INIPRO

Embedded Linux on Zynq

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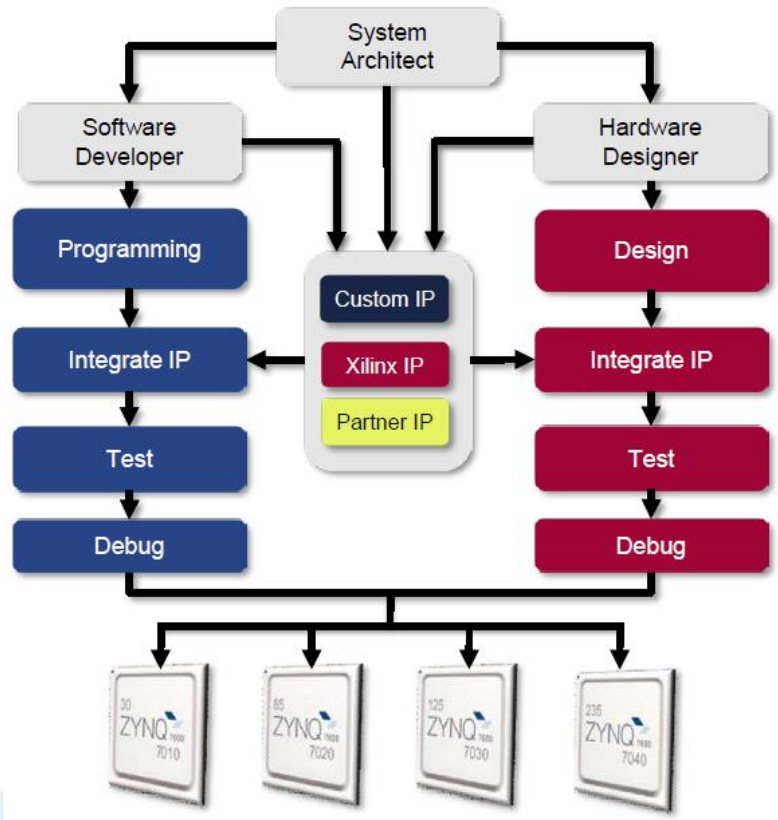
Overview of Zynq

- **Zynq = Dual core ARM (PS: Processing System) + FPGA (PL: Programmable Logic)**
- **Processor concentrated chip**

  Processor runs with minimal(?) PL programming.

  Less flexibility.

  More efficient parallel hardware and software development.



Overview of Zynq PS development

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- **Bare-Metal** without OS

  Possible to write fast programs.

  Difficult to realize complex systems with components like webserver, FTP server, USB support and so on.

  SDK Provides ARM Toolchain.

- **Real-Time OS**

  For applications with strict time constraints.

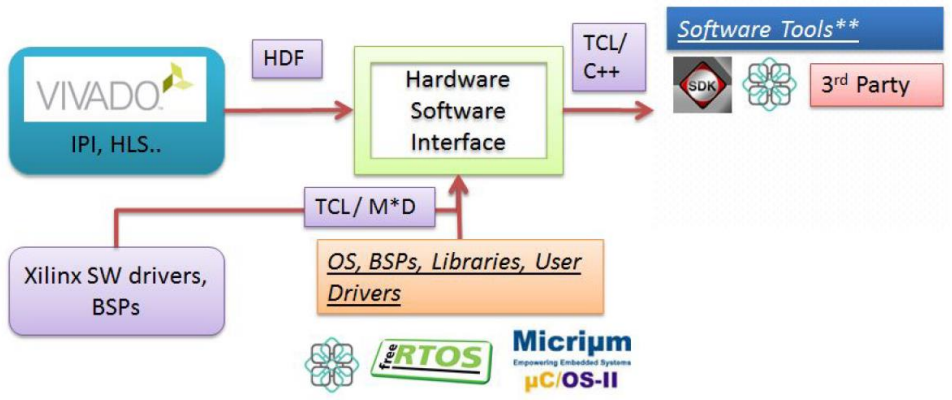
  Most are commercial.

- **Linux**

  Greatest flexibility.

  Many drivers, libraries and software package.

Development Tool



- **Vivado** GUI, CUI(2015.4)

  Design hardware

  Generate bit/hdf files

- **HSI** Hardware Software Interface

  Scalable framework enabled SW tool integration with Vivado

  Compile FSBL / Generate DT

- **Ubuntu** (16.04 LTS)

  (Host) Compile u-boot, kernel and DT

  (Target) Compile drivers / applications

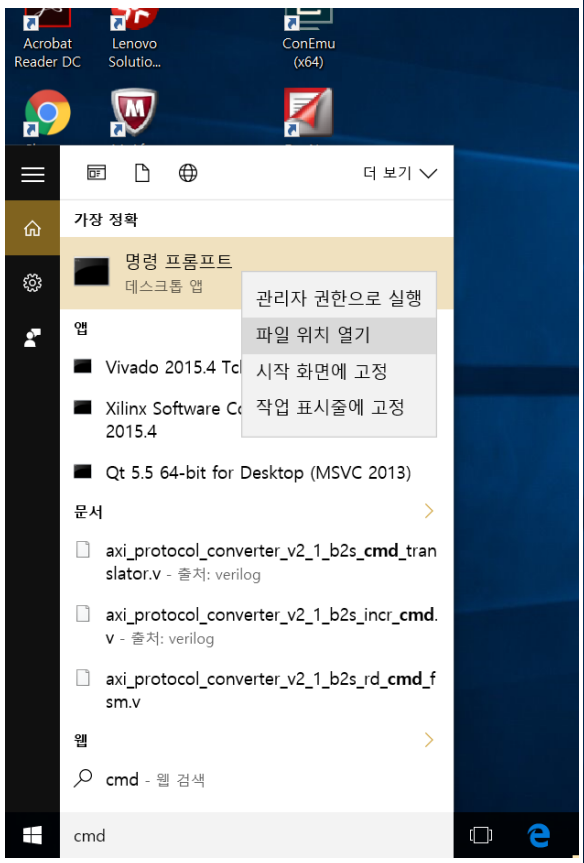
Development Environment Set-up

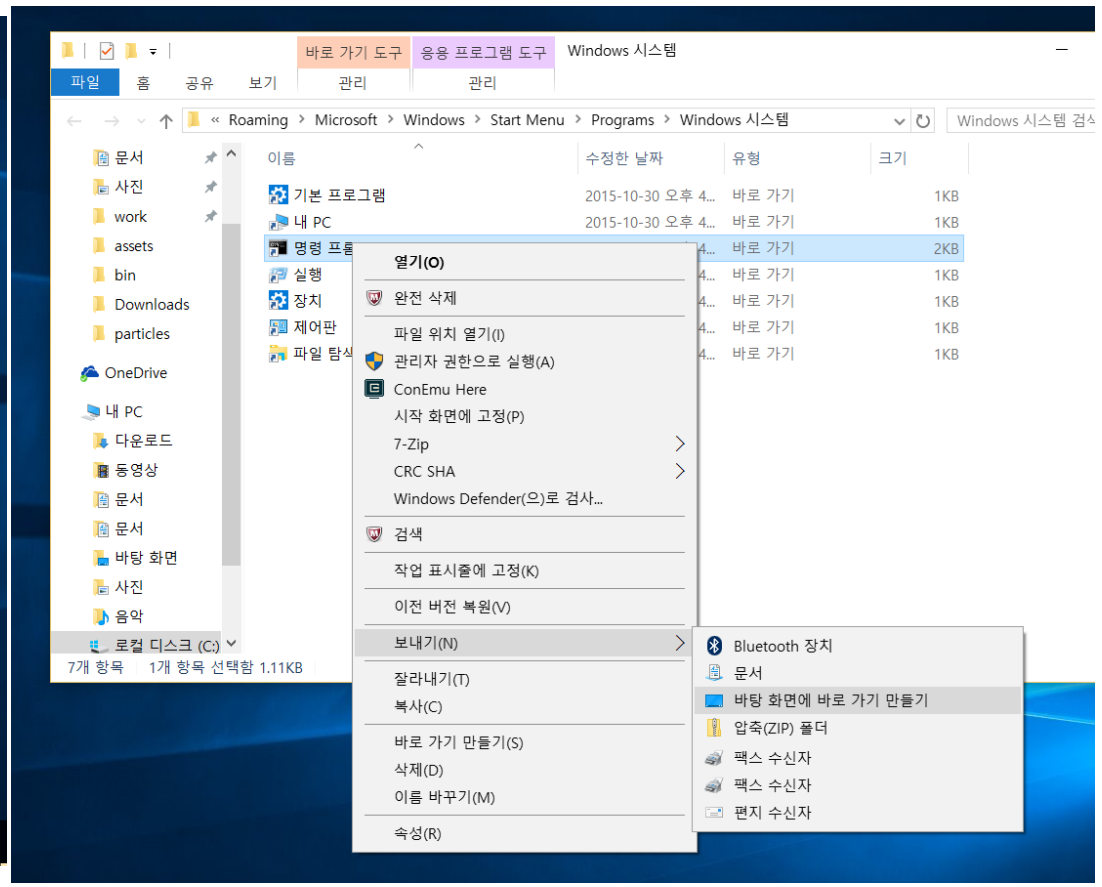
- **Windows** 10

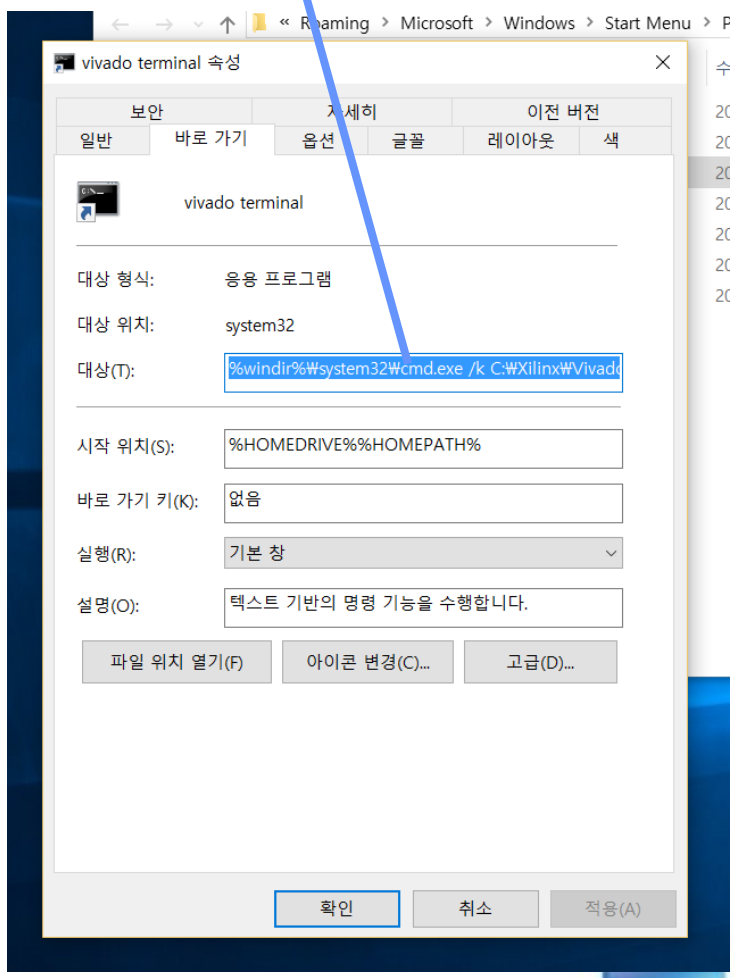
  Install Vivado 2015.4 w/ SDK.

  cmd terminal for Vivado.

