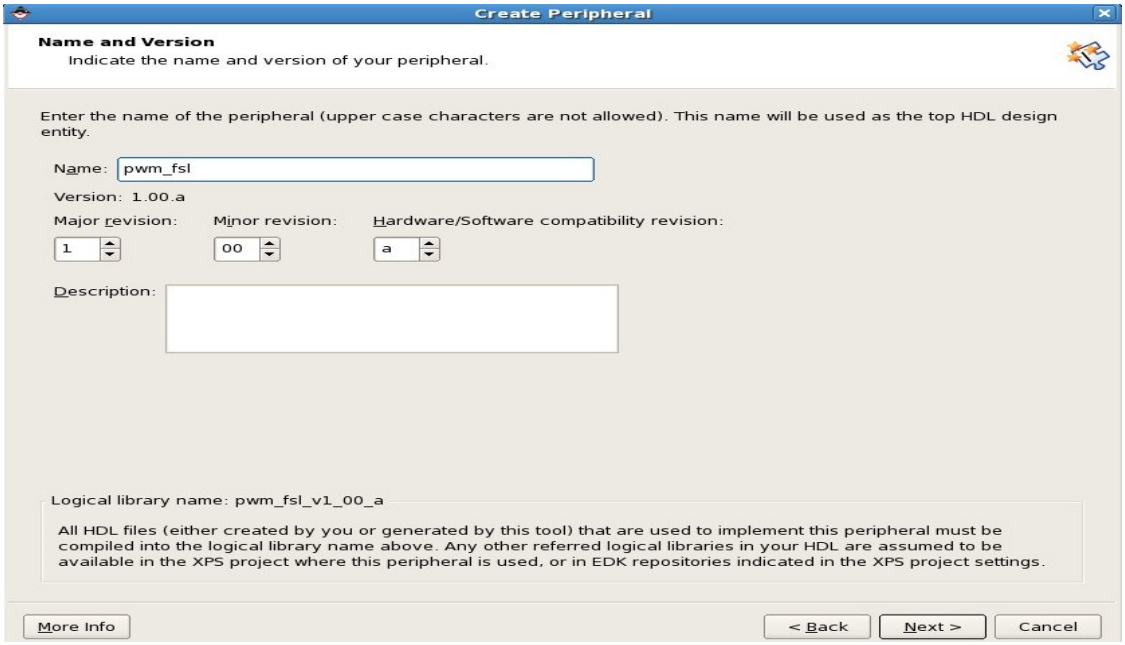
- Click "`Next`" in the welcome window.
- Select "`Create templates for a new peripheral`" in the "`Peripheral flow`" window:



- Click "`Next`".
- Click "`Next`" in the "`Repository or Project`" window with the default setting to save the new IP Core in this XPS project:

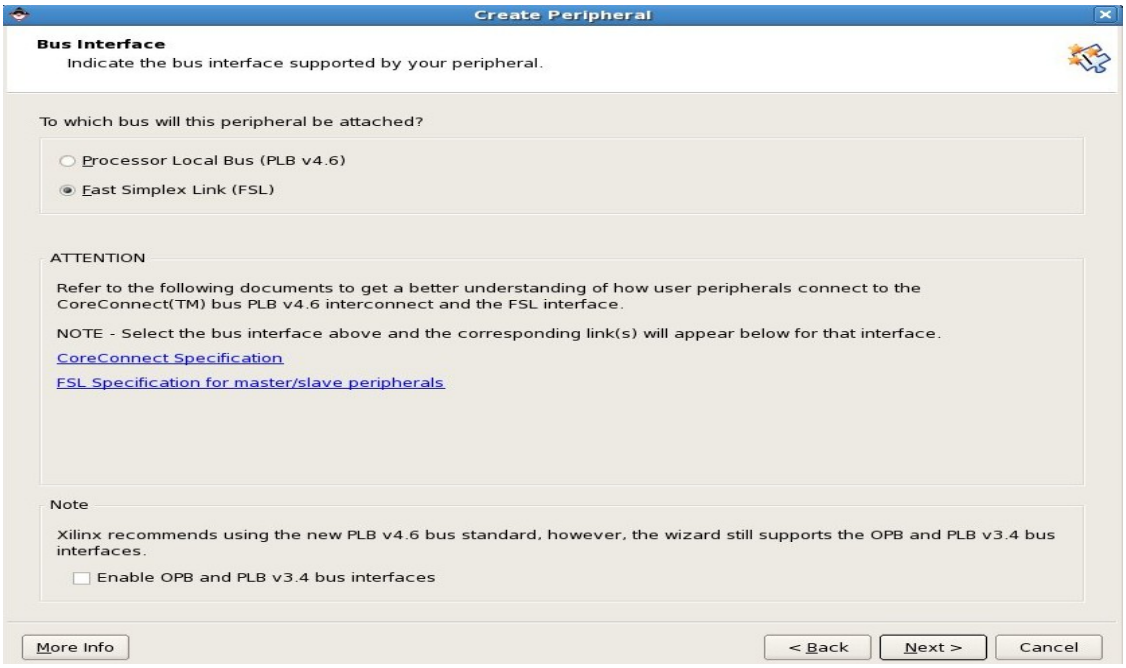


- In the "`Name and Version`" window, type "`pwm_fsl`" in the peripheral name text box:

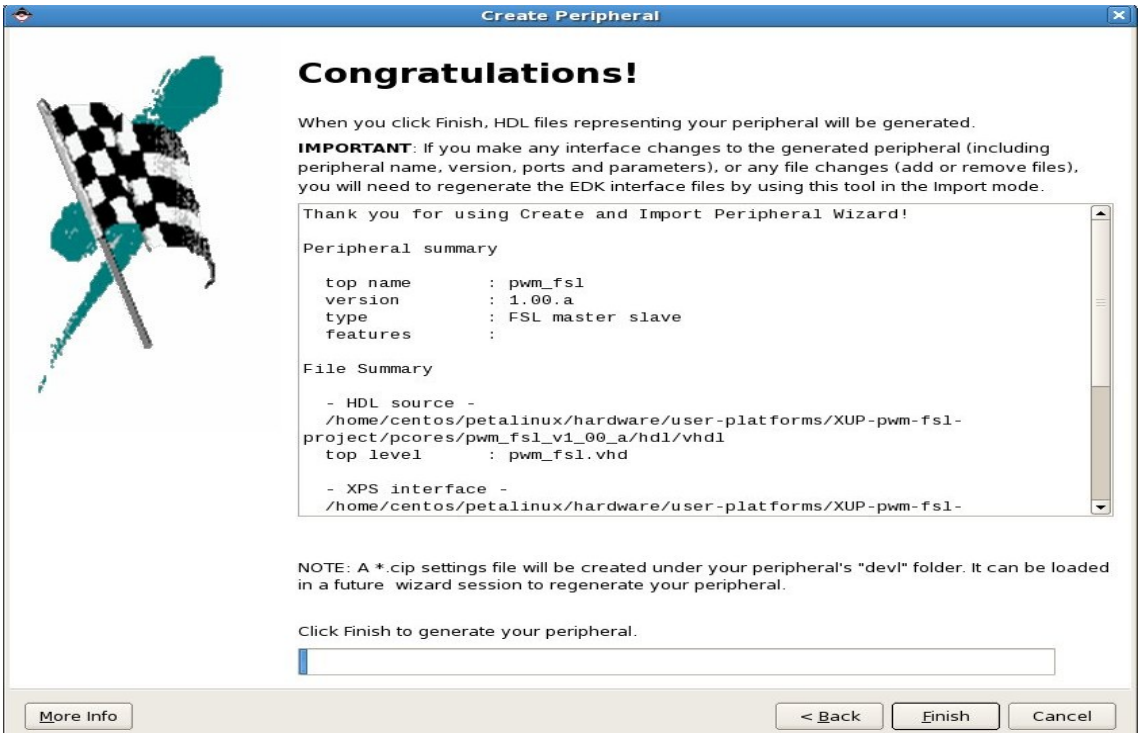


Click "`Next`".

- In the "`Bus Interface`" window, select "`Fast Simplex Link(FSL)`":



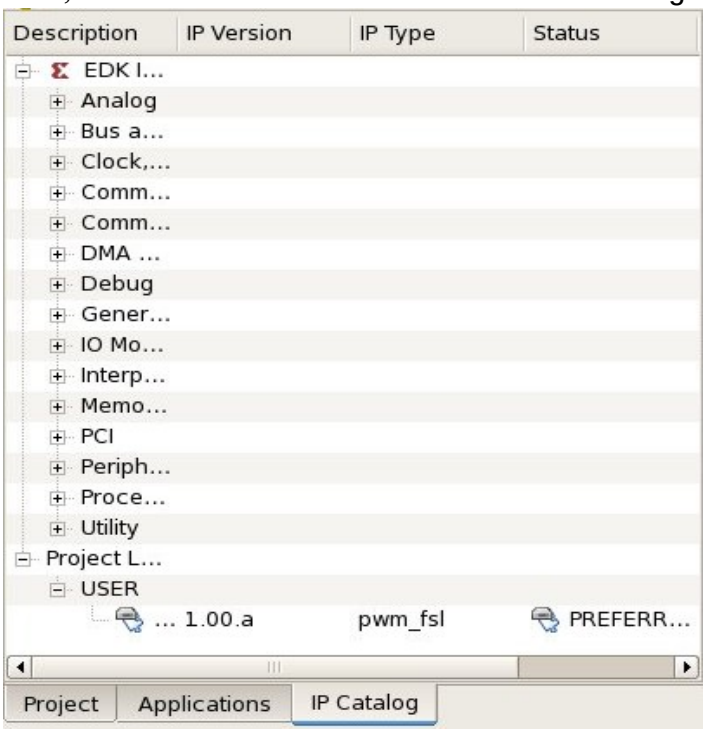
- Click "`Next`" with default settings until reaching the "`Congratulations`" configuration window.



There is a summary of the new IP Core and a list of template files will be created for the IP Core in this window. You can have a look at the summary and click "`Finish`" to finish

creating the core.

- Now, the new IP Core is listed in the "`IP Catalog`" panel:



Modify the Auto Created PWM_FSL to Implement PWM

We have created a new PWM_FSL IP Core. It is just the top level interfacing to the FSL bus but can not do any PWM controlling work..

The auto generated files of the newly created PWM_FSL are located in `~/petalinux/hardware/user-platforms/XUP-pwm-fsl-project/pcores/pwm_fsl_v1_00_a/` directory.

There are three directories in this folder:

- `data`
  - `*.mpd` – Microprocessor Peripheral Definition. Describes the parameters and ports of the IP Core which is used by XPS tools to know the IP Core's interface.
  - `*.pao` – Peripheral Analyze Order. Describes the sources needs analyzing when building the IP Core.
- `devl` – The ISE and XST project files for this IP Core.
- `hdl` – Contain Hardware Description Language files

Let's change the PWM_FSL core generated from Xilinx templates to a true FSL PWM controller by following these instructions:

- Copy the pwm_controller.vhd file from the lab materials into the IP Core's directory by executing:

```
[host] $ cp ~/xup-
materials/labs/lab2.2b/resources/pcores/pwm_fsl_v1_00_a/hdl/vhdl/pwm_controller.vhd
~/petalinux/hardware/user-platforms/XUP-pwm-fsl-
project/pcores/pwm_fsl_v1_00_a/hdl/vhdl/
```

- Copy the fsl_interface.vhd file from the lab materials into the IP Core's directory by executing:

```
[host] $ cp ~/xup-
materials/labs/lab2.2b/resources/pcores/pwm_fsl_v1_00_a/hdl/vhdl/fsl_interface.vhd
~/petalinux/hardware/user-platforms/XUP-pwm-fsl-
project/pcores/pwm_fsl_v1_00_a/hdl/vhdl/
```

  If you have time, please browse this file. This file is the interface to FSL; it takes data from the FSL bus and then set the PWMs values.

- Modify the pwm_fsl.vhd to work with pwm_controller.vhd and fsl_interface.vhd to implement the PWM function:

  (This modification may take some time to finish. Alternately, you can use the pwm_fsl.vhd file in the lab materials by executing:

```
[host] $ cp ~/xup-
materials/labs/lab2.2b/resources/pcores/pwm_fsl_v1_00_a/hdl/vhdl/pwm_fsl.vhd
~/petalinux/hardware/user-platforms/XUP-pwm-fsl-
project/pcores/pwm_fsl_v1_00_a/hdl/vhdl/
```

)

  - Change the pwm_fsl.vhd file:
    - Add PWMs_out port to the pwm_fsl entity by adding the highlighted lines shown as follows to the pwm_fsl.vhd file:

  (**! Please note that the left-most column is the line numbers, don't type line numbers in the file.**)

```
78          entity pwm_fsl is
79                  port
80                  (
81                              -- Output to PWM controller
82                              PWMs_out   : out std_logic_vector(0 to 3);
83                              -- DO NOT EDIT BELOW THIS LINE ----------------
84                              -- Bus protocol ports, do not add or delete.
85                              FSL_Clk : in    std_logic;
86                              FSL_Rst : in    std_logic;
```

```
87                          FSL_S_Clk       : out   std_logic;
```

- Replace the declaration section of the architecture of `pwm_fsl` entity:

```
123         architecture EXAMPLE of pwm_fsl is
124
125            -- Total number of input data.
126            constant NUMBER_OF_INPUT_WORDS  : natural := 8;
127
128            -- Total number of output data
129            constant NUMBER_OF_OUTPUT_WORDS : natural := 8;
130
131            type STATE_TYPE is (Idle, Read_Inputs, Write_Outputs);
132
133            signal state        : STATE_TYPE;
134
135            -- Accumulator to hold sum of inputs read at any point in time
136            signal sum          : std_logic_vector(0 to 31);
137
138            -- Counters to store the number inputs read & outputs written
139            signal nr_of_reads  : natural range 0 to NUMBER_OF_INPUT_WORDS -
           1;
140            signal nr_of_writes : natural range 0 to NUMBER_OF_OUTPUT_WORDS
           - 1;
141
142         begin
```

with the declaration of `fsl_interface` and `pwm_controller` components and the signals to connect these 2 components:

(**! Please note that the left-most column is the line numbers, don't type line numbers in the file.**)

```
122          architecture IMP of pwm_fsl is
123
124            type pwms_value_type is array(0 to 3) of std_logic_vector(0 to
           7);
125            signal pwms_value : pwms_value_type;
126
127            component pwm_controller
128              port (
129                Clk        : in  std_logic;
130                Rst        : in  std_logic;
131                PWM0_Value : in  std_logic_vector(0 to 7);
132                PWM1_Value : in  std_logic_vector(0 to 7);
133                PWM2_Value : in  std_logic_vector(0 to 7);
134                 PWM3_Value : in  std_logic_vector(0 to 7);
135                 PWMs_out   : out std_logic_vector(0 to 3)
136               );
137            end component;
138
139            component fsl_interface
140              port (
```

```
141                Clk           : in  std_logic;
142                Rst           : in  std_logic;
143                FSL_S_Read    : out std_logic;
144                FSL_S_Data    : in  std_logic_vector(0 to 31);
145                FSL_S_Control : in  std_logic;
146                FSL_S_Exists  : in  std_logic;
147                FSL_M_Write   : out std_logic;
148                FSL_M_Data    : out std_logic_vector(0 to 31);
149                FSL_M_Control : out std_logic;
150                FSL_M_Full    : in  std_logic;
151
152                PWM0_Value    : out std_logic_vector(0 to 7);
153                PWM1_Value    : out std_logic_vector(0 to 7);
154                PWM2_Value    : out std_logic_vector(0 to 7);
155                PWM3_Value    : out std_logic_vector(0 to 7)
156              );
157            end component;
158
159          begin
```

- Replace the architecture's implementation section:

```
157            end component;
158
159          begin
160
161              FSL_S_Read  <= FSL_S_Exists   when state = Read_Inputs
           else '0';
162              FSL_M_Write <= not FSL_M_Full when state =
           Write_Outputs else '0';
163
164              FSL_M_Data <= sum;
           ...
208              end process The_SW_accelerator;
209          end architecture EXAMPLE;
```

with `fsl_interface` instantiation and `pwm_controller` instantiation:

(**! Please note that the left-most column is the line numbers, don't type line numbers in the file.**)

```
159          begin
160
161            PWM_I: pwm_controller
162              port map(
163                Clk        => FSL_Clk,
164                Rst        => FSL_Rst,
165                PWM0_Value => pwms_value(0),
166                PWM1_Value => pwms_value(1),
167                PWM2_Value => pwms_value(2),
```

```
168                PWM3_Value => pwms_value(3),
169                PWMs_out   => PWMs_out
170              );
171
172            FSL_INTERFACE_I: fsl_interface
173              port map(
174                Clk           => FSL_Clk,
175                Rst           => FSL_Rst,
176                FSL_S_Read    => FSL_S_Read,
177                FSL_S_Data    => FSL_S_Data,
178                FSL_S_Control => FSL_S_Control,
179                FSL_S_Exists  => FSL_S_Exists,
180                FSL_M_Write   => FSL_M_Write,
181                FSL_M_Data    => FSL_M_Data,
182                FSL_M_Control => FSL_M_Control,
183                FSL_M_Full    => FSL_M_Full,
184
185                PWM0_Value    => pwms_value(0),
186                PWM1_Value    => pwms_value(1),
187                PWM2_Value    => pwms_value(2),
188                PWM3_Value    => pwms_value(3)
189             );
190
191
192            FSL_S_Clk <= FSL_Clk;
193            FSL_M_Clk <= FSL_Clk;
194
195          end architecture IMP;
```

- Because the interface of the PWM_FSL has been changed to included new PWM ports, the `*.mpd` file should be changed, otherwise, the XPS tools cannot see the updated PWM interface.
  - Add the `PWM`*N* ports into `pwm_fsl_v2_1_0.mpd` file:

(**! Please note that the left-most column is the line numbers, don't type line numbers in the file.**)

```
17           ## Peripheral ports
18           PORT PWMs_out = "", DIR = O, VEC = [0 : 3]
19           PORT FSL_Clk = "", DIR=I, SIGIS=Clk, BUS=MFSL:SFSL
```

  - Add "`OPTION ARCH_SUPPORT_MAP = (OTHERS=DEVELOPMENT)`" option ito the `*.mpd` file such that running XPS generation tools will reanalyze the IP Core whenever there is change to the IP Core:

```
9            ## Peripheral Options
10           OPTION IPTYPE = PERIPHERAL
11           OPTION IMP_NETLIST = TRUE
12           OPTION HDL = VHDL
13           OPTION ARCH_SUPPORT_MAP = (OTHERS=DEVELOPMENT)
14           ## Bus Interfaces
```

- PAO file of an IP Core tells the Xilinx synthesis tool which HDL file(s) should be analyzed when synthesizing the IP Core. Because `pwm_controller.vhd` and fsl_interface `.vhd` has been added to the IP Core, the `*.pao` file has to be changed to include PWM_PLB IP Core.

  Add `pwm_controller` and fsl_interface`.vhd` to the `pwm_plb_v2_1_0.pao` file:

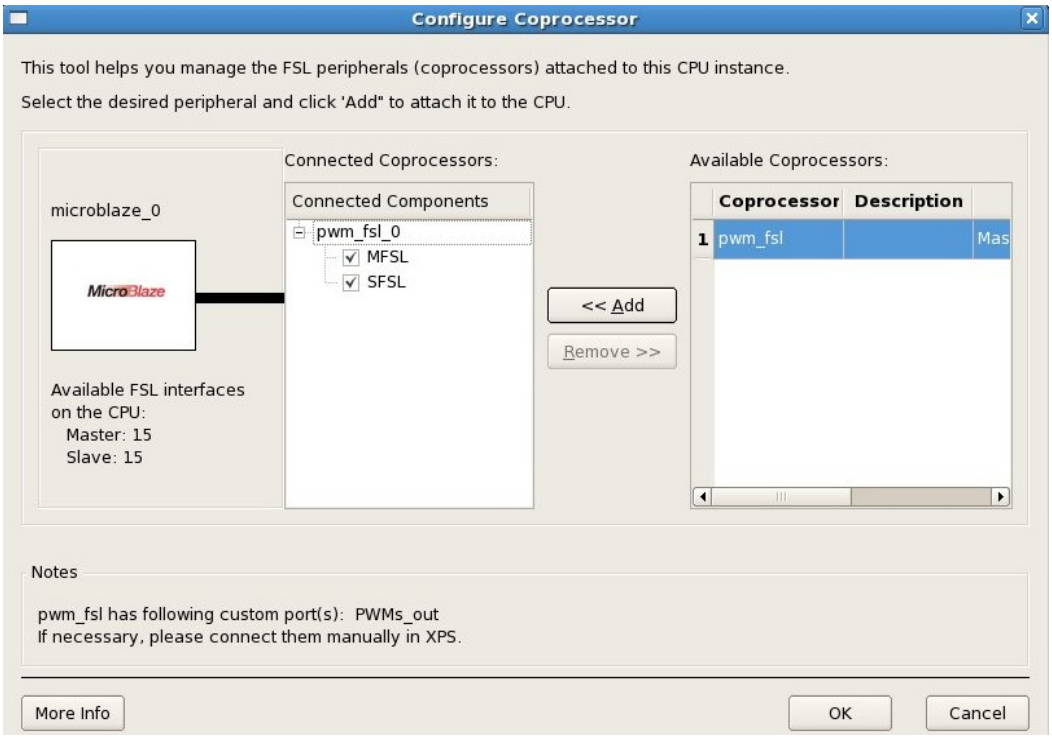
```
7             lib pwm_fsl_v1_00_a pwm_controller vhdl
8             lib pwm_fsl_v1_00_a fsl_interface vhdl
9             lib pwm_fsl_v1_00_a pwm_fsl vhdl
```

- Select "`Project`" --> "`Rescan User Repositories`" on the menu bar of the Xilinx EDK GUI to let the XPS tools know the update of "`pwm_fsl`" IP Core.

PWM_FSL Bus and Ports Connection

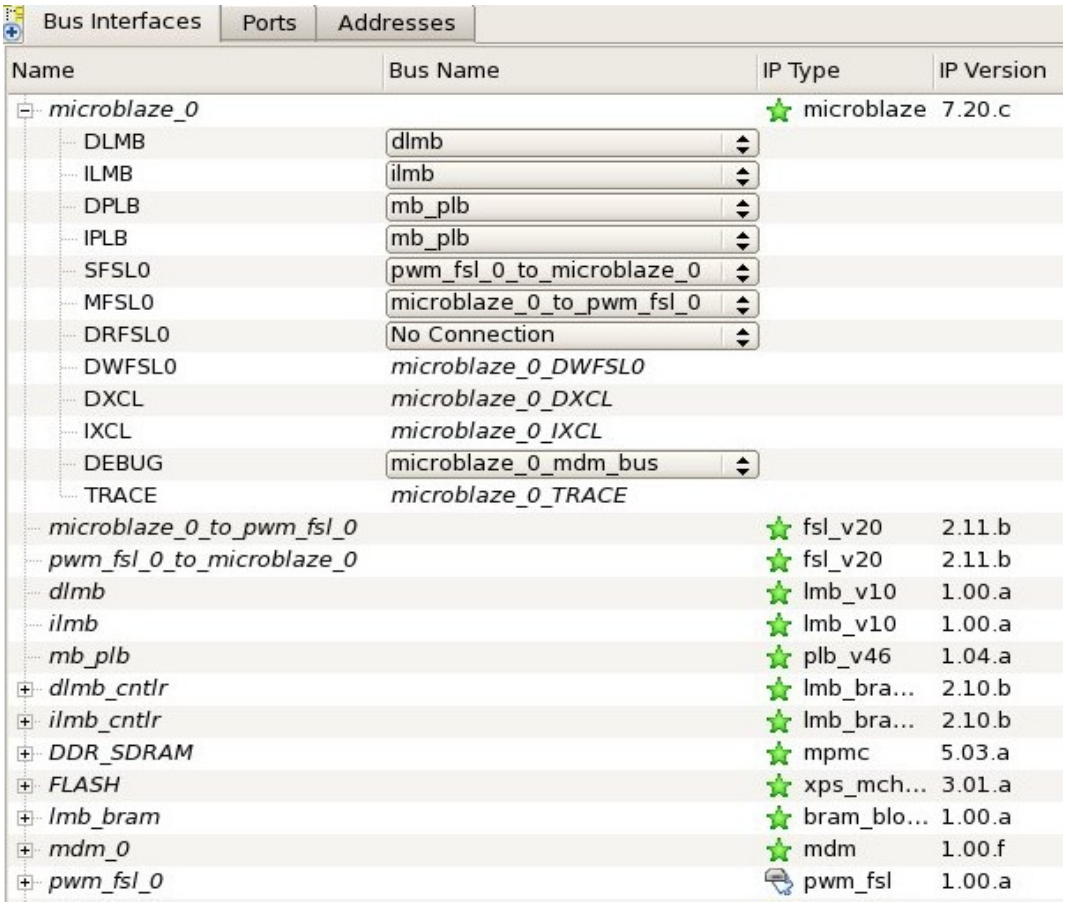
So far, we have created a PWM controller with FSL interface, in this section, we will add it to the system as a FSL coprocessor to the MicroBlaze. Here are the steps:

- Use "`Configure Coprocessor`" wizard to add a "`PWM_FSL`" IP Core to the project and connect it to MicroBlaze on FSL:
  - ***Step1***. Select "`Hardware`" --> "`Configure Coprocessor`" from menu bar to run "`Configure Coprocessor`" wizard.
  - ***Step2***. In the "`Configure Coprocessor`" dialog, select `pwm_fsl` from "`Available Coprocessors`" list and then click "`Add`" button to add "`pwm_fsl`" coprocessor:



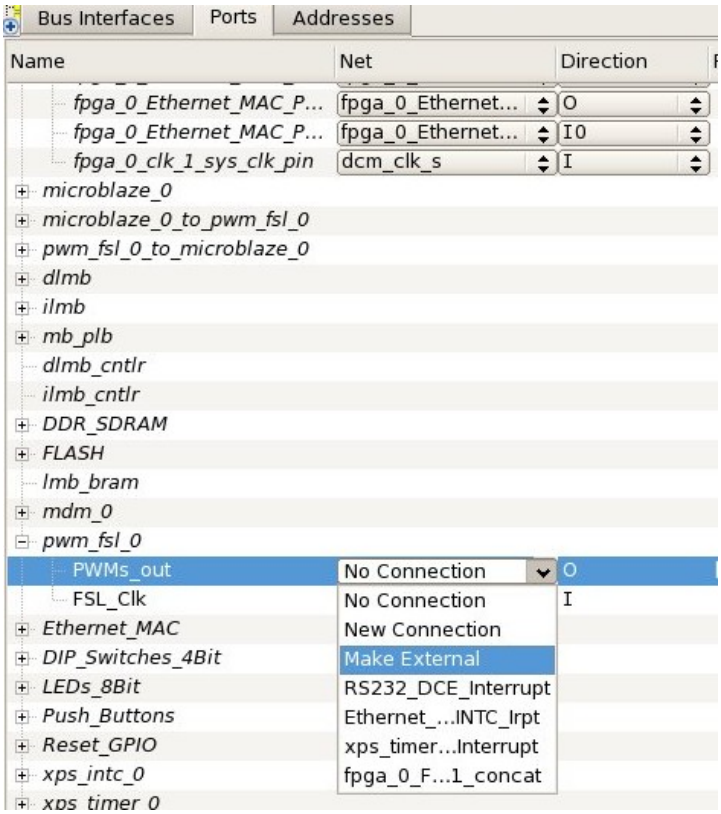
- ***Step3***. Click "OK" button.