  %windir%\system32\cmd.exe /k C:\Xilinx\Vivado\2015.4\settings64.bat

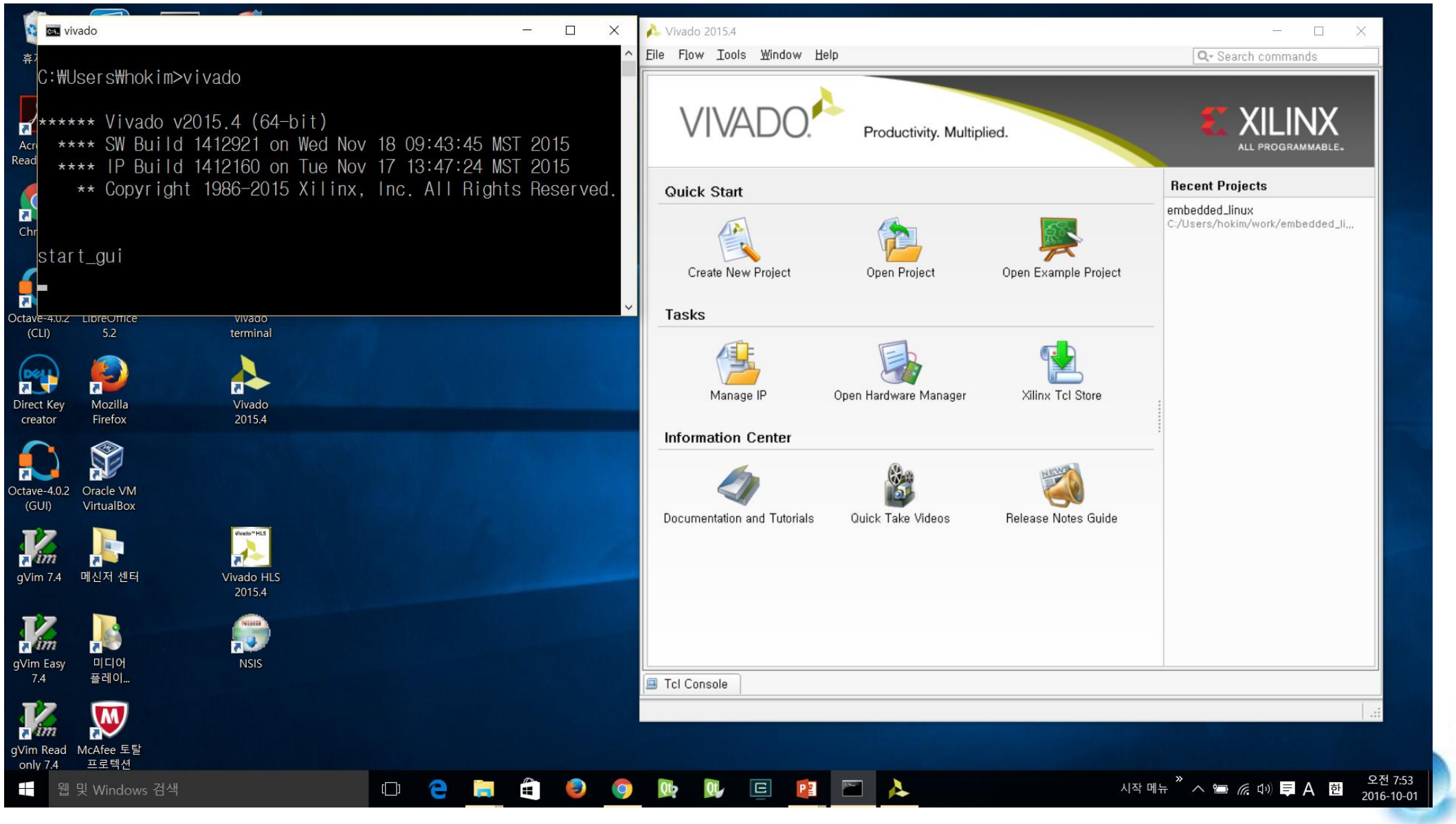






Development Environment Set-up

- **cmd terminal** for Vivado.



Development Environment Set-up

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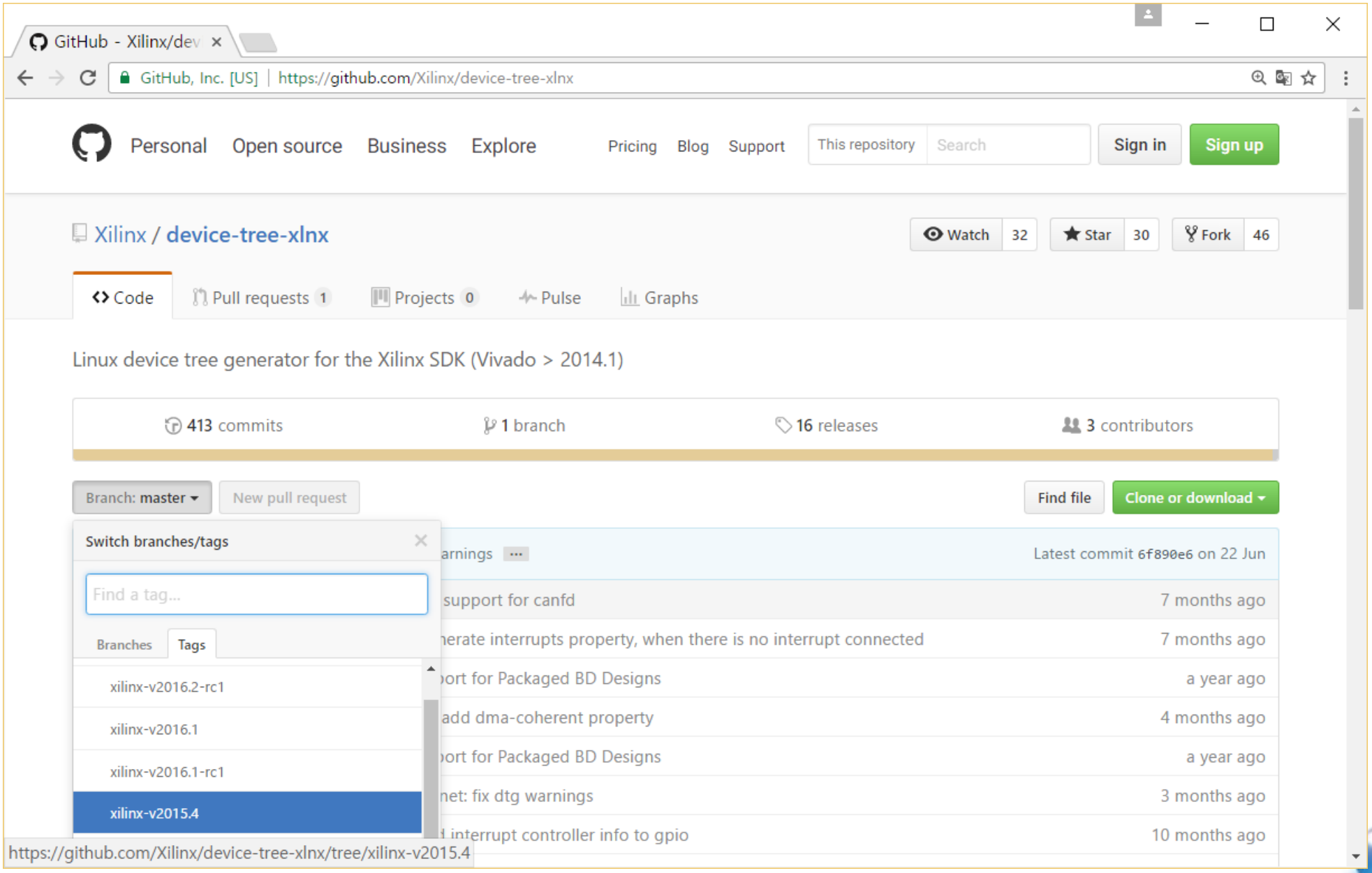
- **Device Tree Source**



Development Environment Set-up

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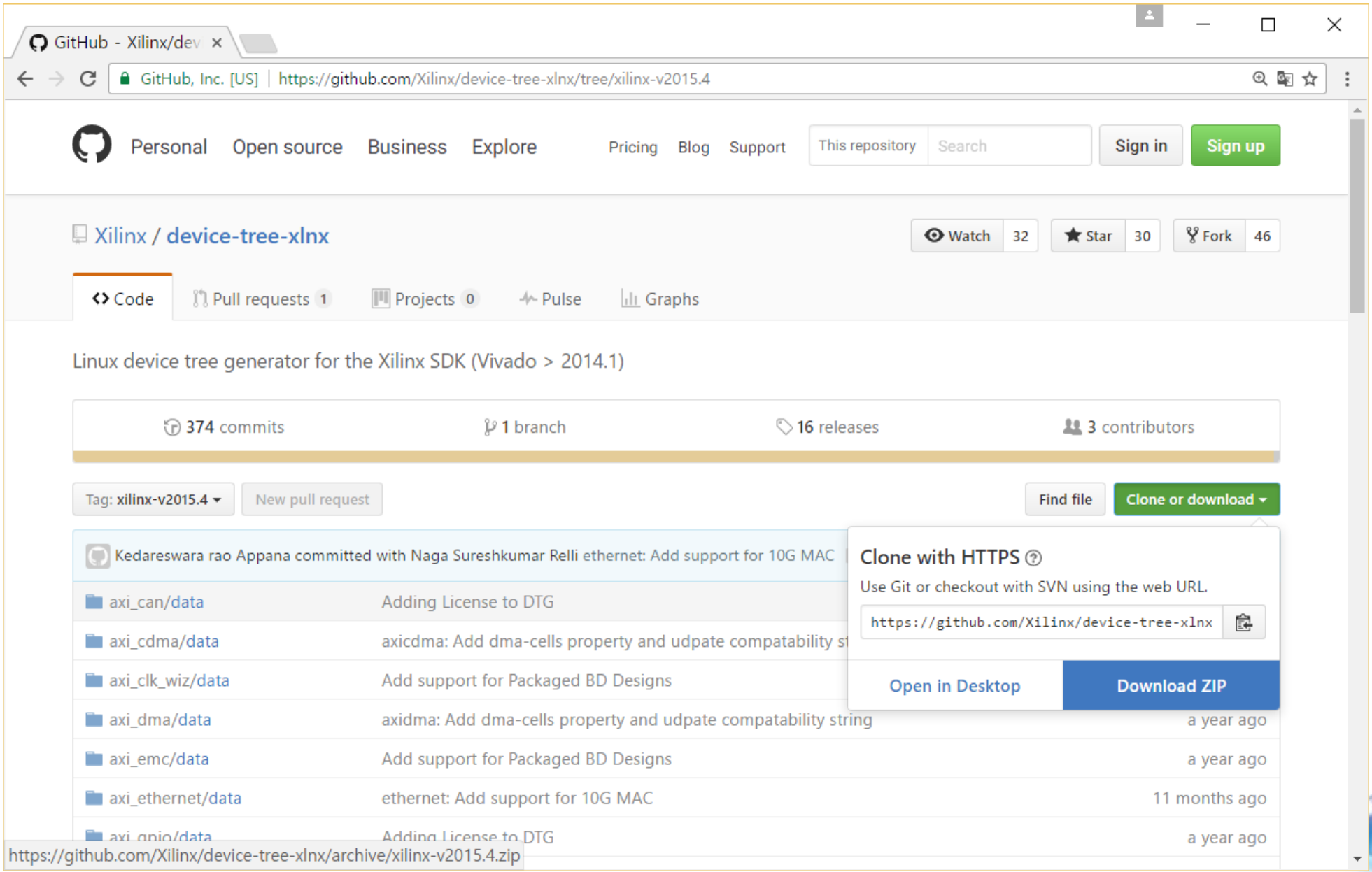