  In the "Bus Interfaces" tab of "System Assembly View", you will see pwm_fsl_0_to_microblaze_0 and microblaze_0_to_pwm_fsl_0 FSLs and pwm_plb_0 instance are added to the project and pwm_plb_0 and microblaze_0 are connected through the FSLs:



Please note that the details shown in the "`Bus Interfaces`" tab of "`System Assembly View`" can be different from the above figure. It depends on the development board and the Xilinx tool you use.

- Because the PWM ports of our PWM_FSL IP Core will be connected to the LED pins outside the FPGA, we will make these ports as external ports by:
  - Go o the "`Ports`" tab of "`System Assembly View`".
  - Expands ports list of pwm_fsl_0 in "Ports" tab.
  - Select "`Make External`" to `PWMs_out` port.



- The external PWM ports will appear in the external port. Click the "+" sign of the "`External Ports`" in the "`Ports`" tab to expand the external ports, you will see the PWM ports are there.

  If you open the project's `system.mhs` file, you can see the new PWM ports are added to the external ports list which is at the top of the file following the version definition.

- Remove LED GPIO from the system because the PWM module will use the LEDs and it is impossible for two IP Cores to access the same PINs:
  - In the "`System Assembly View`", select instance "`LEDs_8Bit`", right click and select "`Delete Instance`".
  - In the "`Delete IP Instance`" options list, select "`Delete instance and its ports(both internal and external)`" and then click "`OK`" to delete the instance.
- Change the project's user constraint file to let the `PWM_PLB` core to access the user LEDs pins:

  Because the it is now the `pwm_fsl_0` instance to access the user LEDs pins rather than the LED GPIO module, the user constraint file has to be changed to reflect this system modification.

  Open the `system.ucf` file by double clicking it from "`Project Files`" list in

"`Project`" panel.

Replace the LED GPIO Net mappings with the PWMs mappings:

Replace:

```
1           #  XUPV5-LX110T Evaluation Platform
2           Net fpga_0_RS232_Uart_1_RX_pin LOC = AG15  |  IOSTANDARD=LVCMOS33;
3           Net fpga_0_RS232_Uart_1_TX_pin LOC = AG20  |  IOSTANDARD=LVCMOS33;
4           Net fpga_0_LEDs_8Bit_GPIO_IO_pin<0> LOC = AE24  |  IOSTANDARD=LVCMOS18  |
            PULLDOWN  |  SLEW=SLOW  |  DRIVE=2;
5           Net fpga_0_LEDs_8Bit_GPIO_IO_pin<1> LOC = AD24  |  IOSTANDARD=LVCMOS18  |
            PULLDOWN  |  SLEW=SLOW  |  DRIVE=2;
6           Net fpga_0_LEDs_8Bit_GPIO_IO_pin<2> LOC = AD25  |  IOSTANDARD=LVCMOS18  |
            PULLDOWN  |  SLEW=SLOW  |  DRIVE=2;
7           Net fpga_0_LEDs_8Bit_GPIO_IO_pin<3> LOC = G16  |  IOSTANDARD=LVCMOS25  |
            PULLDOWN  |  SLEW=SLOW  |  DRIVE=2;
8           Net fpga_0_LEDs_8Bit_GPIO_IO_pin<4> LOC = AD26  |  IOSTANDARD=LVCMOS18  |
            PULLDOWN  |  SLEW=SLOW  |  DRIVE=2;
9           Net fpga_0_LEDs_8Bit_GPIO_IO_pin<5> LOC = G15  |  IOSTANDARD=LVCMOS25  |
            PULLDOWN  |  SLEW=SLOW  |  DRIVE=2;
10          Net fpga_0_LEDs_8Bit_GPIO_IO_pin<6> LOC = L18  |  IOSTANDARD=LVCMOS25  |
            PULLDOWN  |  SLEW=SLOW  |  DRIVE=2;
11          Net fpga_0_LEDs_8Bit_GPIO_IO_pin<7> LOC = H18  |  IOSTANDARD=LVCMOS25  |
            PULLDOWN  |  SLEW=SLOW  |  DRIVE=2;
12          Net fpga_0_Push_Buttons_5Bit_GPIO_IO_pin<0> LOC = AJ6  |
            IOSTANDARD=LVCMOS33  |  PULLDOWN  |  SLEW=SLOW  |  DRIVE=2;
```

With:

```
1           #  XUPV5-LX110T Evaluation Platform
2           Net fpga_0_RS232_Uart_1_RX_pin LOC = AG15  |  IOSTANDARD=LVCMOS33;
3           Net fpga_0_RS232_Uart_1_TX_pin LOC = AG20  |  IOSTANDARD=LVCMOS33;
4           Net pwm_fsl_0_PWMs_out_pin<0> LOC = AE24  |  IOSTANDARD=LVCMOS18  |
            PULLDOWN  |  SLEW=SLOW  |  DRIVE=2;
5           Net pwm_fsl_0_PWMs_out_pin<1> LOC = AD24  |  IOSTANDARD=LVCMOS18  |
            PULLDOWN  |  SLEW=SLOW  |  DRIVE=2;
6           Net pwm_fsl_0_PWMs_out_pin<2> LOC = AD25  |  IOSTANDARD=LVCMOS18  |
            PULLDOWN  |  SLEW=SLOW  |  DRIVE=2;
7           Net pwm_fsl_0_PWMs_out_pin<3> LOC = G16  |  IOSTANDARD=LVCMOS25  |
            PULLDOWN  |  SLEW=SLOW  |  DRIVE=2;
```

```
8             Net fpga_0_Push_Buttons_5Bit_GPIO_IO_pin<0> LOC = AJ6  |
              IOSTANDARD=LVCMOS33  |  PULLDOWN  |  SLEW=SLOW  |  DRIVE=2;
```

Build Bitstream

Build the bitstream as we have learned in Lab 2.1 using Xilinx EDK GUI. If it is your first lab, please refer to section "Build the Hardware Bitstream" section in the Lab 2.1 manual.

We leave the PWM_FSL test to next lab.

Use Completed Resource

The completed Linux image for this lab is available in `~/xup_materials/labs/lab2.2b/completed/`. If you are stuck in any problem in the lab, you are welcome to use the completed resource. Here is the instruction on how to use the completed resource:

- Copy the completed hardware project to `PetaLinux` tree by executing:

  ```
  [host] $ ~/xup_materials/complete_lab 2.2b
  ```

- Download the bitstream to the board by executing:

  ```
  [host] $ cd ~/petalinux/hardware/user-platforms/XUP-pwm-fsl-project
  ```

  ```
  [host] $ impact -batch etc/download.cmd
  ```

  This command will download the bitstream `implementation/download.bit` to the board. (iMPACT is the Xilinx device configuration tool.)

Outcomes

At the completion of this lab you should

- know how to create a custom hardware IP Core with XPS tool
- know how to add a and modify an FSL-based coprocessor using the Xilinx tools
- know how to build bitstream from XPS GUI
- know the common bus interface – FSL

Document Version

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Lab 2.3a – Custom Driver Development

-- PLB Device

Rationale

Usually, after we created a new IP Core in hardware platform, we should create a device driver for it so that the system is able to access the new hardware through its driver.

There are different device models provided by Embedded Linux. Platform devices are devices that typically appear as autonomous entities in the system. What they usually have in common is direct addressing from a CPU bus such as Processor Local Bus (PLB).

Objectives

- Design a driver for the plb_pwm IP Core created in the previous lab.
- Write a simple application to test the driver.

Introduction

In the previous Lab 2.2a, we have created a PWM controller with PLB interface. In this lab, we are going to create an Embedded Linux driver for the PWM with PLB interface IP Core and an application to test it.

Time

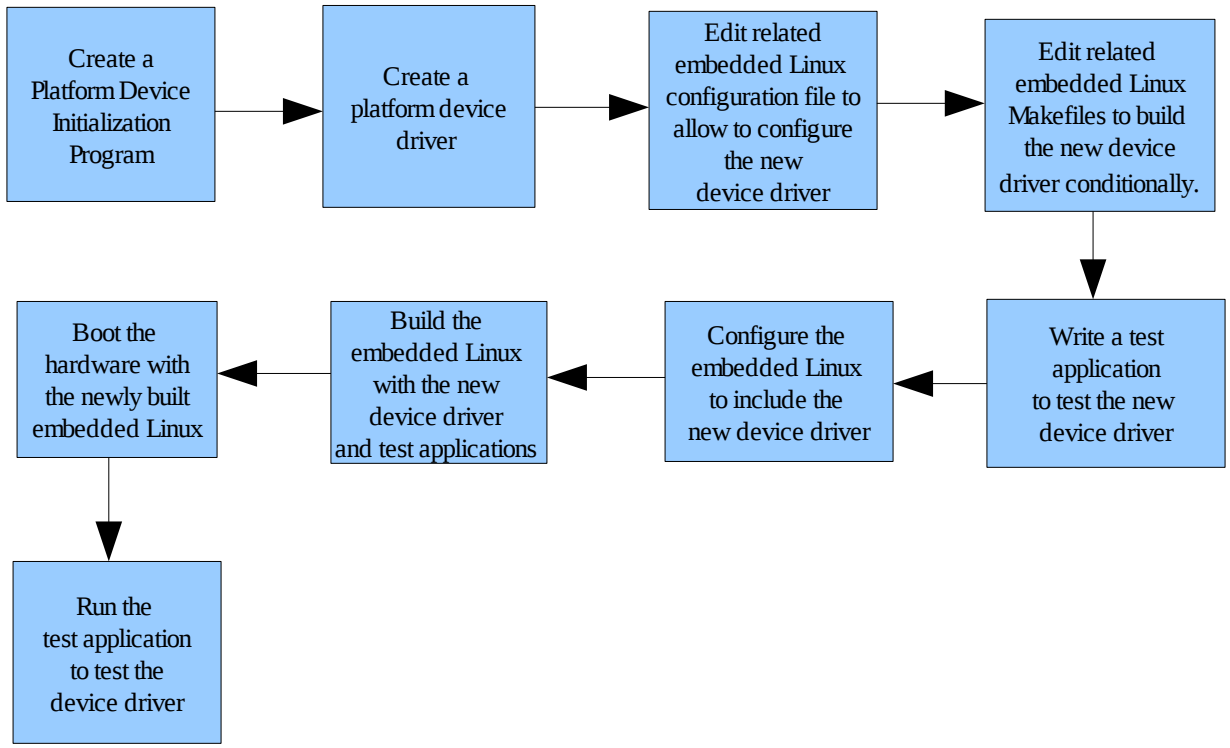
This session will run for approximately 60 minutes.

Preparation

If this is the first lab you are doing then please refer to sections "Before You Start" of Lab 1.1 document for necessary preparatory information on how to setup the hardware environment.

Lab overview

The following diagram is a high level overview of the steps taken in this Lab:



Hardware Project Preparation

This lab will use the hardware project we have created in the previous Lab 2.2a. Alternatively, you can use the pre-built hardware project in lab materials in this CentOS image by executing:

```
[host] ~/xup_materials/complete_lab 2.2a
```

This command will copy the hardware project from

```
~/xup-materials/labs/lab2.2a/completed/XUP-pwm-plb-project
```

to

```
~/petalinux/hardware/user-platforms/XUP-pwm-plb-project
```

PWM_PLB Embedded Linux Driver Development

As mentioned in Rationale section, we can use the platform device driver model for PLB device. In this section we are going write an embedded Linux device driver based on platform device driver model for the `PWM_PLB` IP Core.

Get Addressable Resource of PWM_PLB

In order to access a platform device, the Linux system needs to know where a platform device is. Thus, first of all, we need to write a initialization program for the Embedded Linux system to know what is the accessible resource of the PWM_PLB device at the early stage of the embedded Linux system startup.

- Create a PWM_PLB device initialization program by following these steps:
  - Go to `~/petalinux/software/petalinux-dist/linux-2.6.x/arch/microblaze/platform` directory by executing the following command on the host machine:

    ```
    [host] $ cd ~/petalinux/software/petalinux-dist/linux-2.6.x/arch/microblaze/platform
    ```

    There are platforms directories in this folder. Our `pwm_plb` device is independent to any special platform, thus, we will put the program in the `common` directory.
  - Go to the `common` directory by executing:

    ```
    [host] $ cd common
    ```

    There is a ready-to-use program to get resources of `PWM_PLB` core in the lab materials. Please copy that program to the `common` directory by executing:

    ```
    [host] $ cp ~/xup-materials/labs/lab2.3a/resources/platform/common/petalogix_pwm.c ./
    ```
- Browse the `petalogix_pwm.c` file.

  This file has a function "`ppm_platform_init()`" to get the accessible resource information of PWM_PLB device and register the device.

  The line "`device_initcall(ppwm_platform_init);`" at the end of the file will expose the "`ppm_platform_init()`" function to the kernel initialization process such that this function will be called when the system is booting.

  After the platform device has been registered, the Embedded Linux will try to bind the device with a driver.

Write PWM_PLB Driver

Now, we go to write a driver for the PWM_PLB platform device by following these steps:

- Let's consider the PWM_PLB device driver as a miscellaneous device driver which is a type of char devices. Go to `drivers/misc` directory by executing:

  ```
  [host] $ cd ~/petalinux/software/petalinux-
  ```

```
dist/linux-2.6.x/drivers/misc
```

- There is a ready-to-use driver file for this device in the lab materials. Please copy that file to thedirectory by executing:

  ```
  [host] $ cp ~/xup-
  materials/labs/lab2.3a/resources/drivers/misc/ppwm_adapter.c .
  ```

- Have a look at the driver file.

  In this `ppwm_adapter.c` file, it defines the misc device file operations and the platform device operations for the `PWM_PLB` device.

  User accessing the `PWM_PLB` device is almost the same as accessing a normal file. The driver provides these file access functions: `open()`, `release()`, `read()`, `write()` and `ioctl()`.

  `PWM_PLB` is a platform device, the driver also defines platform device driver operations such as `probe()` to allocate system resource for the device and then register it as a miscellaneous device; and `remove()` to unregister it as miscellaneous device and then delete all the system resource for the device.

  A platform device driver has to be registered before it can be used, thus, in the module initialization function--`ppwm_init()`, it register the PWM platform device driver. Accordingly, in the module exit function--`ppwm_cleanup()`, it unregister the PWM platform device driver.

- Write a header file for `pwm_plb` driver's `ioctl()` function.

  The `ioctl()` function is usually used to write/read a control word or a single data to the device. In the pwm_plb driver, the `ioctl()` is designed to write/read a single data to/from a specified channel. We need some customized data structure and macros to implement this function. Thus, we need a header file for the customized `ioctl()`.

  The header file, `ppwm_ioctl.h` is already in the lab materials. Please copy that file to `~/petalinux/software/linux-2.6.x-petalogix/include/asm-microblaze` by executing:

  ```
  [host] $ cd ~/petalinux/software/linux-2.6.x-
  petalogix/include/asm-microblaze
  ```

  ```
  [host] $ cp ~/xup-
  materials/labs/lab2.3/resources/asm/ppwm_ioctl.h ./
  ```

- Browse the `ppwm_ioctl.h` file.

  This header file defines a PWM ioctl data structure, and `in/out` PWM device ioctl operations macros.

Make the PWM PLB Driver Configurable

The PWM PLB driver is not a critical component to an embedded Linux system. Besides, not all hardware platform has PWM PLB components configured. Thus, we are going to make the PMW PLB driver optional.

- We have learned how to use `menuconfig` to configure our embedded Linux system. Now, we are going to expose the PWM PLB module to `menuconfig`.

  There is a `Kconfig` file in `~/petalinux/software/petalinux-dist/linux-2.6.x/drivers/misc` directory.

  Add the highlighted section of the following code into the `Kconfig` file:

  (**! Please note that the left-most column is the line numbers, don't type line numbers in the file.**)

```
5             menu "Misc devices"
6
7             config PETALOGIX_PWM
8                     bool "PetaLogix PWM Driver"
9                     depends on MICROBLAZE
10                    ---help---
11                      This is a driver for PetaLogix PWM device
```

  After making this change, you will be able to see "`PetaLogix PWM Driver`" option when running the `menuconfig`. Variable `CONFIG_PETALOGIX_PWM` will be set if this option is selected.

Change Makefiles to Build the PWM PLB Driver

Since the PWM PLB driver is optional, the Makefiles for the PWM PLB initialization program and the driver should only compile the PWM PLB related files if it is configured. Follow the following steps to change the related Makefiles:

- Change the Makefile in `drivers/misc/` to compile the PWM_PLB driver only if it is configured by user:

  Add the highlighted section in the following text into `Makefile` file in `~/petalinux/software/petalinux-dist/linux-2.6.x/drivers/misc` directory:

  (**! Please note that the left-most column is the line numbers, don't type line numbers in the file.**)

```
4             obj- := misc.o  # Dummy rule to force built-in.o to be made
5
```

```
6           obj-$(CONFIG_PETALOGIX_PWM)     += ppwm_adapter.o
7           obj-$(CONFIG_IBM_ASM)           += ibmasm/
```

- Change the MicroBlaze platform device initialization Makefile to compile the PWM_PLB initialization file only if it is configured by user:

  Add the highlighted section in the following text into `Makefile` file in `~/petalinux/software/petalinux-dist/linux-2.6.x/arch/microblaze/platform/common` directory:

  (**! Please note that the left-most column is the line numbers, don't type line numbers in the file.**)

```
11          # Build a local list of -y and -m driver options.
12          platobj-$(CONFIG_PETALOGIX_PWM) += petalogix_pwm.o
13          platobj-$(CONFIG_MTD_PHYSMAP) += physmap-flash.o
14          platobj-$(CONFIG_XILINX_LLTEMAC) += xlltemac.o
... ...
23
24          obj-y += $(platobj-y) $(platobj-m)
25
26          # Make these platform setup sources dependent on .config
27          # This is necessary because fixdep is not smart enough to "look
            inside"
28          # the device struct initialiser macros and find the real
            dependencies
29          # on the CONFIG_XILINX_ macros, when we use macro string
            substitution
30          #
31          $(obj)/built-in.o:      .config
32          $(obj)/petalogix_pwm.o: .config
33           $(obj)/xsysace.o:       .config
```

Create PWM PLB Test Application

So far, we have created a driver for PWM PLB device. In this section, we will write a simple test application to test the driver.

Create a Test Application to Use ioctl() to Write Data to the PWM PLB Device

As it is mentioned earlier in this lab, we can use ioctl() to write data to the device, we are going to create a test application to use ioctl() to write data to pwm_plb in this section. Here are the steps:

- Use PetaLogix tool to create a new user application by executing:

```
[host] $ petalinux-new-app pwm_plb_test_ioctl
```

- There is a ready-to-use PWM PLB `ioctl` test application in the lab materials. Copy those test application files to the newly created `pwm_plb_test_ioctl` directory by executing:

```
[host] $ cd ~/petalinux/software/user-apps/pwm_plb_test_ioctl
[host] $ cp ~/xup-materials/labs/lab2.3a/resources/user-apps/pwm_plb_test_ioctl/* ./
```

- Browse the files in the `pwm_plb_test_ioctl` directory. Here is a brief description of these files:
  - `Makefile` – Build the `pwm_plb_test_ioctl` application and create a device file `ppwm0` to `/dev/` directory in the root file system.
  - `pwm_plb_test_ioctl.c` – A simple test program to get input from 4 buttons and send PWM value to PWM_PLB driver. Each button corresponds to one LED. The PWM value will increase by "10" from 0 to 255 whenever the corresponding button is pressed; when the value saturates, it will drop to "0" or "5"; and then it will increase by "10" again when the button is pressed.

Note: The file name of the button's GPIO device is hard coded (#define BUTTON_FILE "/dev/gpio1")in the source files. Please make sure it is correct. The sequence of the GPIOs listed in "/dev" directory is the same as the alphabet sequence of the hardware instance names of the GPIOs.

Create PWM PLB Test Application to Use write()

We have created a test application to test the `ioctl()` function of the driver, in this section, we will create an application to test the `write()` function of the `pwm_plb` driver. Here are the steps:

- Use PetaLogix tool to create a new user application

```
[host] $ petalinux-new-app  pwm_plb_test_write
```

- There is a ready-to-use PWM PLB `write()` test application in the lab materials. Copy those test application files to the newly created `pwm_plb_test_write` directory by executing:

```
[host] $ cd ~/petalinux/software/user-apps/pwm_plb_test_write
[host] $ cp ~/xup-materials/labs/lab2.3a/resources/user-apps/pwm_plb_test_write/* ./
```

- Browse the files in the `pwm_plb_test_write` directory. Here is a brief description of these files:
  - `Makefile` – Build the `pwm_plb_test_write` application and create a device file `ppwm0` to `/dev/` directory in the root file system.

- `pwm_plb_test_write.c` – A simple test program to implement the same function as `pwm_plb_test_ioctl.c`. But it uses `write()` to write the PWM_PLB core instead of `ioctl()`.

Create PWM PLB Test Application to Read Data from the Device

We have created test applications to write data to the PWM PLB device. Now we are going to write a test application to read the PWM value from it. Here are the steps:

There is an already-done test application in `~/xup-materials/labs/lab2.3/resources/user-apps/pwm_plb_testr`.

- Use PetaLogix tool to create a new user application

```
[host] $ petalinux-new-app pwm_plb_testr
```

- There is a ready-to-use read PWM PLB test application in the lab materials. Copy those test application files to the newly created `pwm_plb_testr` directory by executing:

```
[host] $ cd ~/petalinux/software/user-apps/pwm_plb_testr
[host] $ cp ~/xup-materials/labs/lab2.3a/resources/user-apps/pwm_plb_testr/* ./
```

- Browse the files in the `pwm_plb_testr` directory. Here is a brief description of these files:
  - `Makefile` – Build the `pwm_plb_testr` applicationand create a device file `ppwm0` to `/dev/` directory in the root file system.
  - `pwm_plb_testr.c` – A simple test program to read PWM values from PWM_PLB with `ioctl()` and `read()`.

Build Embedded Linux

So far, we have created PWM_PLB driver and PWM_PLB test application. In this section, we will build an Embedded Linux image including the PWM PLB driver and the test applications by following these instructions:

- Use `menuconfig` to select a proper reference platform for the embedded Linux system. Follow these steps:
  - Run `menuconfig` by executing:

```
[host] $ cd ~/petalinux/software/petalinux-dist
[host] $ make menuconfig
```

  - Select the "`Vendor/Product Selection  --->`" sub-menu.
  - Set the vendor to "`Xilinx`" and product to "`-edk113`" in the "`Vendor/Product`

`Selection ---->`" sub-menu.

- Select `Exit` the `menuconfig` and then `save` the change.

- Go to the hardware project directory and copy the hardware configuration to PetaLinux by executing:

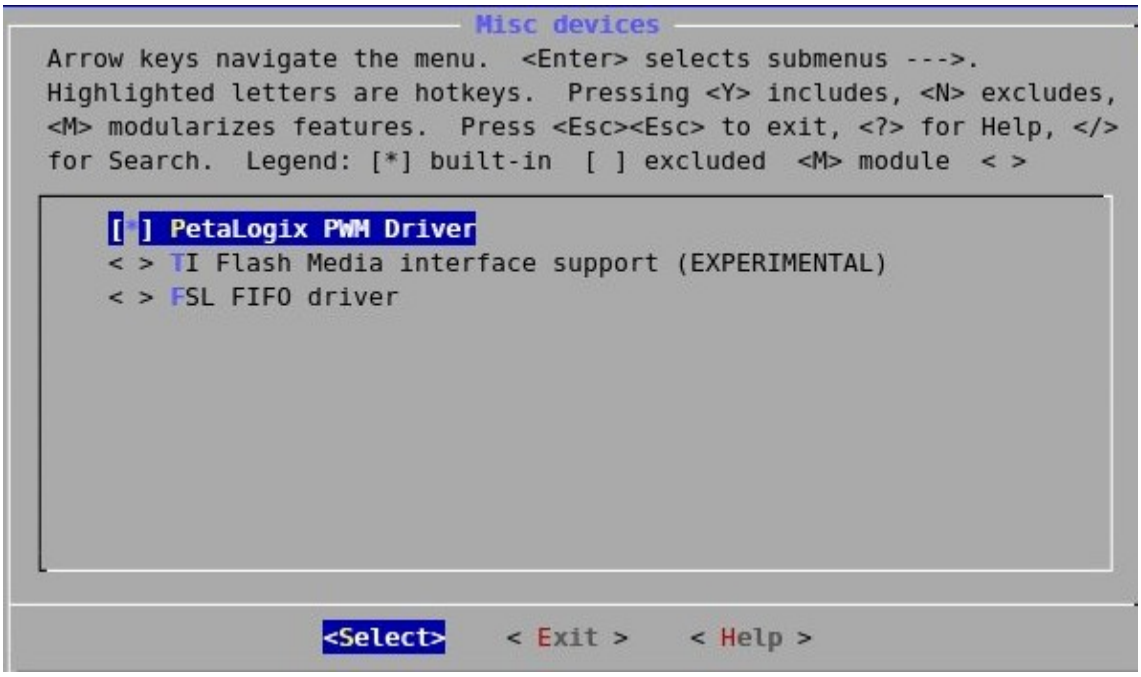
```
[host] $ cd ~/petalinux/hardware/user-platforms/XUP-pwm-plb-project
[host] $ petalinux-copy-autoconfig
```

- Use `menuconfig` to configure the embedded Linux system to include the PWM PLB driver by following these steps:
  - Run `menuconfig` by executing:

```
[host] $ cd ~/petalinux/software/petalinux-dist
[host] $ make menuconfig
```

  - Select "`[*] Customise Kernel Settings`" in "`Kernel/Library/Defaults Section`" sub-menu.
  - Exit and save the configuration.
  - When the "`Linux Kernel Configuration`" menu pop up, select the "`Device Drivers`" sub-menu.
  - Select "`Misc devices`" sub-menu in "`Device Drivers`" menu.
  - Select "`PetaLogix PWM Driver`" in "`Misc devices`" menu:

```
[*] PetaLogix PWM Driver
```



- Exit the `menuconfig` and save the configuration

- Build the MicroBlaze Linux image by executing:

```
[host] $ cd ~/petalinux/software/petalinux-dist
[host] $ make
```

- Build the test applications into the MicroBlaze Linux image by executing:

```
[host] $ cd ~/petalinux/software/user-apps/pwm_plb_test_ioctl
[host] $ make all romfs image
```

  Repeat the above 2 steps to build `pwm_plb_test_write` and `pwm_plb_testr`.