Development Environment Set-up

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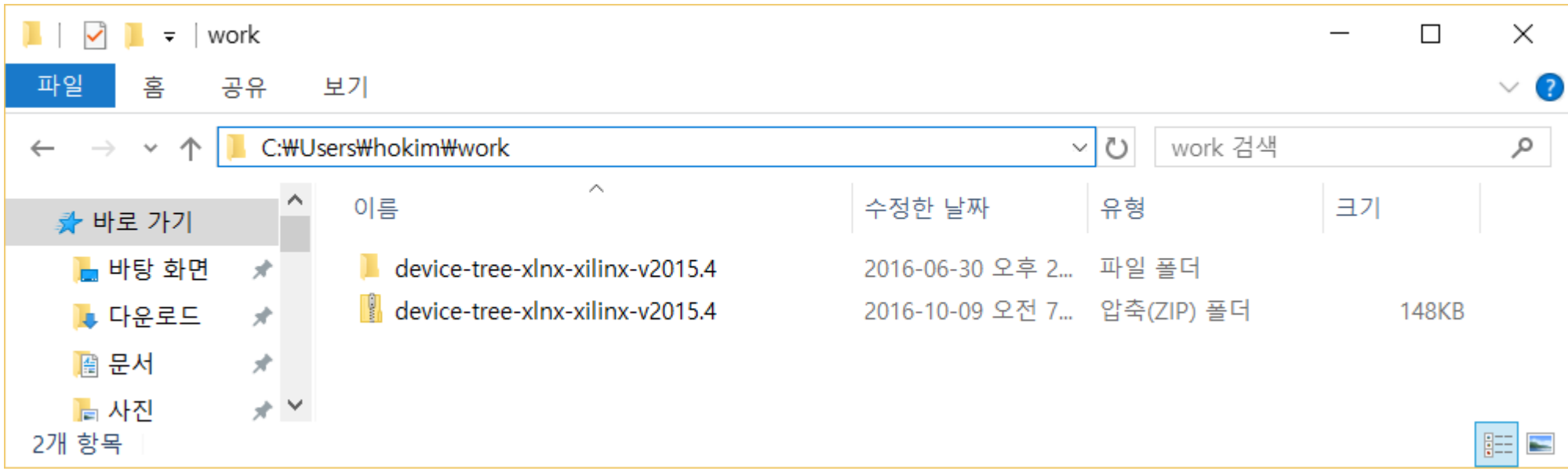

Development Environment Set-up

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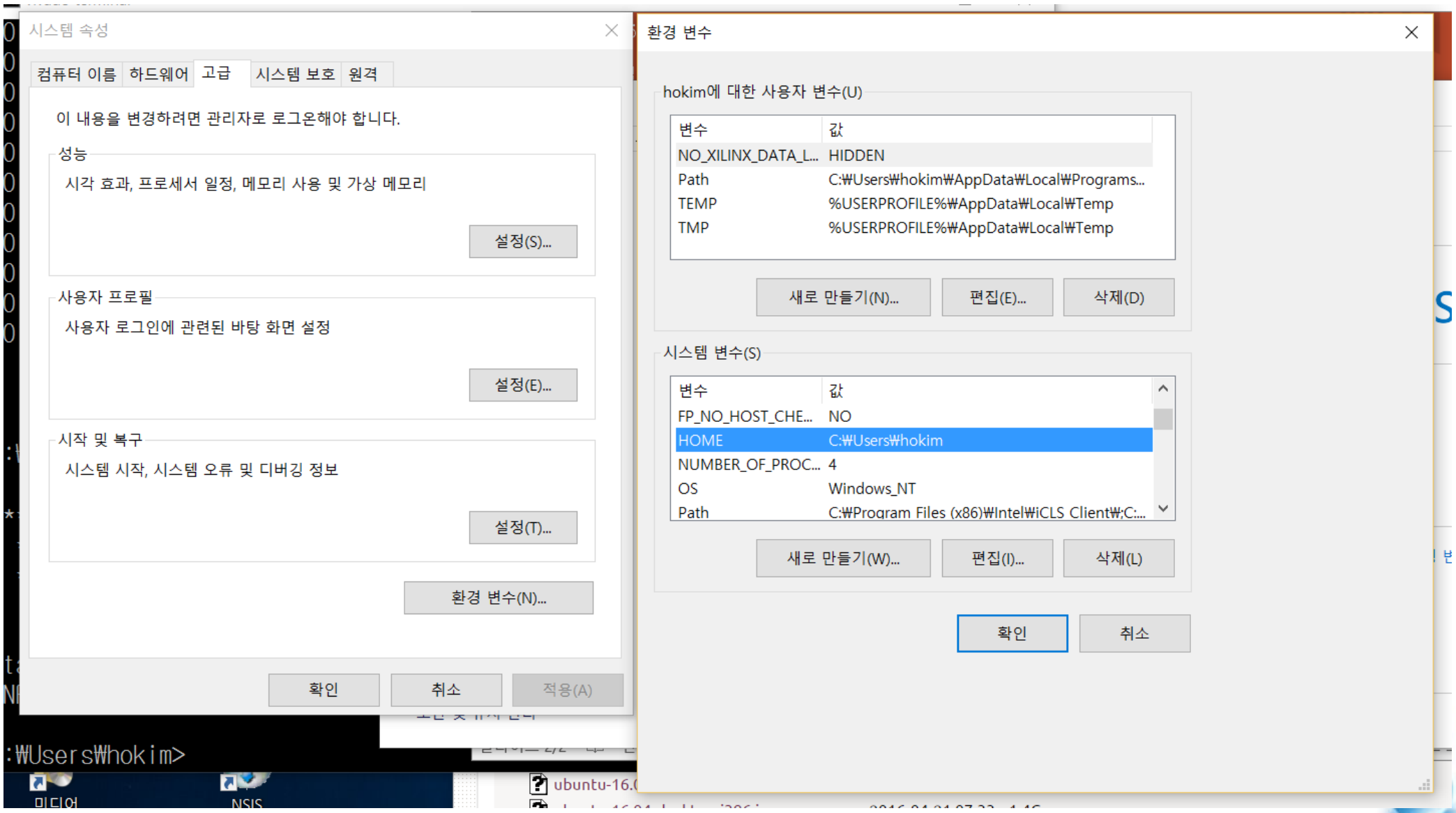
Environment Variable(HOME)



Development Environment Set-up

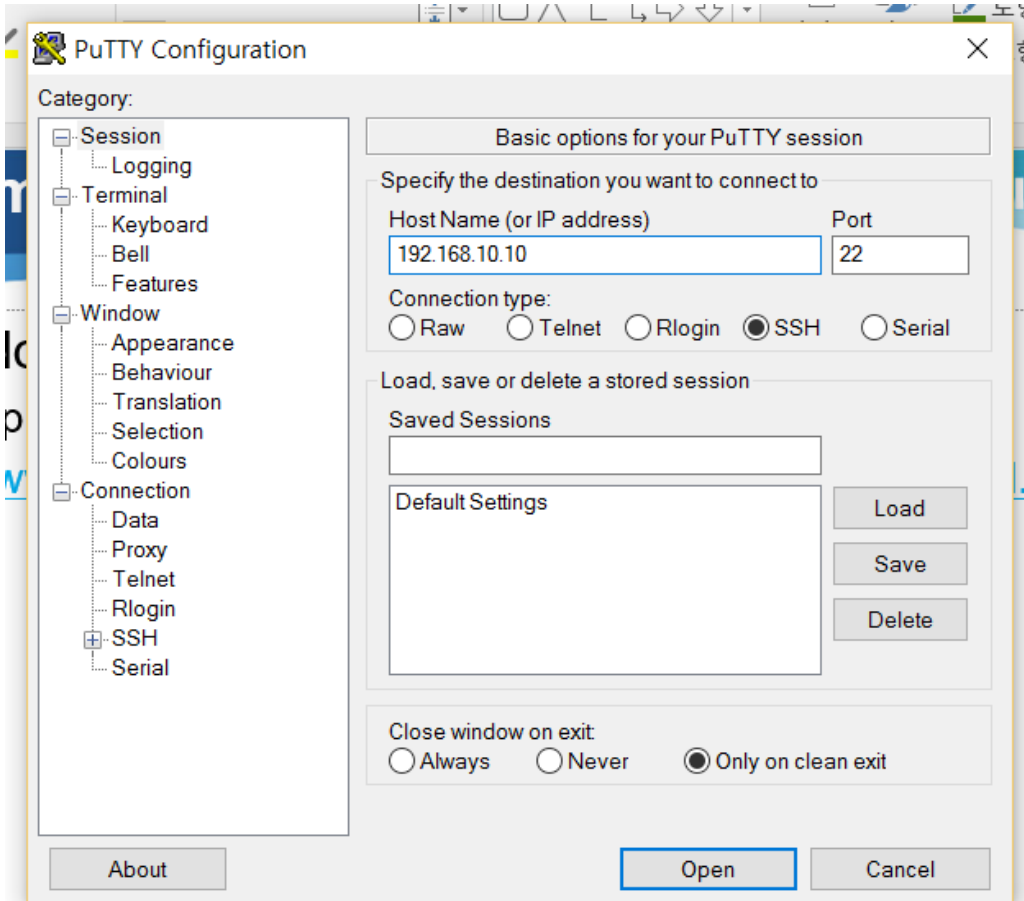
- **Windows ←→ Ubuntu**

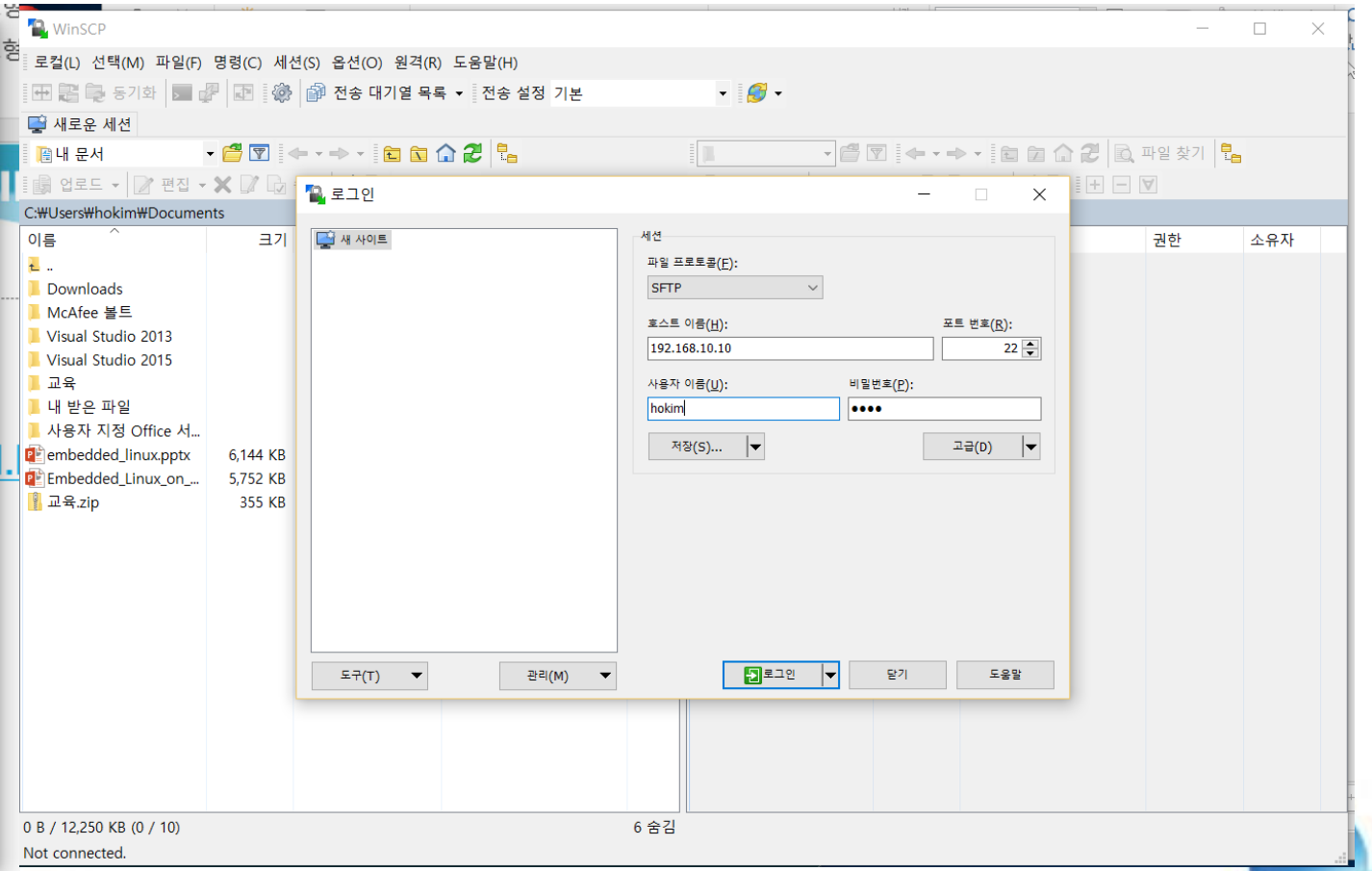
Install putty.exe for remote login shell.

(http://www.chiark.greenend.org.uk/~sgtatham/putty/download.html)

Install WinSCP for file transfer.

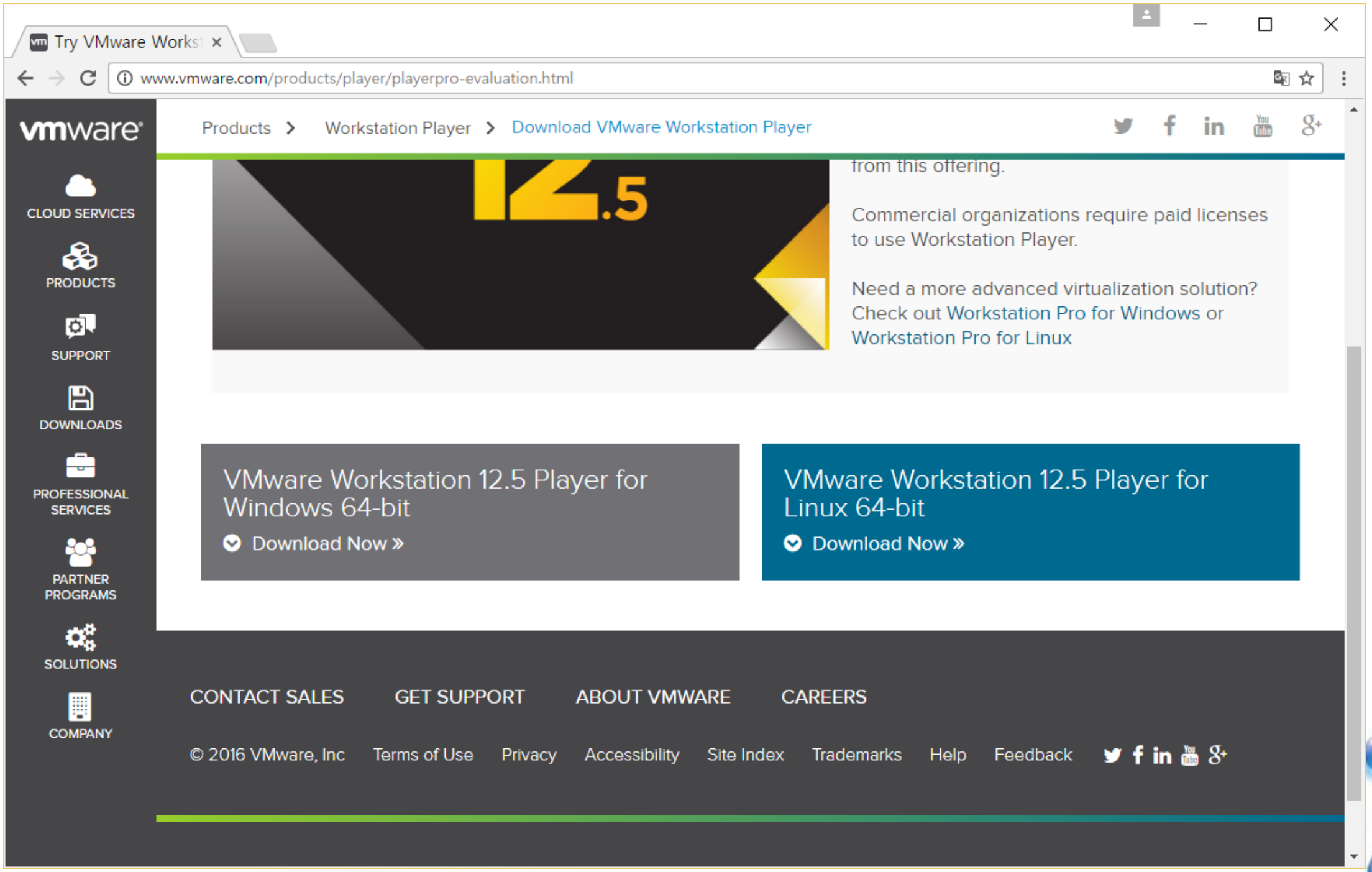
(https://winscp.net/eng/download.php)





Development Environment Set-up

- **Ubuntu on VMware-player**



Development Environment Set-up

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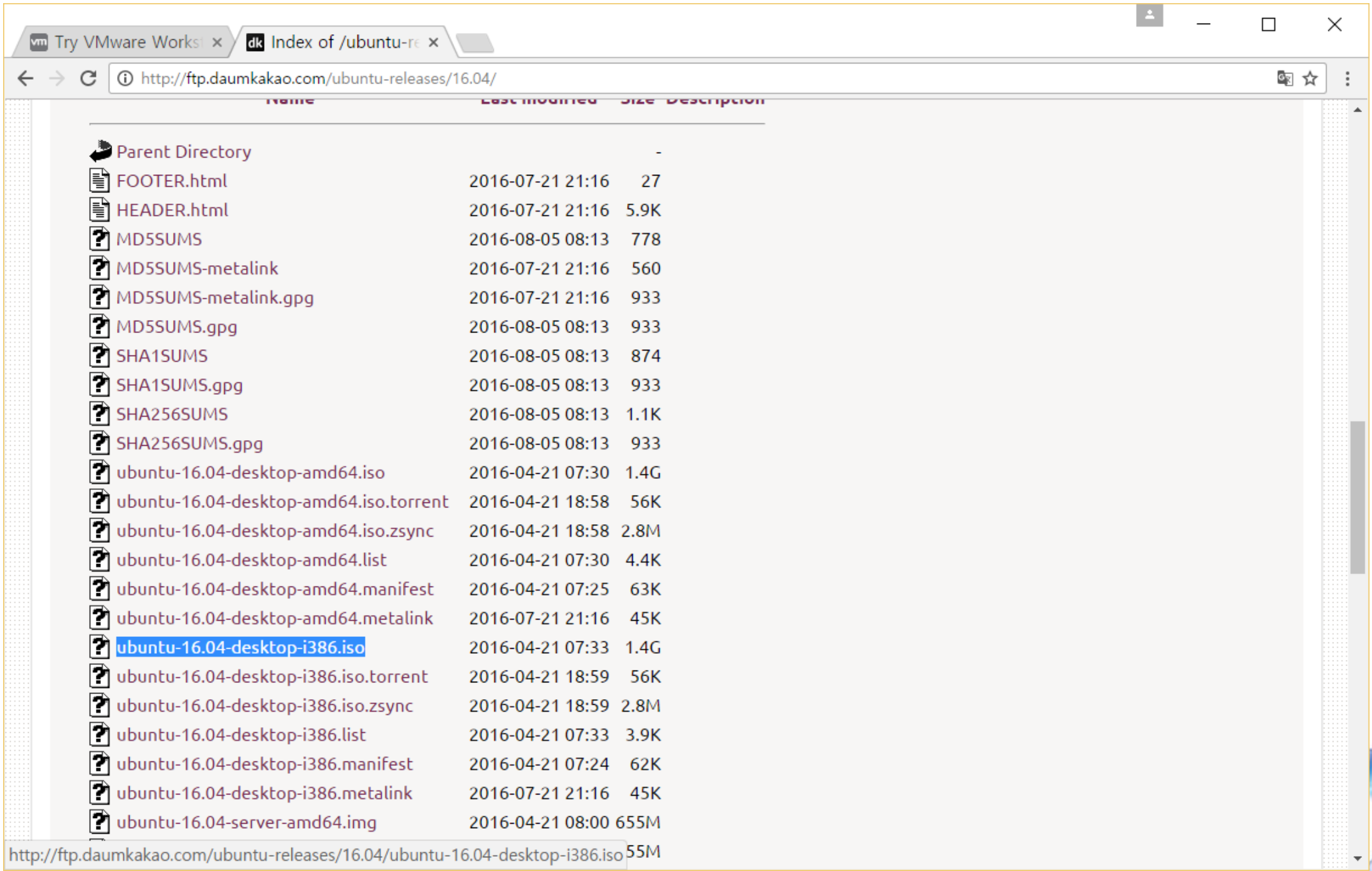

Development Environment Set-up

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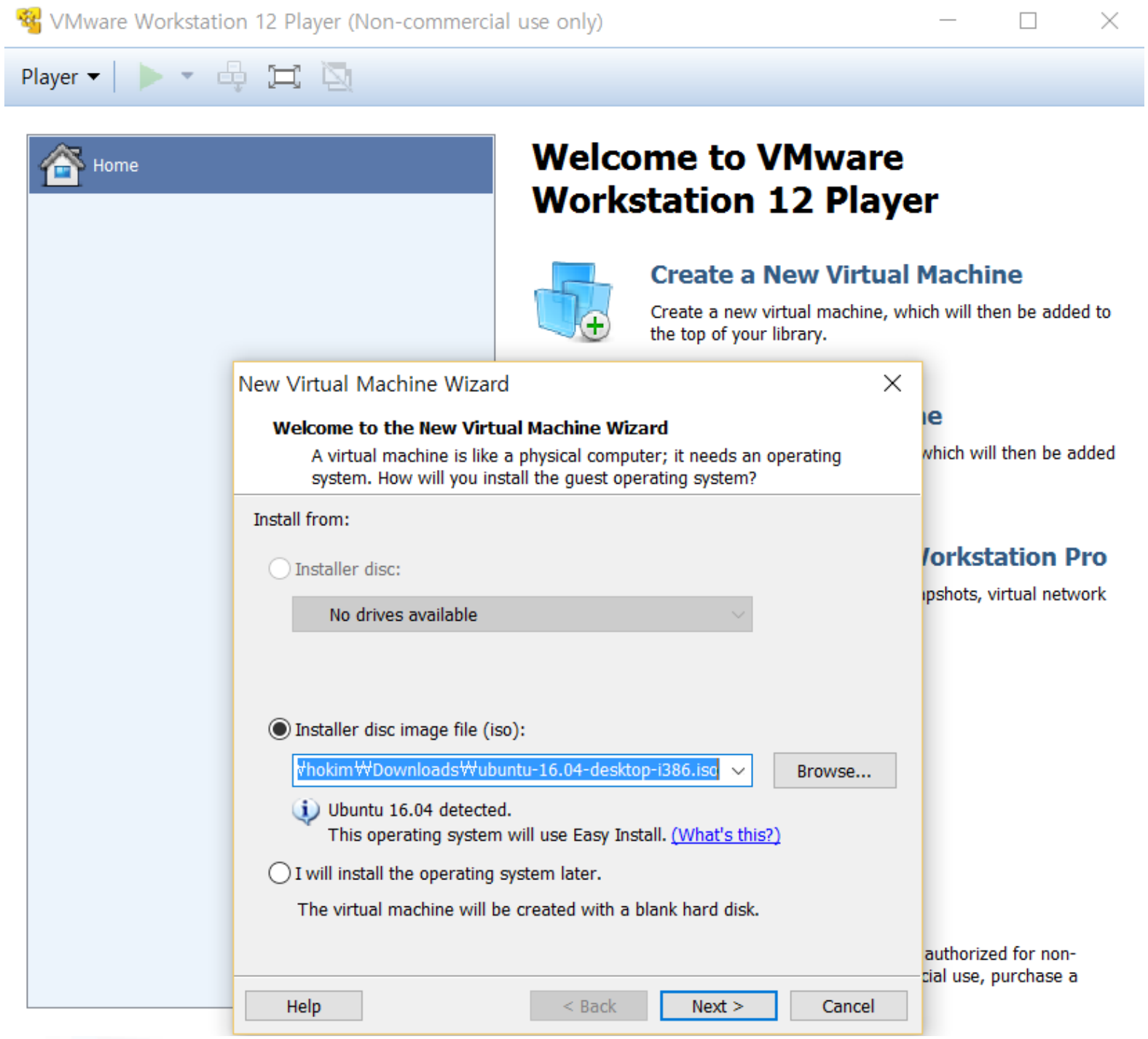