  After the image has been successfully built, the new image should be in `/tftpboot` directory.

Load the Board with the New Image and Play

- Program the FPGA with the hardware bitstream by executing:

```
[host] $ cd ~/petalinux/hardware/user-platforms/XUP-pwm-plb-project
[host] $ impact -batch etc/download.cmd
```

  Watch the output on the `kermit` console.

- Use mouse to select the `kermit` console. Break the auto boot by hit any key when the

messages similar to the following are shown on the `kermit` console:

```
FLASH: 16 MB
ETHERNET: MAC:00:0a:35:00:22:01


Hit any key to stop autoboot:  4
```

- Download the Embedded Linux image to the board using `tftp` and boot the system by executing the following command on the `kermit` console:

```
U-Boot> run netboot
```

- Watch the MicroBlaze Linux booting information on the `kermit` console, you should see the PWM_PLB driver initialization information similar to this:

```
ppwm0 #0 at 0xC9C00000 mapped to 0xC9C00000 device: 10,128
```

- Login when the MicroBlaze Linux system is boot.
- Try `pwm_plb_test_ioctl` by executing the following command on the `kermit` console:

```
# pwm_plb_test_ioctl
```

The following message will be shown on the `kermit` console:

```
PWM PLB Test -- ioctl()
```

Push button N, E, S, W corresponds to GPIO LED 4 ~ 7. When you press the buttons, you will see the brightness change of the GPIO LEDs.

- Try `pwm_plb_test_write` and press the buttons. The same as running `pwm_plb_test_ioctl`, you should see the brightness change of the LEDs.
- Try `pwm_plb_testr`, you will see the current PWM values.

e.g.

```
# pwm_plb_testr
Read PWM PLB Test
Read PWM PLB -- ioctl()
PWM[0]:      200
PWM[1]:      150
PWM[2]:      130
```

```
PWM[3]:       60
Read PWM PLB    read()
PWM[0]:      200
PWM[1]:      150
PWM[2]:      130
PWM[3]:       60
```

Use Completed Resource

The completed Linux image for this lab is available in `~/xup_materials/labs/lab2.3a/completed/`. If you are stuck in any problem in the lab, you are welcome to use the completed resource. Here is the instruction on how to use the completed resource:

- Copy the completed Linux images to `/tftpboot` directory by executing the following command on the host machine:

  ```
  [host] $ ~/xup_materials/complete_lab 2.3a
  ```

- Boot the board with `tftp` as usual.

Outcomes

At the completion of this lab you should

- know how to create a platform device driver
- know how to change the embedded Linux configuration file for the new device driver.
- know how to change the embedded Linux Makefiles for the new platform device driver.

Document Version

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Lab 2.3b – Custom Driver Development

-- FSL Device

Rationale

Usually, after we created a new IP Core in hardware platform, we should create a device driver for it so that the system is able to access the new hardware through its driver.

In the previous Lab 2.2b, we have created a PWM FSL IP Core. This IP Core connects to the MicroBlaze on the Fast Simplex Link(FSL) bus. FSL is a commonly used bus to connect the MicroBlaze to its coprocessors. PetaLinux has an existing FSL driver and thus, we can use the PetaLinux FSL driver for our PWM FSL IP Core.

Objectives

- Use the existing PetaLinux FSL driver for a newly created FSL hardware device.
- Write a simple application to use the PetaLinux FSL driver to test the FSL PWM controller.

Introduction

In the previous lab2.2b, we have created a PWM controller with FSL interface. We are going to use the existing PetaLinux FSL driver for it and write an test application to test the PWM FSL device.

Time

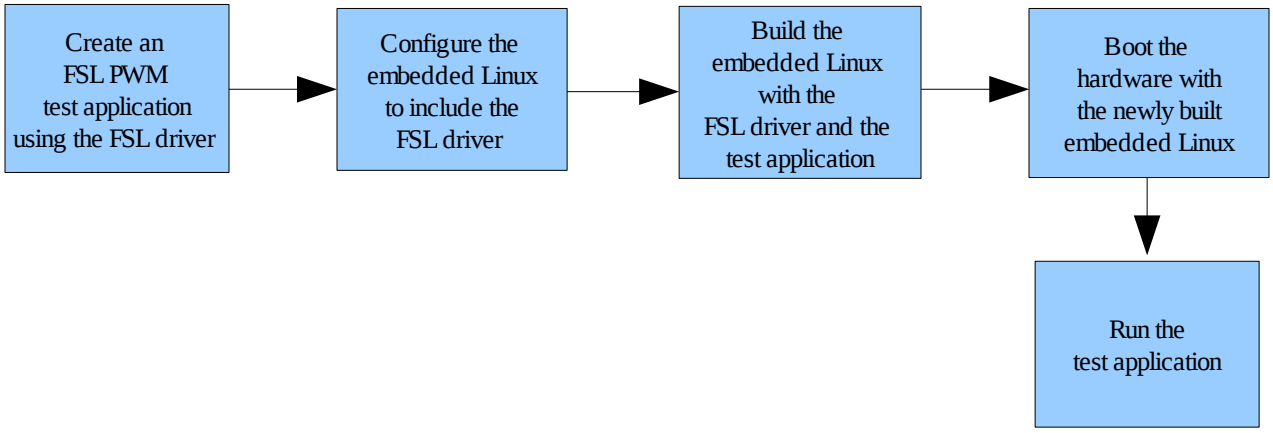
This session will run for approximately 60 minutes.

Preparation

If this is the first lab you are doing then please refer to sections "Before You Start" of Lab 1.1 document for necessary preparatory information on how to setup the hardware environment.

Lab overview

The following diagram is a high level overview of the steps taken in this Lab:



Hardware Project Preparation

This lab will use the hardware project we have created in the previous Lab 2.2b. Alternatively, you can use the pre-built hardware project in the lab materials in this CentOS image by executing:

```
[host] ~/xup_materials/complete_lab 2.2b
```

This command will copy the hardware project from `~/xup-materials/labs/lab2.2b/completed/XUP-pwm-fsl-project` to `~/petalinux/hardware/user-platforms/XUP-pwm-fsl-project`.

Browse the PetaLinux FSL Driver

The FSL driver files can be found in `~/petalinux/software/linux-2.6.x/drivers/misc/fslfifo/` directory. Go to this directory and have a look at the files in it. Here is a brief description of these files:

- `fslfifo.h` – The header file for the FSL driver.
- `fslfifo.c` – The source file the the FSL driver. It defines the file operations for an FSL device file.
  User accessing the `FSL` devices is almost the same as accessing a normal file. The driver provides these file access functions: `open()`, `release()`, `read()`, `write()` and `ioctl()`.

  The FSL driver write/read the FSL bus(es) in polling mode. The driver blocks until there is some data in the receiving buffer of the FSL when it reads data from the FSL device and it blocks until it can write some data to the transmit buffer when it writes data to the FSL device.

  The same as other device drivers, the FSL driver has module initialization function and module

exit function. A misc device has to be registered before it can be used, thus, in the module initialization function--init_fsl_fifo_devices(), it register the FSL device(s) as misc device(s). Accordingly, in the module exit function--fsl_fifo_cleanup(), it unregister the FSL device(s).

- `Makefile` – The Makefile to build the FSL driver.

The FSL driver is configurable, you can configure whether to build the FSL driver or not and configure how many FSL devices are in the system on `menuconfig`. The the `linux-2.6.x-petalogix/drivers/misc/Kconfig` file defines how to configure the FSL driver and other misc device drivers.

The FSL driver has its own `ioctl` operations, the `linux-2.6.x-petalogix/include/asm/fslfifo_ioctl.h` file defines the macros for the FSL driver `ioctl` operations.

Write Test Application for PWM_FSL

We have browsed the source files of the FSL driver. Now we are going to create a test application to use the FSL driver to test our PWM FSL IP Core.

Here are the steps to create the test application:

- Use PetaLinux tool to create a new user application by executing the following command on the host machine:

  ```
  [host] $ petalinux-new-app pwm_fsl_test
  ```

- A ready-to-use test application is alreadt in the lab materials. Please copy it to the newly created application directory `pwm_fsl_test` by executing:

  ```
  [host] $ cd ~/petalinux/software/user-apps/pwm_fsl_test
  [host] $ cp ~/xup-materials/labs/lab2.3b/resources/user-apps/pwm_fsl_test/* ./
  ```

- Have a look at the contents of `pwm_fsl_test.c` file before we move on.

  This file has a very simple test program to test the PWM FSL IP Core. The program takes the button input as requests to change the PWM duty ratio. It will increase a PWM channel's value from 0 to 255 by 10 every time the corresponding button is pressed; when the value saturates, it will drop to "0" or "5"; and then it will increase by "10" again when the button is pressed..

Note: The file name of the button's GPIO device is hard coded (#define BUTTON_FILE "/dev/gpio1")in the source files. Please make sure it is correct. The sequence of the GPIOs listed in "`/dev`" directory is the same as the alphabet sequence of the hardware instance names of the GPIOs.

Build Embedded Linux

So far, we have created PWM_FSL test application. In this section, we will build an embedded Linux image including the test application by following these instructions:

- Use `menuconfig` to select a proper reference platform for the embedded Linux system. Follow these steps:
  - Run `menuconfig` by executing:

    ```
    [host] $ cd ~/petalinux/software/petalinux-dist
    [host] $ make menuconfig
    ```

  - Select the "`Vendor/Product Selection --->`" sub-menu.
  - Set the vendor to "`Xilinx`" and product to "`-edk113`" in the "`Vendor/Product Selection --->`" sub-menu.
  - Select `Exit` the `menuconfig` and then `save` the change.
- Go to the hardware project directory and copy the hardware configuration to PetaLinux by executing:

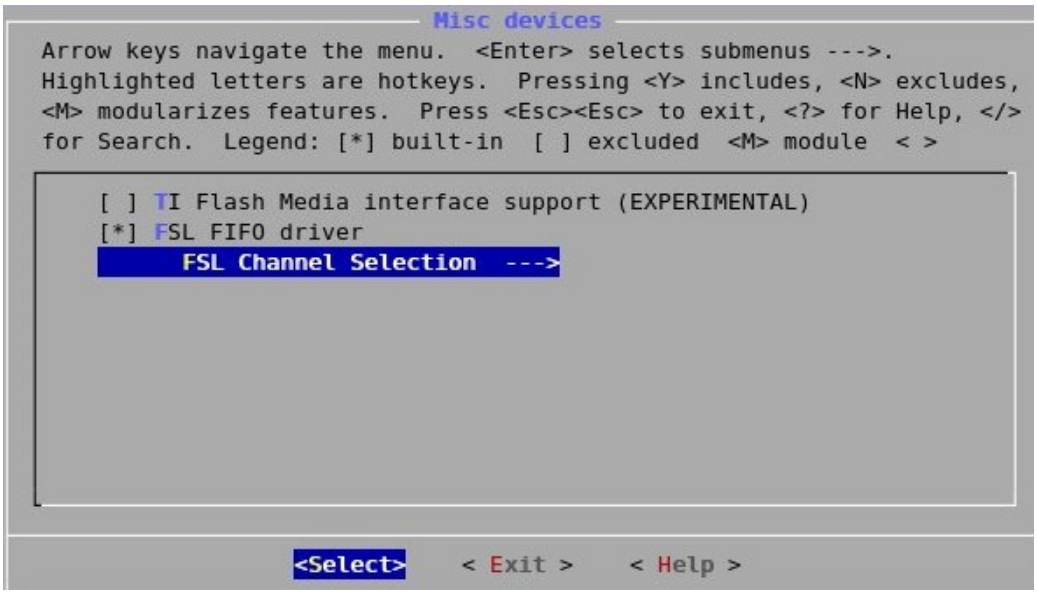
  ```
  [host] $ cd ~/petalinux/hardware/user-platforms/XUP-pwm-fsl-project
  [host] $ petalinux-copy-autoconfig
  ```

- Use `menuconfig` to configure the FSL driver by following these steps:
  - Run `menuconfig` by executing:

    ```
    [host] $ cd ~/petalinux/software/petalinux-dist
    [host] $ make menuconfig
    ```