Development Environment Set-up

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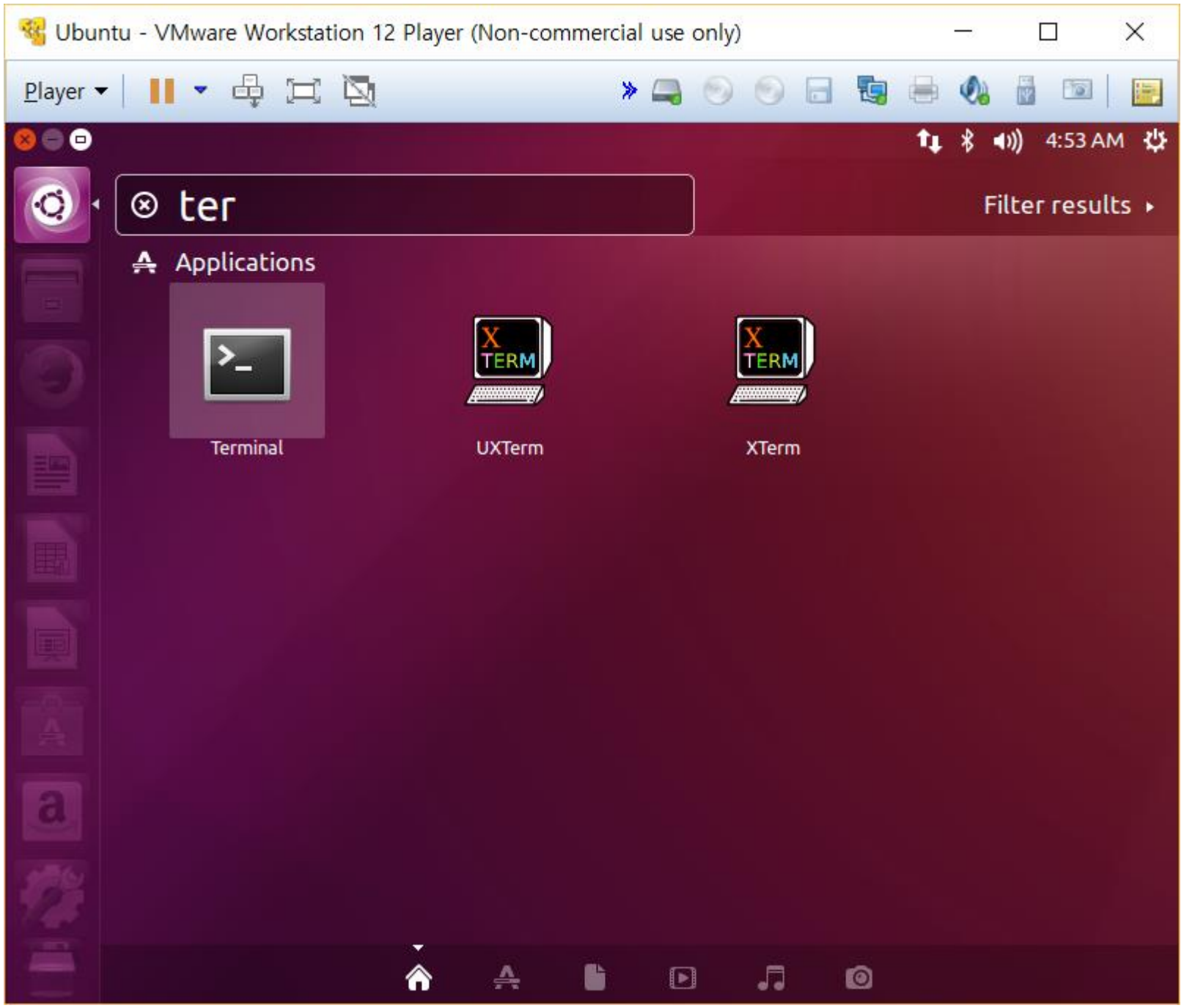
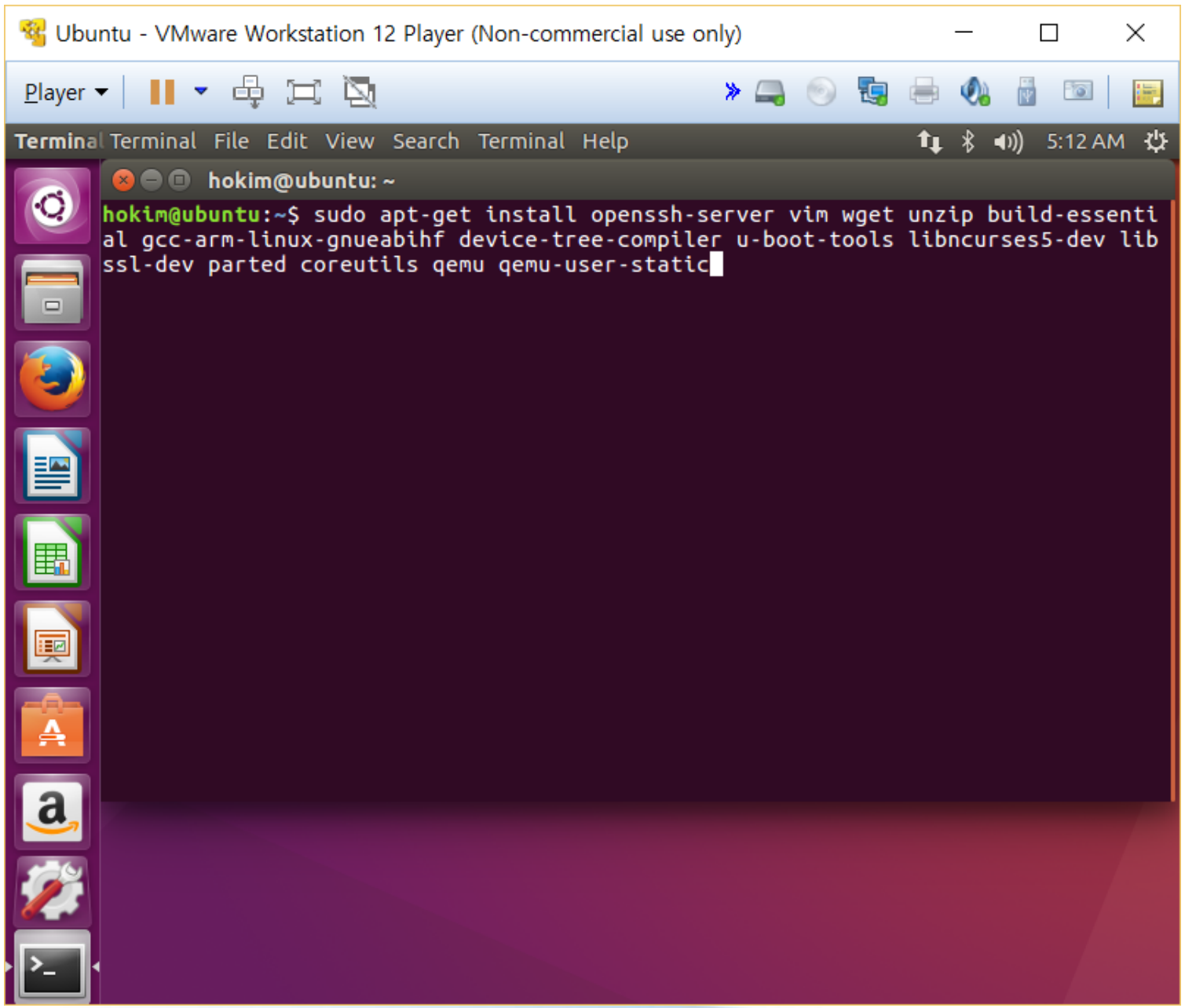


Development Environment Set-up

Ubuntu on VMware-player

$ sudo apt-get install openssh-server vim wget unzip build-essential gcc-arm-linux-gnueabihf device-tree-compiler u-boot-tools libncurses5-dev libssl-dev parted coreutils qemu qemu-user-static

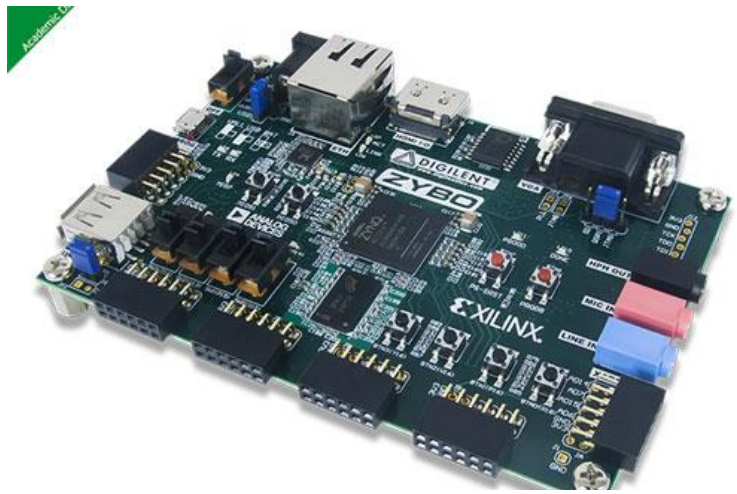


Development Process

- **Target Board** Zybo(Zynq-7010)