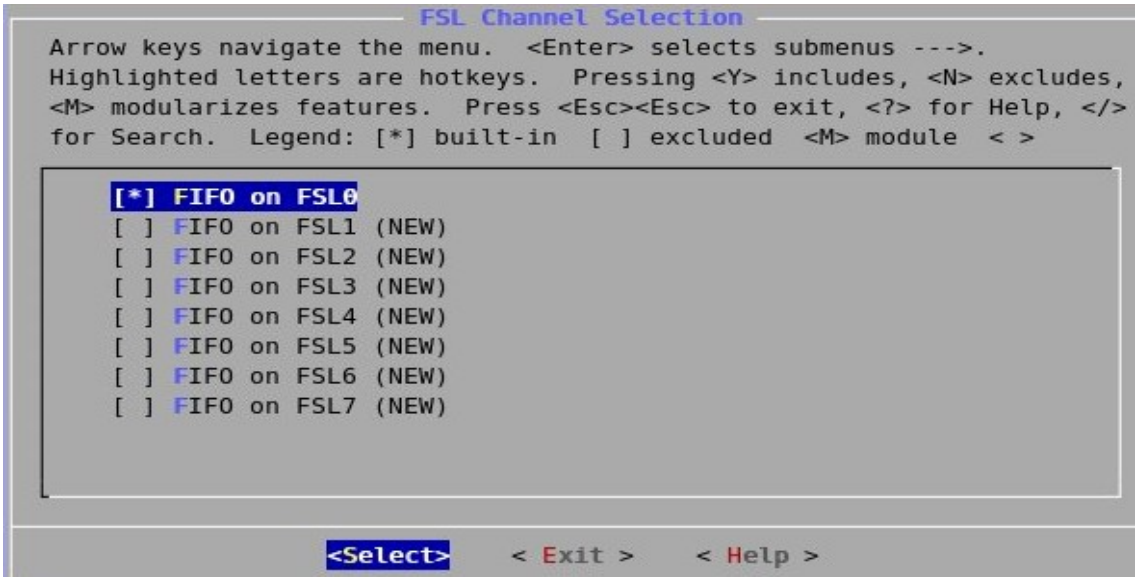
  - Select "`[*] Customise Kernel Settings`" in "`Kernel/Library/Defaults Section`" sub-menu.
  - Exit and save the configuration.
  - When the "`Linux Kernel Configuration`" menu pop up, select "`Device Drivers`" sub-menu.
  - Select "`Misc devices`" sub-menu in "`Device Drivers`" menu.
  - Select "`FSL FIFO Driver`" as built-in driver in the "`Misc devices`" menu:

    ```
    <*> FSL FIFO driver
    ```



- Select the "`FSL Channel Selection`" sub-menu in the "`Misc devices`" menu, and then select "`FIFO on FSL0`":

```
[*] FIFO on FSL0
```



- Exit and save the configuration

- Build the MicroBlaze Linux image by executing:

```
[host] $ cd ~/petalinux/software/petalinux-dist
[host] $ make
```

- Build the test applications into the MicroBlaze Linux image by executing:

```
[host] $ cd ~/petalinux/software/user-apps/ pwm_fsl_test
[host] $ make all romfs image
```

After the image has been successfully built, the new image should be in `/tftpboot` directory.

Load the Board with the New Image and Play

- Program the FPGA with the hardware bitstream by executing:

  ```
  [host] $ cd ~/petalinux/hardware/user-platforms/XUP-pwm-fsl-project
  [host] $ impact -batch etc/download.cmd
  ```

  Watch the output on the `kermit` console.

- Use mouse to select the `kermit` console. Break the auto boot by hit any key when the messages similar to the following are shown on the `kermit` console:

  ```
  FLASH: 16 MB
  ETHERNET: MAC:00:0a:35:00:22:01


  Hit any key to stop autoboot:  4
  ```

- Download the Embedded Linux image to the board using `tftp` and boot the system by executing the following command on the `kermit` console:

  ```
  U-Boot> run netboot
  ```

- Watch the Embedded Linux booting information, you should be able to see the FSL driver initialization information similar to this:

  ```
  FSL FIFO[0] initialised.
  ```

- Login when the system is boot up.
- Try `pwm_fsl_test` by executing the following command on the `kermit` console:

  ```
  # pwm_fsl_test
  ```

- The following message will be shown on the `kermit` console:

  ```
  PWM FSL Test
  ```

  Push buttons N, E, S, W corresponds to GPIO LED 4 ~7 on the board. When you press the buttons, you will see the brightness change of the GPIO LEDs.

Use Completed Resource

The completed Linux image for this lab is available in `~/xup_materials/labs/lab2.3b/completed/`. If you are stuck in any problem in the lab, you are welcome to use the completed resource. Here is the instruction on how to use the completed resource:

- Copy the completed Linux images to `/tftpboot` directory by executing the following command on the host machine:

  ```
  [host] $ ~/xup_materials/complete_lab 2.3b
  ```

- Boot the board with `tftp` as usual.

Outcome

At the completion of this lab you should

- know how to use the existing embedded Linux driver for the newly created device.

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Lab 2.4 – Working with WishBone and OpenCores

Rationale

The WishBone Bus is an open source hardware computer bus intended to let the parts of an integrated circuit communicate with each other. The aim of WishBone Bus is to allow the connection of different cores to each other inside of a chip. WishBone Bus is used by many designs in the OpenCores project.

Objectives

- Add a pre-wrapped WishBone IP Core, and the PLB2WishBone bus bridge to an EDK project
- Use low level hardware debugging to exercise the core

Introduction

In this lab, we will create a hardware project based on the PetaLinux reference design and then add a pre-wrapped WishBone IP Core to it. We will then use the WishBone IP Core to drive the 8 LEDs and will test WishBone IP Core by XMD.

Time

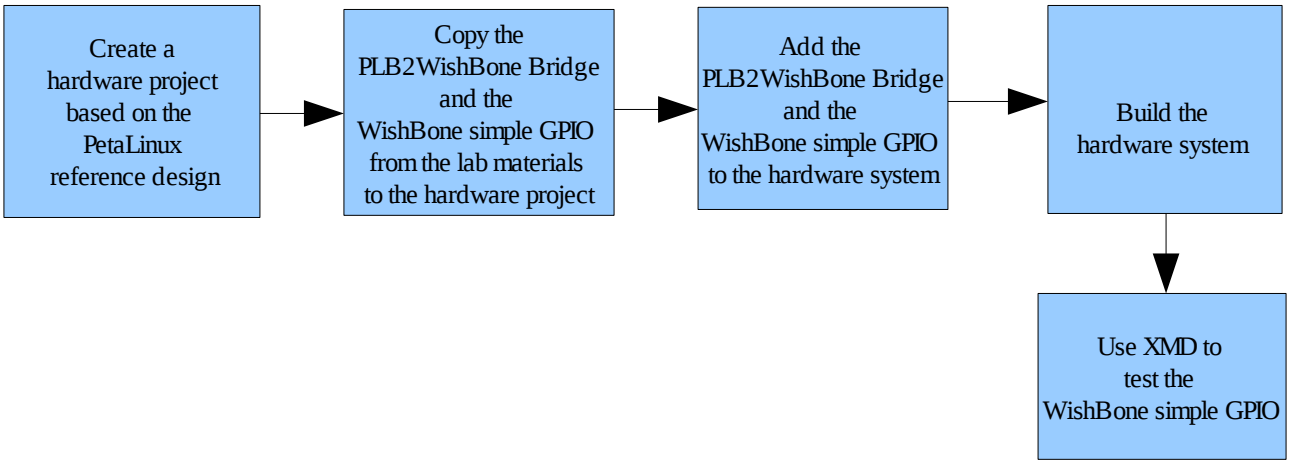
This session will run for approximately 45 minutes.

Preparation

If this is the first lab you are doing then please refer to sections "Before You Start" of Lab 1.1 document for necessary preparatory information on how to setup the hardware environment.

Lab overview

The following diagram is a high level overview of the steps taken in this Lab:



Create a WishBone Project Based on Reference Design

Similar to Lab 2.3, we will create a hardware project based on the reference design.

- Create a directory to hold the project by executing the following commands on the host machine:

```
[host] $ cd ~/petalinux/hardware/user-platforms
[host] $ mkdir XUP-WishBone-GPIO
```

- Copy the reference design to the project directory by executing:

```
[host] $ cd  XUP-WishBone-GPIO
[host] $ cp -r ~/petalinux/hardware/reference-designs/Xilinx--
edk113/* ./
```

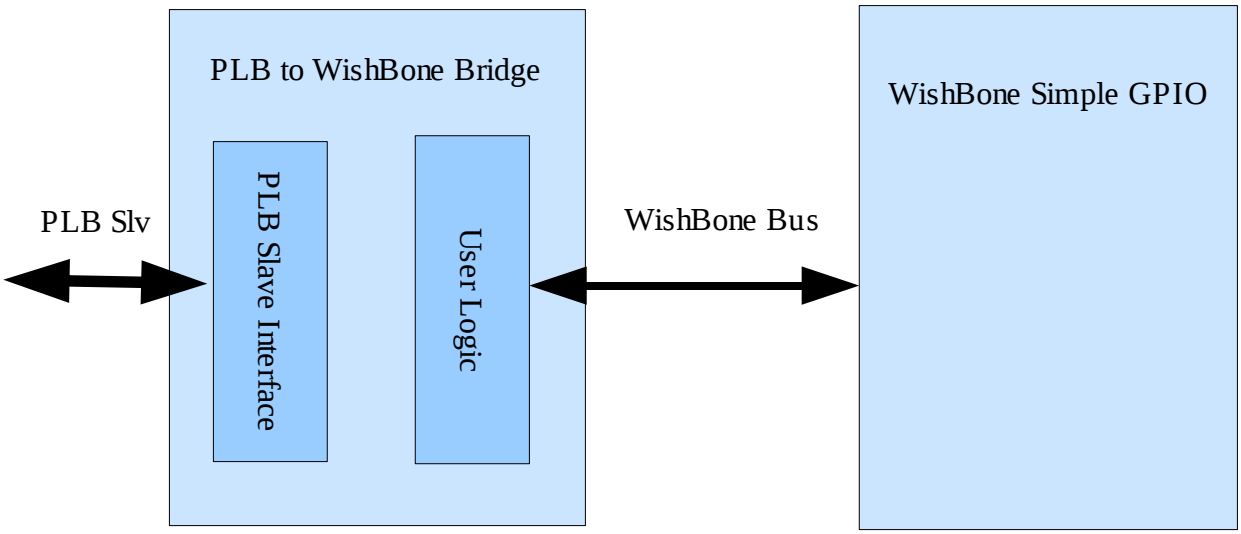
WishBone Simple GPIO and PLB2WishBone Bridge Introduction

A lot of IP Cores with WishBone Interface can be found in OpenCores's webpage, `www.opencores.org`. In this lab, we will use the "`Simple General Purpose IO`".

Because the MicroBlaze doesn't have a WishBone interface, we will use a "`PLB to WishBone Bridge`" to connect the WishBone "`Simple General Purpose IO`" to PLB and then to MicroBlaze.

Below is a brief description on the "`PLB to WishBone Bridge`" and the WishBone "`Simple`

`General Purpose IO`".



- At first, let's have a look at the "PLB to WishBone Bridge":

  Sources are in `~/xup-materials/labs/lab2.4/resources/pcores/plbv46_2_wb_v1_10_a`.

  Please have a look at the sources before moving on.

  Here is an explanation of the "`PLB to WishBone Bridge`":

  ```
  |-plbv46_2_wb  (Top level wrapper entity )
       |-plbv46_slave_single (PLB slave interface entity)
       |-user_logic  (entity to bridge PLB and WishBone)
  ```

  The PLB to WishBone Bridge translates PLB signals into WishBone signals and WishBone signals into PLB signals.

- Secondly, have a look at the "WishBone Simple GPIO":

  Sources are in `~/xup-materials/labs/lab2.4/resources/pcores/simple_gpio_wb_v1_00_a`.
  Please have a look at the sources before we move on.

  ```
  |-simple_gpio_wb.vhd  (Top Level Wrapper.)
       |- simple_gpio.v (WishBone Simple GPIO implementation)
  ```

  This simple GPIO supports up to 8 channels (1 bit per channel). There are read/write and read-only modes for each channel. The default mode of each channel is read-only. User can change the channels' mode by setting the IP Core's control word. Each channel is related to a bit in the control word. If the control bit is '0', the corresponding channel is in read-only mode, otherwise, the channel is in read/write mode.

Add WishBone IP Core to the Project

After a brief introduction of the WishBone IP Core used in this lab, let's add them into the project we have just created.

- Copy the WishBone IP Cores from lab materials into our project's IP Cores repository by executing:

  ```
  [host] $ cd ~/petalinux/hardware/user-platforms/XUP-WishBone-GPIO
  ```

  ```
  [host] $ cp -r ~/xup-materials/labs/lab2.4/resources/pcores/* pcores/
  ```

- Add WishBone IP Cores into our project
  - Open the `XUP-WishBone-GPIO` project by executing the following command in the project directory:

    ```
    [host] $ xps system.xmp
    ```

    At this point, Version Management wizard might appear if the Xilinx version you used is newer than the one used to generate the reference design. If it is the case, click "`Next`" as required, and then "`Finish`" to upgrade the project files.

    After the project is opened, the WishBone simple GPIO and the PLB to WishBone Bridge can be found in the IP catalog:

    - The "PLB to WishBone Bridge" is in "`Project Local pcores`"--> "`Bus and Bridge`";
    - The "WishBone Simple GPIO" is in "`Project Local pcores`"--> "`General Purpose IO`".
  - Add the WishBone IP Cores to the project:

    Double click the "`PLBv46 to Wishbone B3 Bridge`" and "`Simple GPIO with WishBone Interface`" in the "`IP Catalog`" tab to add the IP Cores to the project.

    You should be able to see the newly added IP Cores in the "`System Assembly View`".

Connect the WishBone IP Cores to the System

So far, we have added the "WishBone Simple GPIO" and "PLB to WishBone Bridge" to the project. Now, we need to connect them to the system.

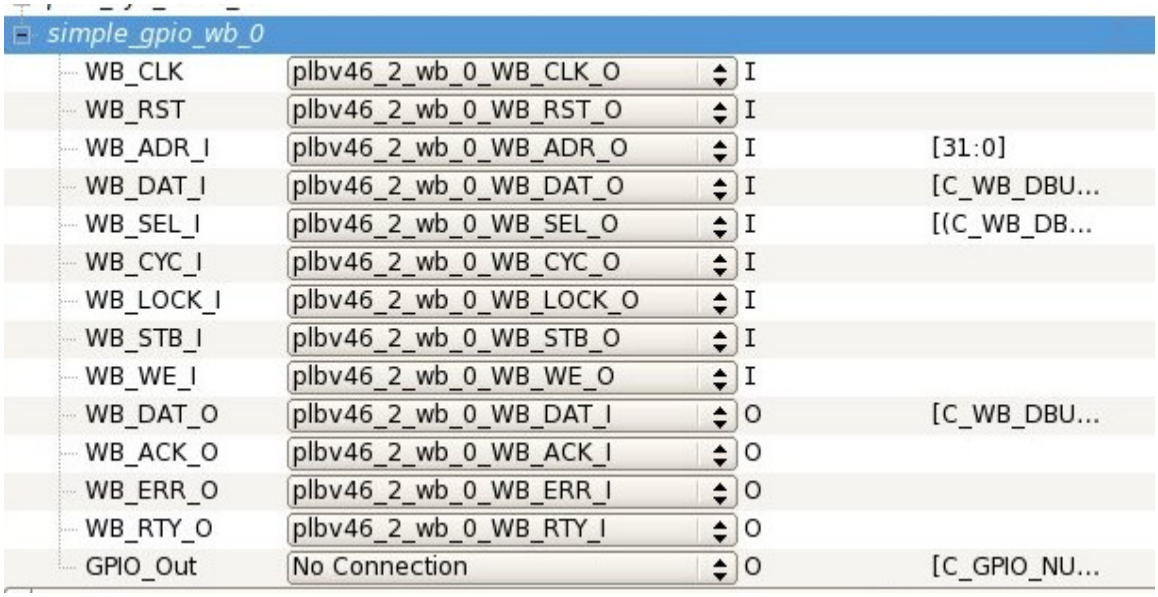
- Connect the "PLB to WishBone Bridge" to the PLB bus:

In the "Bus Interfaces" tab of "System Assembly View", expand the bus interface list of plbv46_2_wb_0 by clicking the "+" sign next to the instance; and then connect the SPLB bus interface to the PLB bus mb_plb.

- Generate address by selecting "Address" tab of "System Assembly View" and clicking "Generate Addresses" at the right top corner.
- Connect the "PLB to WishBone Bridge" and the "WishBone Simple GPIO":

  In the "Ports" tab of "System Assembly View",

  - Expand the ports list of "plbv46_2_wb_0" by clicking the "+" sign next to the instance. All the WishBone ports of the instance are listed
  - Select "New Connection" in the "net" column for each port of "plbv46_2_wb_0".
  - Connect the "simple_gpio_wb_0" WishBone ports to the "plbv46_2_wb_0" WishBone ports:



- Connect the GPIO outputs of the "WishBone Simple GPIO" to the 8 LED pins:
  - Because we will use the WishBone Simple GPIO to driver the LEDs and it's impossible to have two IP Cores to drive the same pins, delete the existing LEDs GPIO from the system by:
    - In the "System Assembly View", select instance "LEDs_8Bit", right click and select "Delete Instance".
    - In the "Delete IP Instance" options list, select "Delete instance and its ports(both internal and external)" and then click "OK" to delete the instance.

- Make `GPIO_Out` port of `simple_gpio_wb_0` as external port by select "`Make External`" in the "`net`" column for "`GPIO_Out`" port.

  The exported "`simple_gpio_wb0_GPIO_Out`" should be in the "`External Ports`" list at the top of the "`Ports`" tab of "`System Assembly View`".

- Connect the exported `simple_gpio_wb0_GPIO_Out` port to the LED pins:
  - Open `data/system.ucf` file by double clicking the file name in the "`Project`" tab.
  - Replace the old `LEDs_8Bit` ports to LED pins connection with the "WishBone Simple GPIO" ports to LED pins connection:

    Replace:

```
1           #  XUPV5-LX110T Evaluation Platform
2           Net fpga_0_RS232_Uart_1_RX_pin LOC = AG15  |  IOSTANDARD=LVCMOS33;
3           Net fpga_0_RS232_Uart_1_TX_pin LOC = AG20  |  IOSTANDARD=LVCMOS33;
4           Net fpga_0_LEDs_8Bit_GPIO_IO_pin<0> LOC = AE24  |  IOSTANDARD=LVCMOS18  |
            PULLDOWN  |  SLEW=SLOW  |  DRIVE=2;
5           Net fpga_0_LEDs_8Bit_GPIO_IO_pin<1> LOC = AD24  |  IOSTANDARD=LVCMOS18  |
            PULLDOWN  |  SLEW=SLOW  |  DRIVE=2;
6           Net fpga_0_LEDs_8Bit_GPIO_IO_pin<2> LOC = AD25  |  IOSTANDARD=LVCMOS18  |
            PULLDOWN  |  SLEW=SLOW  |  DRIVE=2;
7           Net fpga_0_LEDs_8Bit_GPIO_IO_pin<3> LOC = G16  |  IOSTANDARD=LVCMOS25  |
            PULLDOWN  |  SLEW=SLOW  |  DRIVE=2;
8           Net fpga_0_LEDs_8Bit_GPIO_IO_pin<4> LOC = AD26  |  IOSTANDARD=LVCMOS18  |
            PULLDOWN  |  SLEW=SLOW  |  DRIVE=2;
9           Net fpga_0_LEDs_8Bit_GPIO_IO_pin<5> LOC = G15  |  IOSTANDARD=LVCMOS25  |
            PULLDOWN  |  SLEW=SLOW  |  DRIVE=2;
10          Net fpga_0_LEDs_8Bit_GPIO_IO_pin<6> LOC = L18  |  IOSTANDARD=LVCMOS25  |
            PULLDOWN  |  SLEW=SLOW  |  DRIVE=2;
11          Net fpga_0_LEDs_8Bit_GPIO_IO_pin<7> LOC = H18  |  IOSTANDARD=LVCMOS25  |
            PULLDOWN  |  SLEW=SLOW  |  DRIVE=2;
12          Net fpga_0_Push_Buttons_5Bit_GPIO_IO_pin<0> LOC = AJ6  |
            IOSTANDARD=LVCMOS33  |  PULLDOWN  |  SLEW=SLOW  |  DRIVE=2;
```

    With:

```
1           #  XUPV5-LX110T Evaluation Platform
2           Net fpga_0_RS232_Uart_1_RX_pin LOC = AG15  |  IOSTANDARD=LVCMOS33;
3           Net fpga_0_RS232_Uart_1_TX_pin LOC = AG20  |  IOSTANDARD=LVCMOS33;
4           Net simple_gpio_wb_0_GPIO_Out_pin<0> LOC = AE24  |  IOSTANDARD=LVCMOS18  |
            PULLDOWN  |  SLEW=SLOW  |  DRIVE=2;
5           Net simple_gpio_wb_0_GPIO_Out_pin<1> LOC = AD24  |  IOSTANDARD=LVCMOS18  |
            PULLDOWN  |  SLEW=SLOW  |  DRIVE=2;
6           Net simple_gpio_wb_0_GPIO_Out_pin<2> LOC = AD25  |  IOSTANDARD=LVCMOS18  |
            PULLDOWN  |  SLEW=SLOW  |  DRIVE=2;
7           Net simple_gpio_wb_0_GPIO_Out_pin<3> LOC = G16  |  IOSTANDARD=LVCMOS25  |
            PULLDOWN  |  SLEW=SLOW  |  DRIVE=2;
8           Net simple_gpio_wb_0_GPIO_Out_pin<4> LOC = AD26  |  IOSTANDARD=LVCMOS18  |
            PULLDOWN  |  SLEW=SLOW  |  DRIVE=2;
9           Net simple_gpio_wb_0_GPIO_Out_pin<5> LOC = G15  |  IOSTANDARD=LVCMOS25  |
            PULLDOWN  |  SLEW=SLOW  |  DRIVE=2;
10          Net simple_gpio_wb_0_GPIO_Out_pin<6> LOC = L18  |  IOSTANDARD=LVCMOS25  |
```

```
                PULLDOWN  |  SLEW=SLOW  |  DRIVE=2;
11              Net simple_gpio_wb_0_GPIO_Out_pin<7> LOC = H18  |  IOSTANDARD=LVCMOS25  |
                PULLDOWN  |  SLEW=SLOW  |  DRIVE=2;
12              Net fpga_0_Push_Buttons_5Bit_GPIO_IO_pin<0> LOC = AJ6  |
                IOSTANDARD=LVCMOS33  |  PULLDOWN  |  SLEW=SLOW  |  DRIVE=2;
```

Build Bitstream

Build the bitstream as we have learned in Lab 2.1 using Xilinx EDK GUI. If it is your first lab, please refer to section "Build the Hardware Bitstream" section in the Lab 2.1 manual.

Download Bitstream to the Board

Now, we can program the FPGA with the newly built bitstream as we have learned in section "Program the FPGA" in the Lab 2.1 manual.

Debug the WishBone Simple GPIO with XMD

- Run XMD from command line by executing:

  ```
  [host] $ xmd
  ```

- After the XMD started, connect XMD to the target by executing the following command on the XMD console:

  ```
  XMD% connect mb mdm
  ```

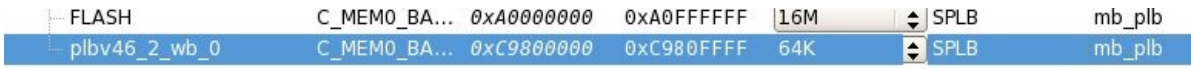
- Stop the running application on MicroBlaze. Because the board is boot up with application to initialize BRAM and we cannot access registers when applications are running on MicroBlaze, before accessing PLB registers, we have to stop the running application. Here is the XMD command to stop the running application:

  ```
  XMD% stop
  ```

- Set the "WishBone Simple GPIO" control word to make all 8 GPIO channels writable:

  We can get the "WishBone Simple GPIO" address from "`Addresses`" tab of "`System Assembly View`".

  The address of the "PLB to WishBone Bridge" is the PLB address of the "WishBone Simple GPIO":

  The "WishBone Simple GPIO" has two registers, control register and data register.

- Control register: PLB Address Offset: 0x0

  The lowest 8 bits of the control register control the mode of 8 GPIO channels. '0' – read-only, '1' – readable and writable.

- Data register: PLB Address Offset: 0x4

  The lowest 8 bits of the data register are the value of the 8 GPIO channels.

E.g. The PLB base address of WishBone Simple GPIO is 0xc9800000. The control register's PLB address is 0xc9800000 and the data register's PLB address is 0xc9800004.

- Set the control register to make all 8 GPIO channels writable by executing the following XMD command:

```
XMD% mwr 0xc9800000 0xff
```

  Now all the 8 LEDs should be turned off.

- Write values to WishBone data register to turn on GPIO LEDs by executing the following XMD command:

  e.g. `XMD% mwr 0xc9800004 8`

  Watch the board to see the status change of the GPIO LEDs.

- Read the WishBone registers by executing the following XMD command:

  e.g. `XMD% mrd 0xc9800000 2`

```
C9800000:   000000FF
C9800004:   00000008
```

  Values of both control register and data register are shown on the console.

  Try other control word values and data register values.

- Close XMD by typing `exit` at the xmd command prompt

Use Completed Resource

The completed Linux image for this lab is available in `~/xup_materials/labs/lab2.4/completed/`. If you are stuck in any problem in the lab, you are welcomed to use the completed resource. Here is the instruction on how to use the completed resource:

- Copy the completed hardware project to `PetaLinux` tree and the Linux images to `/tftpboot` directory by executing the following command:

```
[host] $ ~/xup_materials/complete_lab 2.4
```

- Download the bitstream to the board by executing:

  ```
  [host] $ cd ~/petalinux/hardware/user-platforms/XUP-WishBone-GPIO
  ```

  ```
  [host] $ impact -batch etc/download.cmd
  ```

  This command will download the bitstream `implementation/download.bit` to the board. (iMPACT is an Xilinx device configuration tool.)

Outcomes

At the completion of this lab you should understand

- what is WishBone bus
- how to connect a WishBone IP Core to MicroBlaze.
- where to find IP cores on the OpenCores website.

Document Version

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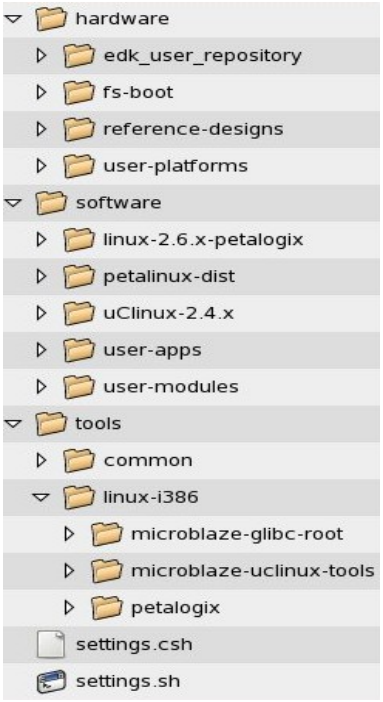
PetaLinux Tips

The "PetaLinux Tips" will give you a general idea about the PetaLinux structure and the XUP workshop materials structure such that you will know how PetaLinux organizes its resources and where to find the XUP workshop materials. This document also contains a brief description of commonly used Linux commands, hot keys and PetaLinux commands for those who are not familiar with Linux and/or PetaLinux.