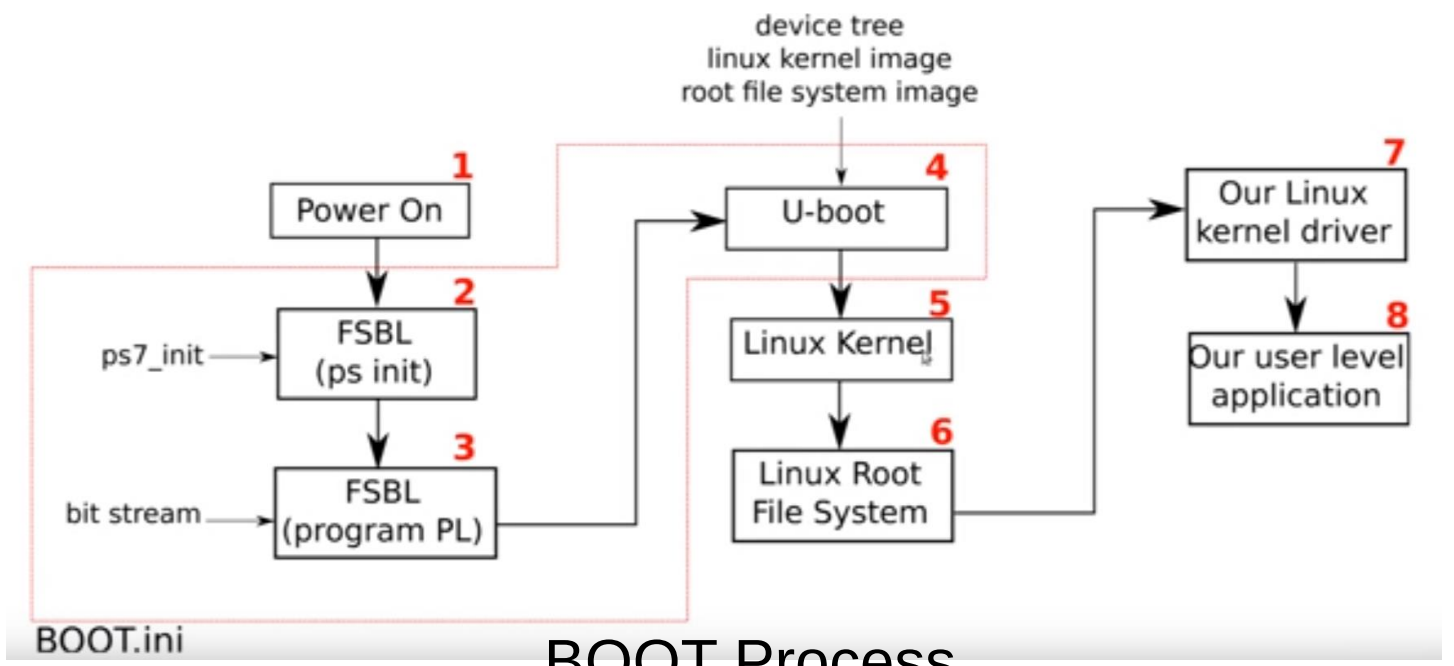
  Gigabit Ethernet, USB, SD, UART

  28,000 logic cells, 240 KB BRAM



- **Development Process**

1. bit stream
2. FSBL
3. DT Generation
4. u-boot
5. DT Compile
6. linux kernel image
7. root file system image
8. BOOT.bin(fsbl + bit + u-boot)
9. Update BOOT.bin / DT / kernel
10. (user kernel driver)/user application

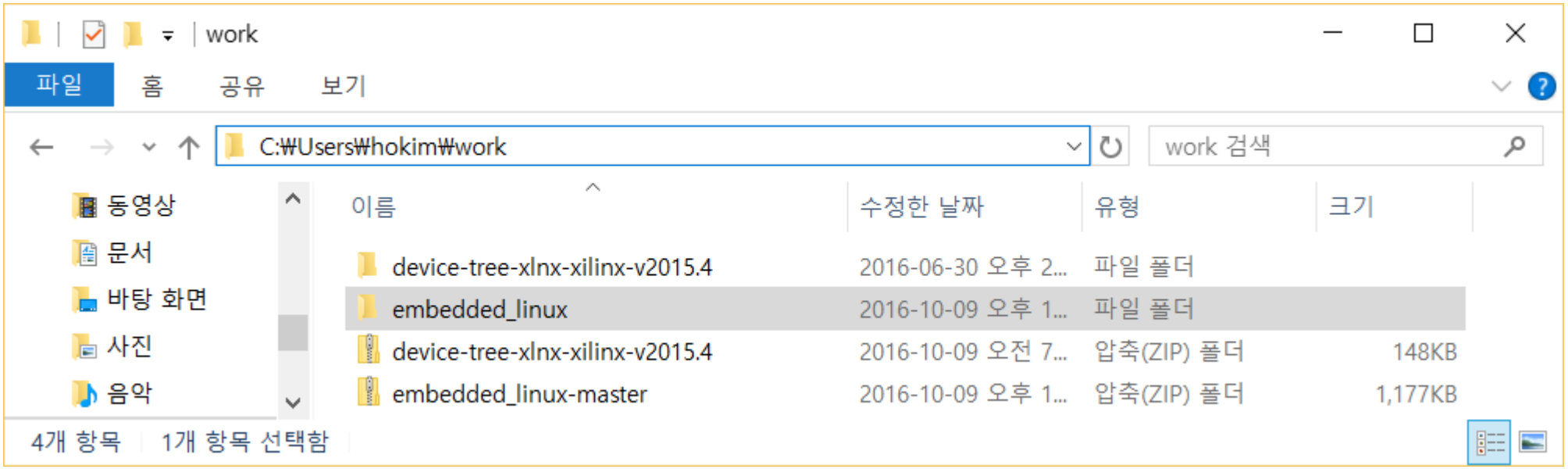


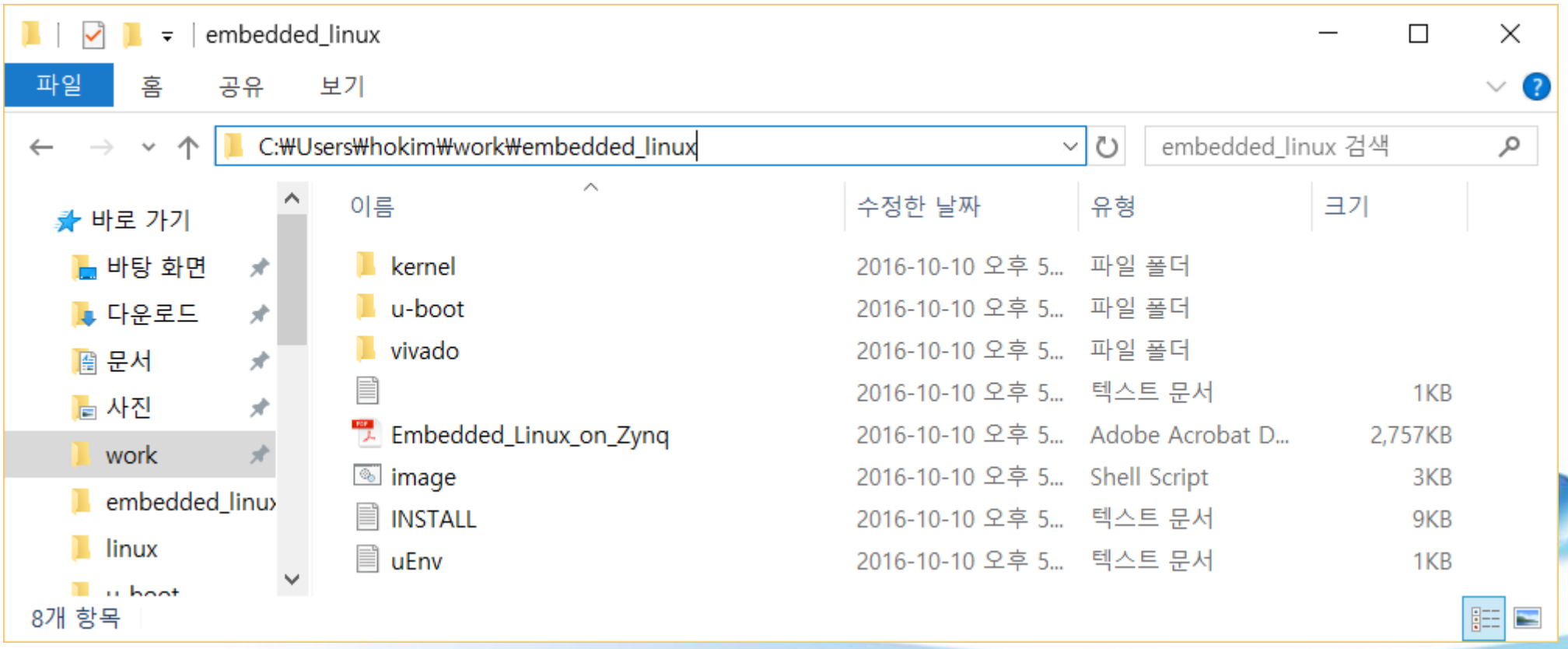
BOOT Process

Development Process

- **Source code**

https://github.com/inipro/embedded_linux





Design of Zynq PS Hardware

- **Vivado Design**

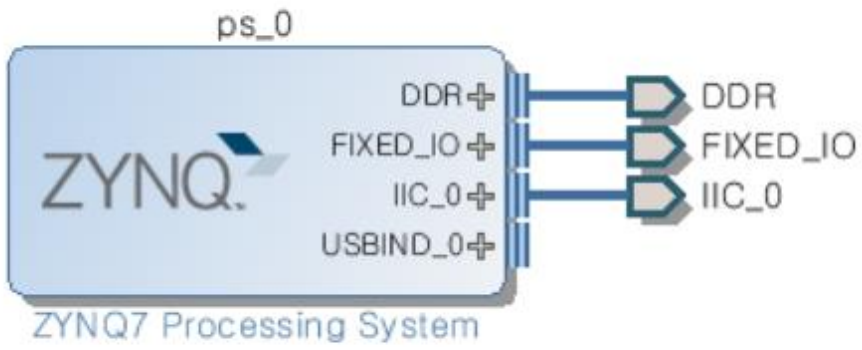
SD0 (boot files, root file system)

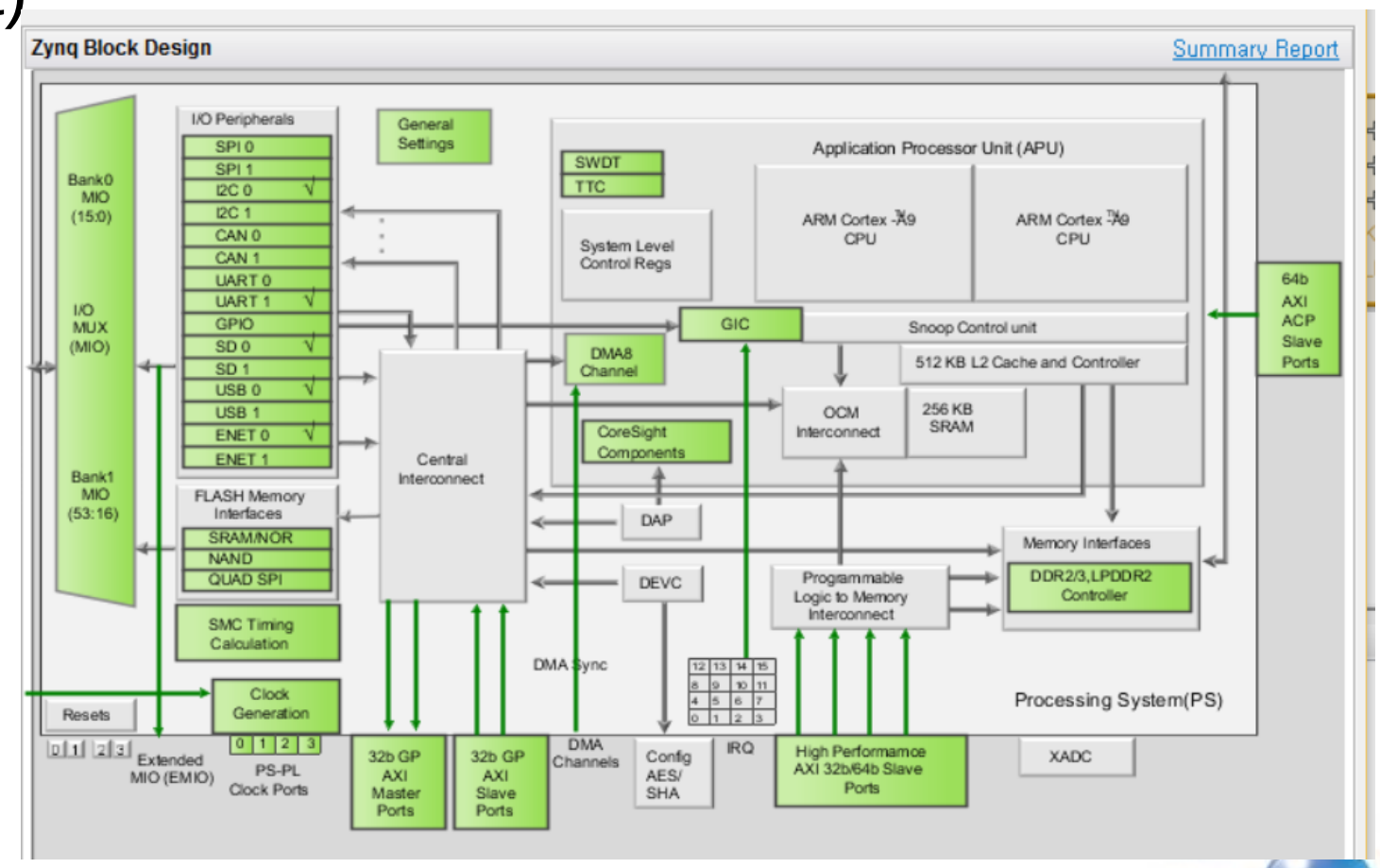
UART1 (console)