PetaLinux Structure



`hardware`:
- `edk_user_repository`: commonly used PetaLogix bsp, pcores for EDK;
- `fs-boot`: sources and headers for fs-boot application;
- `reference-designs`: PetaLogix reference hardware platforms configuration for commonly used Xilinx boards.
- `user-platforms`: User created hardware platforms

`software`:
- `linux-2.6.x-petalogix`: petalinux source with 2.6 Linux kernel
- `uClinux-2.4.x`: petalinux source with 2.4 Linux kernel
- `petalinux-dist`: petalinux distribution
- `user-apps`: user created Embedded Linux applications
- `user-modules`: user created Embedded Linux modules

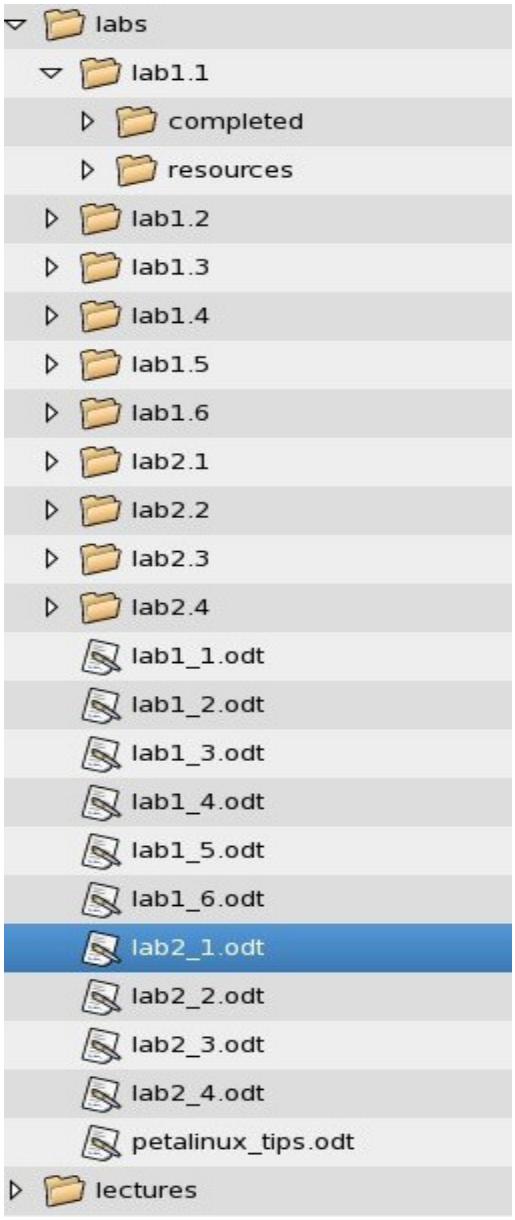
`tools`:
- `common`: commonly used petalinux tools
- `linux-i386`: tools for linux-i386

`settings.csh`:
petalinux configuration script for C Shell

`settings.sh`:
petalinux configuration script for Bash Shell

XUP Workshop Lab materials

All the materials including lectures, lab tutorials and lab sources are in `~/xup-materials`. Diagram below shows the structure of this directory.



`labs`

- `lab`*`N_M`*`.odt` file : Lab tutorials
- `lab`*`N.M`* directory
  - `completed`: completed hardware project and/or software project
  - `resources`: HDL sources and/or software sources

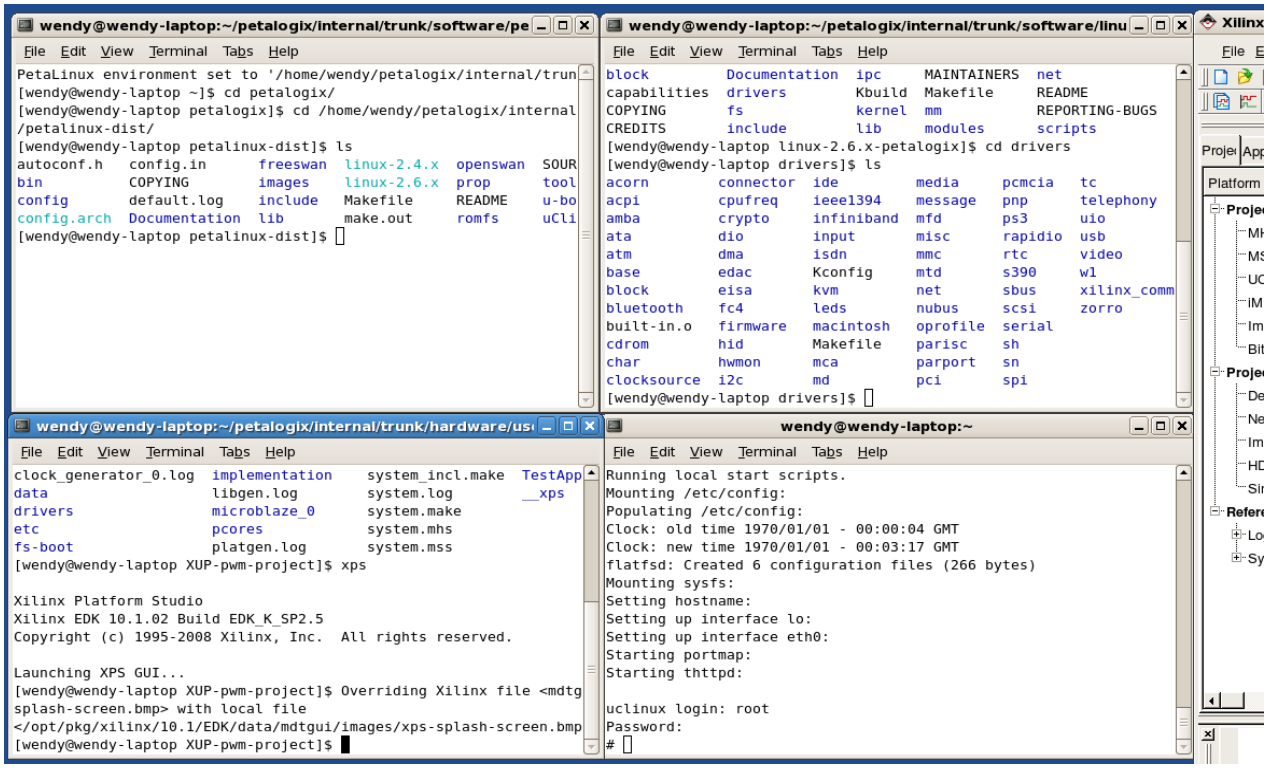
`lectures` : Lectures

If you have any problems in the labs, you can refer to the sources in `~/xup-materials/labs/lab*N.M*/resources/` directory and/or the completed projects in `~/xup-materials/labs/lab*N.M*/completed/` directory.

Command `~/xup-materials/complete_lab` *`N.M`* will copy the completed resources of lab*N.M* to `PetaLinux` tree and/or `/tftpboot` directory.

Linux Tips

- Use multiple windows for development.
  - One console for hardware project
  - One console for software development
  - One console for configuring/building petalinux
  - One console for monitoring the Linux running on the board with serial terminal software `minicom` or `kermit`.



- Use Tab for auto-complete

  Linux provides a very useful auto-complete function. When you type the beginning of a command or a file/directory name and then press the TAB key, Linux will search the current directory and the $PATH to find the closest one and automatically complete the name or command.

  e.g. PetaLinux commands such as petalinux-copy-autoconfig

  As long as you have sourced the PetaLinux settings script, you can use Linux auto complete function to type PetaLinux commands.

- Type up arrow key `↑` on command line to show the previously entered commands.
- "~" is an alias for the user's home directory.

  e.g. list home directory:

  ```
  [host] $ ls ~
  ```

Commonly used Linux commands

Command	***cd***
Description	Go to a specified directory or the default directory(home directory).

Example	`cd`
	This command will go to home directory.
	
	`cd directory_name`
	This command will go to the `directory_name` directory in the working directory.
	
	`cd path/directory_name`
	This command will go to the `directory_name` directory in `path/`.

Command	***ls***
Description	This command will list the files of a specified directory or the working directory.

Example	`ls path/directory_name`
	This command will list the filenames in `directory_name` directory in `path`.
	
	`ls -l path/directory_name`
	This command will list the detailed properties information of the files in `directory_name` directory in `path/`.
	
	`ls -l path/file_name`
	This command will list the detailed properties information of the file `file_name` in `path/`.

Command	***cp***
Description	Copy file(s) and/or a directory from source to target

Example	`cp sourcepath/sourcefile targetpath/targetfile`
	This command will copy the `sourcefile` from `sourcepath/` to `targetfile` in `targetpath/`.
	
	`cp sourcepath/sourcefile targetpath/`
	This command will copy the `sourcefile` from `sourcepath/` to `sourcefile` in `targetpath/`.
	
	`cp -r sourcepath/sourcedir targetpath/targetdir`
	This command will copy the `sourcedir` directory from `sourcepath/` to `targetdir` directory in `targetpath/`.
	
	`cp -r sourcepath/sourcedir targetpath/`
	This command will copy the `sourcedir` directory from `sourcepath/` to `sourcedir` directory in `targetpath/`.

command	***`cat`***
Description	This command will show the contents of a file on the standard output
Example	`cat path/file_name` This command will show the contents of file `file_name` in `path/` on the standard output, by default the standard output is the working console.
command	***`sudo`***
Description	This will execute the Linux command with root permission. The password of root is required to run a command with `sudo`.

Example	`sudo /etc/init.d/nfs start` This command will start NFS server as root user.

Edit Text Files in CentOS

In CentOS, we can edit a text file through `vi` or `gedit`.

- `vi` allows you to edit a text file directly on the console.
- `gedit` allows you to edit a text file through a graphic editor.

  Command `gedit path/file_name` will open the file specified by `path/file_name` in a graphic text editor.

  Alternatively, you can select `Applications` --> `Accessories` --> `Text Editor` on the CentOS panel to open `gedit` graphic text editor.

Commonly used PetaLinux Tools

Only, the PetaLinux tools can only be used .

Running the `settings.csh` and `settings.sh` scripts will set all the necessary PetaLinux environment variables.

Command	**petalinux-copy-autoconfig [-p platform | -v vendor | -k kernel_ver (2.6/2.4) | -noupdateconfig | projectfile.xmp]**
Description	This tool will copy the hardware configuration information of a hardware project to petalinux.

Example	Before running this command:
	● Make sure the hardware project have been successfully built or at least the libraries of the hardware project have been built.
	● Make sure the vendor/project of PetaLinux has been set correctly by running `make menuconfig` in `petalinux-dist` directory.
	
	`[host] $ cd ~/petalinux/hardware/user-platforms/XUP-pwm-project`
	`[host] $ petalinux-copy-autoconfig`
	`INFO: Attempting vendor/platform auto-detect`
	`INFO: Auto-detected Xilinx/Spartan3DSP1800A-Rev1 combination.`
	`Auto-config file successfully updated for Xilinx Spartan3DSP1800A-Rev1`

Command	**petalinux-new-platform [-force] [-k kernel] [-v vendor] -p platform**
Description	This tool will create a new platform in PetaLinux.

Example	`[host] $ cd ~/petalinux/software/petalinux-dist`
	`[host] $ petalinux-new-platform -k 2.6 -v Xilinx -p XUP-S3DSP-project`
	This command will create platform named XUP-S3DSP-project whose vendor is Xilinx only supporting 2.6 kernel. After running this command, when you run the `make menuconfig` , you will see the new platform is on the platform lists of the specified vendor.

Command	**petalinux-new-app [-force] app-name**
Description	This tool will create a new user application with PetaLinux source file template, Makefile template and development instructions in `~/petalinux/software/user-apps` directory.

Example	`[host] $ petalinux-new-app mytest` A directory `mytest` containing templates will be created in `~/petalinux/software/user-apps` directory.
Command	**petalinux-new-module [-force] module-name**
Description	This tool will create a new user module with PetaLinux source file templates, Make template and development instructions in `~/petalinux/software/user-modules` directory.
Example	`[host] $ petalinux-new-app mymodule` A directory `mymodule` containing templates will be created in `~/petalinux/software/user-modules` directory.
Command	**petalinux-jtag-boot [-p projfile.xmp] -t <target> -a <startaddr> [-c cmdline] -i <imagefile> [-x xmd_connect_args] ** **[-t <target> -a <startaddr> [-c cmdline] -i <imagefile>] ** **[-t <target> -a <startaddr> [-c cmdline] -i <imagefile>] ...**
Description	This tool will download a specified Embedded Linux image file to the specified MicroBlaze target using XMD utility and boot the MicroBlaze with the image.

Example	`[host] $ cd ~/petalinux/hardware/user-platforms/XUP-pwm-project`
	`[host] $ petalinux-jtag-boot -t 0 -a 0x88000000 -i /tftpboot/image.bin`
	The image `/tftpboot/image.bin` will be downloaded to memory region starting from 0x88000000 JTAG. As soon as the image finishes download, the tool will boot the MicroBlaze_0 with the image through XMD.

There are more PetaLinux tools provided, please visit http://developer.petalogix.com/wiki/UserGuide/PetaLinuxTools for more details.