I2C0 (eeprom w/ Ethernet mac address; EMIO)

USB0 (usb host)

ENET0 (Gigabit Ethernet)





Vivado Project

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embedded_linux.tcl

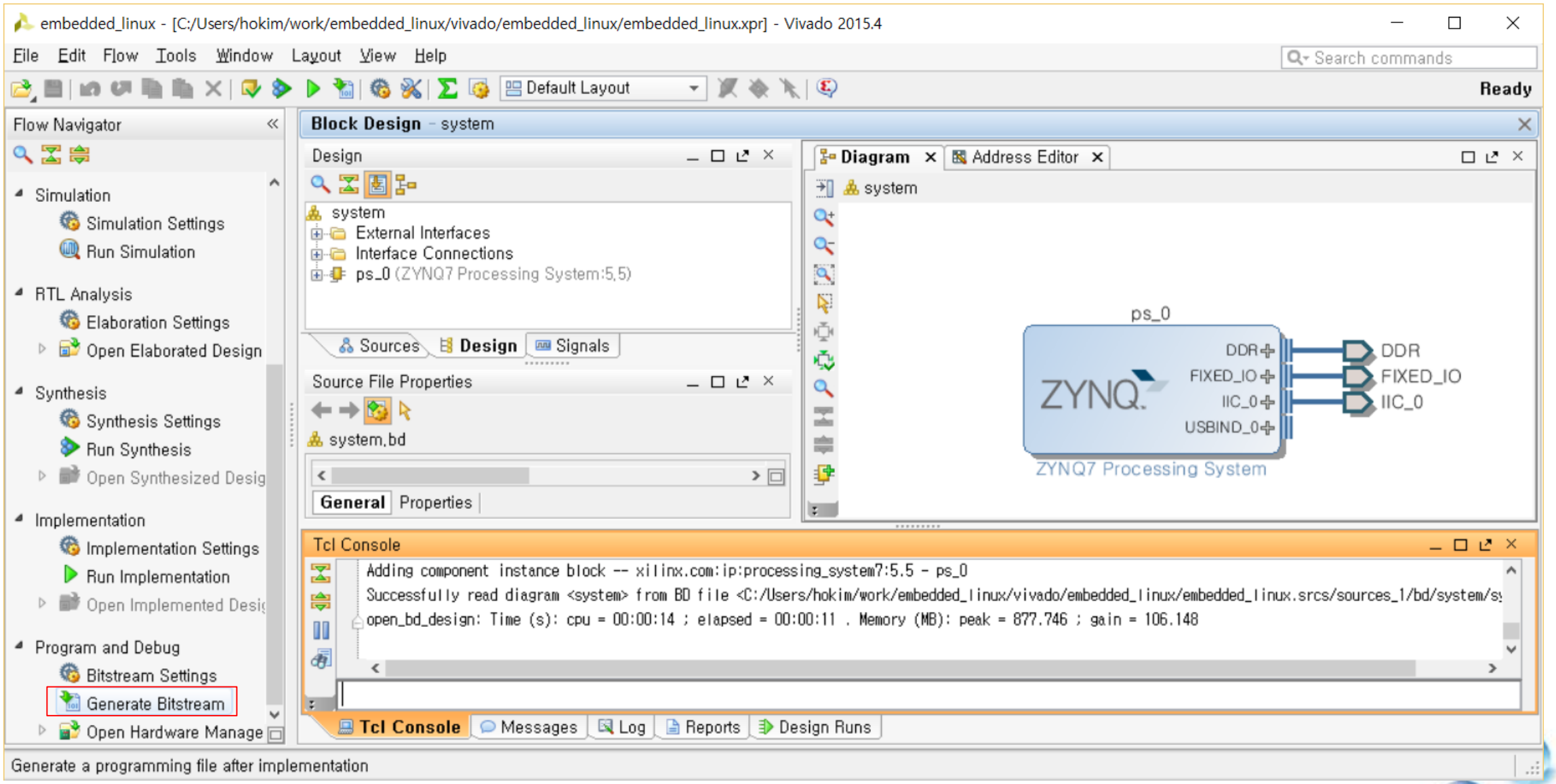
```
set project_name embedded_linux
set part_name xc7z010clg400-1
#set ip_dir ip
set bd_path $project_name/$project_name.srcs/sources_1/bd/system
file delete -force $project_name
create_project -part $part_name $project_name $project_name
#set_property ip_repo_paths $ip_dir [current_project]
#update_ip_catalog
create_bd_design system

create_bd_cell -type ip -vlnv xilinx.com:ip:processing_system7:5.5 ps_0
source embedded_linux_preset.tcl
set_property -dict [apply_preset IPINST] [get_bd_cells ps_0]
apply_bd_automation -rule xilinx.com:bd_rule:processing_system7 -config {
                make_external {FIXED_IO, DDR}
} [get_bd_cells ps_0]
create_bd_intf_port -mode Master -vlnv xilinx.com:interface:iic_rtl:1.0 IIC_0
connect_bd_intf_net [get_bd_intf_pins ps_0/IIC_0] [get_bd_intf_ports IIC_0]

generate_target all [get_files $bd_path/system.bd]
make_wrapper -files [get_files $bd_path/system.bd] -top
add_files -norecurse $bd_path/hdl/system_wrapper.v
add_files -norecurse -fileset constrs_1 zybo.xdc
set_property verilog_define {TOOL_VIVADO} [current_fileset]
close_project
```

In cmd window for Vivado

```
C:\ cd C:\Users\hokim\work\embedded_linux\vivado
C:\ vivado  -nolog -nojournal -mode batch -source embedded_linux.tcl
```

output : embedded_linux\embedded_linux.xpr…

Bit Generation



HDF Generation

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hwdef.tcl

```
# vivado -nolog -nojournal -mode batch -source hwdef.tcl

set project_name embedded_linux

open_project $project_name/$project_name.xpr

if {[get_property PROGRESS [get_runs synth_1]] != "100%"} {
                launch_runs synth_1
                wait_on_run synth_1
}

file delete -force $project_name/$project_name.hwdef

write_hwdef -force -file $project_name/$project_name.hwdef

close_project
```

```
C:\ vivado  -nolog -nojournal -mode batch -source hwdef.tcl
```

output : embedded_linux\embedded_linux.hwdef

FSB Compile

fsbl.tcl

```
# hsi -nolog -nojournal -mode batch -source fsbl.tcl

set project_name embedded_linux

set hard_path $project_name/$project_name.hard
set fsbl_path $project_name/$project_name.fsbl

file delete -force $hard_path $fsbl_path

file mkdir $hard_path
file copy -force $project_name/$project_name.hwdef $hard_path/$project_name.hdf

open_hw_design $hard_path/$project_name.hdf
create_sw_design -proc ps7_cortexa9_0 -os standalone fsbl

add_library xilffs
add_library xilrsa

generate_app -proc ps7_cortexa9_0 -app zynq_fsbl -dir $fsbl_path -compile

close_hw_design [current_hw_design]
```

```
C:\ hsi  -nolog -nojournal -mode batch -source fsbl.tcl
```

output : embedded_linux\embedded_linux.fsbl/executable.elf

DT Generation

INIPRO

devicetree.tcl

```
# hsi -nolog -nojournal -mode batch -source devicetree.tcl

set project_name embedded_linux

set boot_args {console=ttyPS0,115200 root=/dev/mmcblk0p2 ro rootfstype=ext4 earlyprintk rootwait}

set hard_path $project_name/$project_name.hard
set tree_path $project_name/$project_name.tree

file delete -force $hard_path $tree_path

file mkdir $hard_path
file copy -force $project_name/$project_name.hwdef $hard_path/$project_name.hdf

set_repo_path $::env(HOME)/work/device-tree-xlnx-xilinx-v2015.4

open_hw_design $hard_path/$project_name.hdf
create_sw_design -proc ps7_cortexa9_0 -os device_tree devicetree

set_property CONFIG.kernel_version {2015.4} [get_os]
set_property CONFIG.bootargs $boot_args [get_os]

generate_bsp -dir $tree_path

close_sw_design [current_sw_design]
close_hw_design [current_hw_design]
```

C:\ hsi -nolog -nojournal -mode batch -source devicetree.tcl

output : embedded_linux\embedded_linux.tree/*

File Transfer (Windows → Ubuntu)

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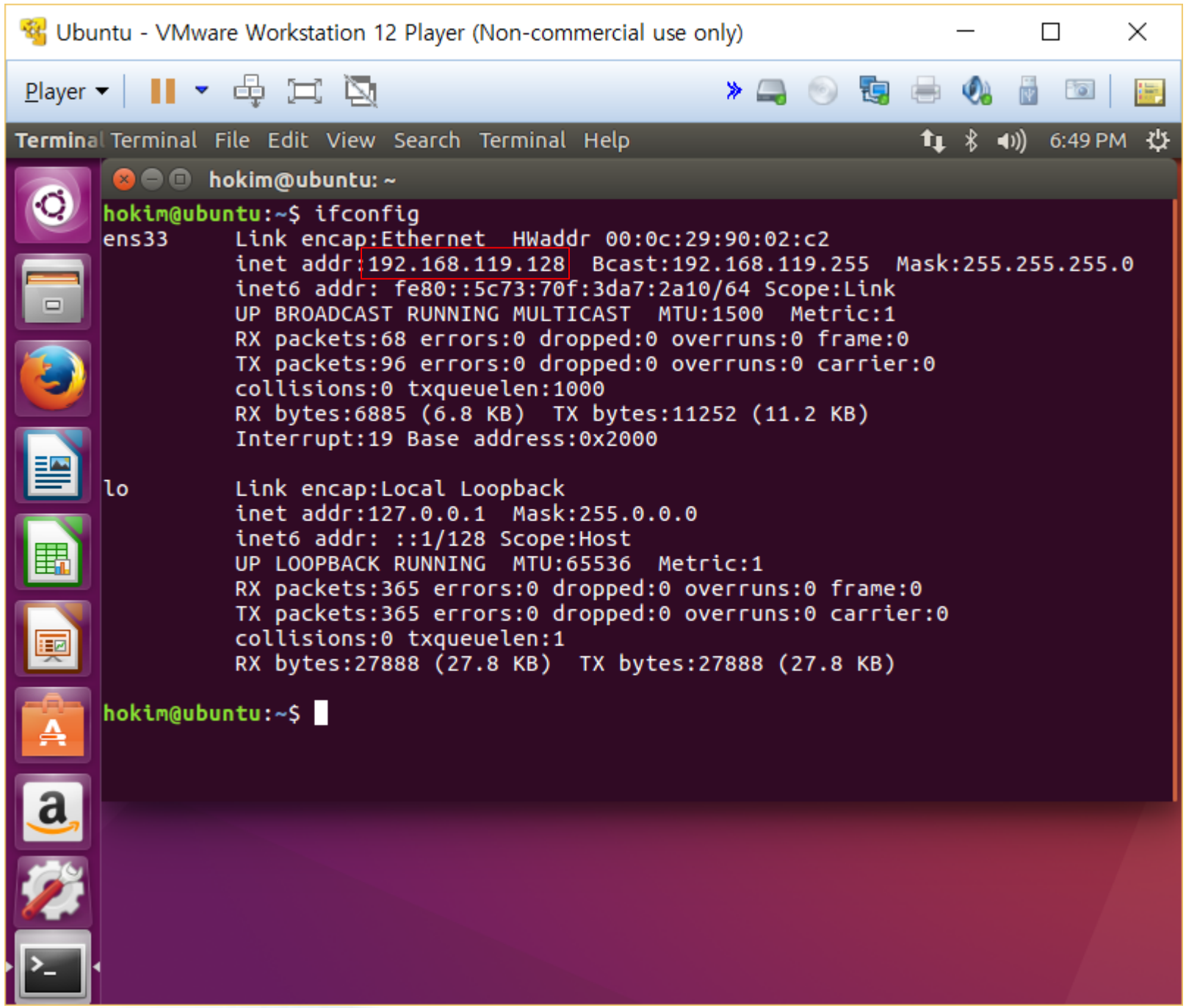
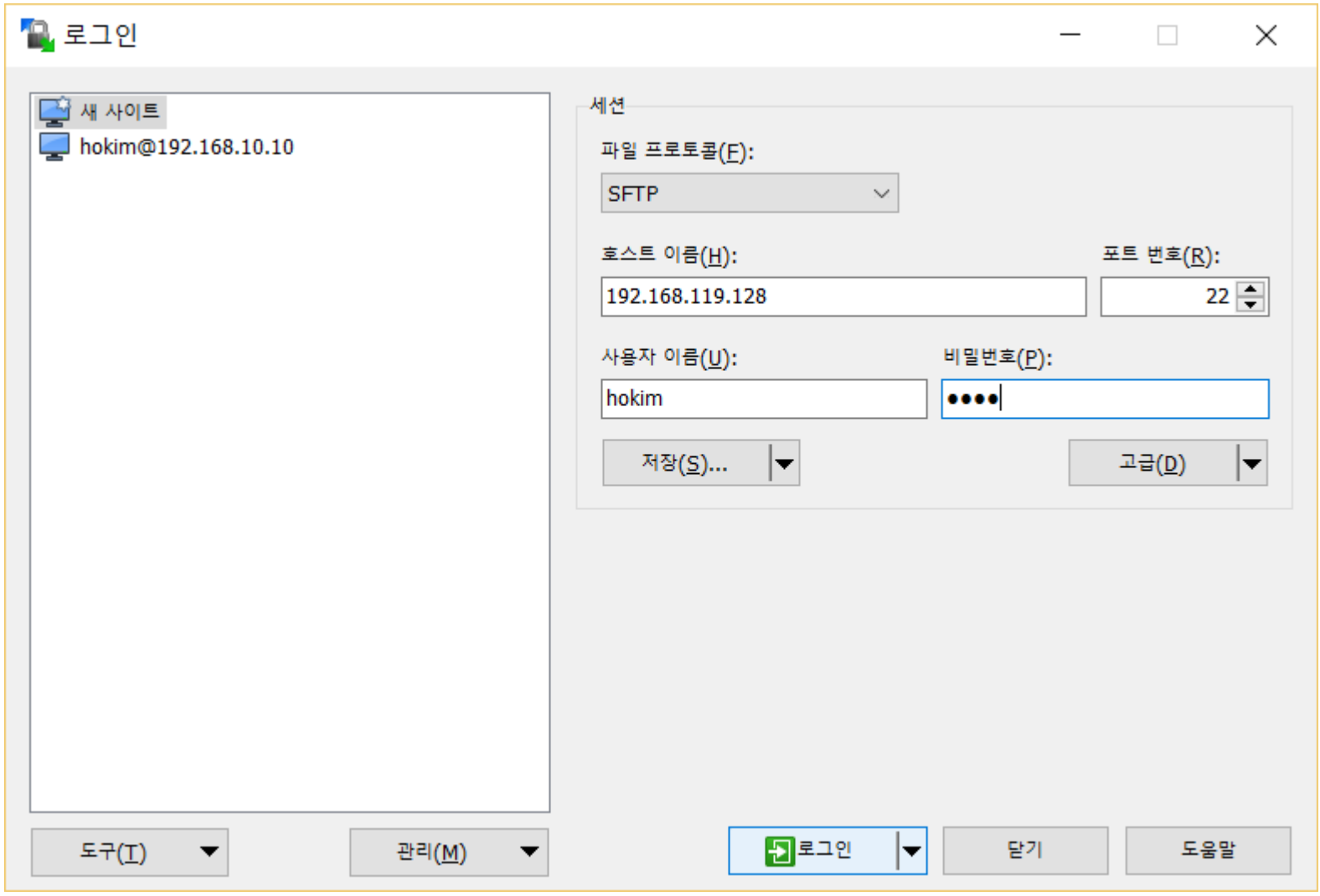
Ubuntu network IP



File Transfer (Windows → Ubuntu)

INIPRO

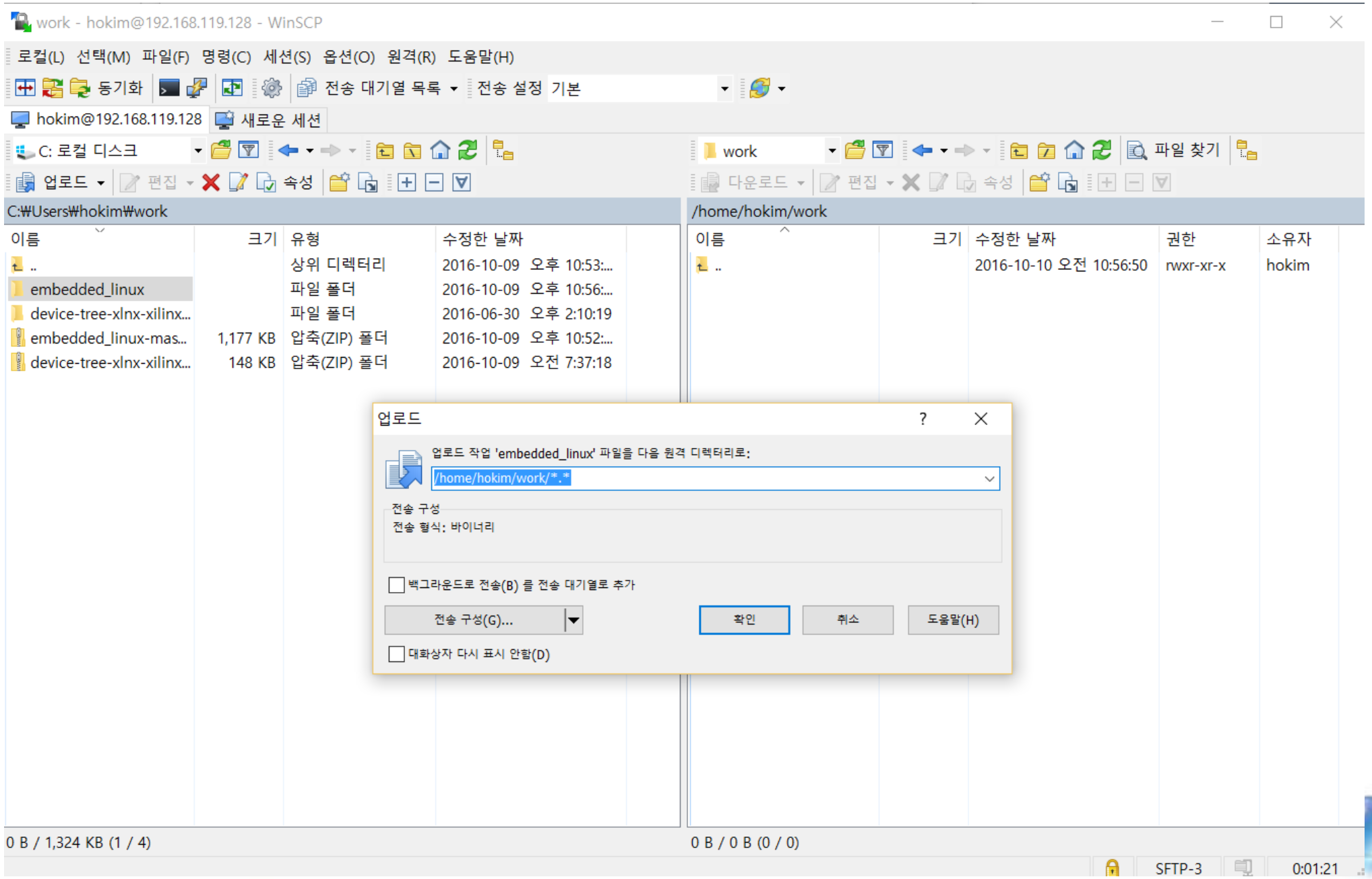
embedded_linux using WinSCP



File Transfer (Windows → Ubuntu)

INIPRO

embedded_linux using WinSCP



- **Boot loader** for linux

  Load linux kernel(uImage, devicetree.dtb) from SD to DRAM.

  Set ethernet using mac address from i2c eeprom.

  Boot uImage.

u-boot Compile

In Terminal of Ubuntu
Can use gedit instead of vi
- : deletion
+ : insert

```
$ cd ~/work/embedded_linux
$ mkdir -p dl
$ wget https://github.com/Xilinx/u-boot-xlnx/archive/xilinx-
v2015.4.tar.gz -O dl/u-boot-xlnx-xilinx-v2015.4.tar.gz
$ cd u-boot
$ tar xvzf ../dl/u-boot-xlnx-xilinx-v2015.4.tar.gz
$ cd u-boot-xlnx-xilinx-v2015.4
$ nano board/xilinx/zynq/board.c
```

u-boot Compile

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board/Xilinx/zynq/board.c

```
 int board_late_init(void)
 {
+   #if defined(CONFIG_ZYNQ_GEM_EEPROM_ADDR) && \
+       defined(CONFIG_ZYNQ_GEM_I2C_MAC_OFFSET)
+           unsigned char enetaddr[6];
+
+           if (eeprom_read(CONFIG_ZYNQ_GEM_EEPROM_ADDR,
+                           CONFIG_ZYNQ_GEM_I2C_MAC_OFFSET,
+                           enetaddr, ARRAY_SIZE(enetaddr)))
+                   printf("I2C EEPROM MAC address read failed\n");
+           else
+                   eth_setenv_enetaddr("ethaddr", enetaddr);
+   #endif
+
    switch ((zynq_slcr_get_boot_mode()) & ZYNQ_BM_MASK) {
    case ZYNQ_BM_QSPI:
```

```
$ nano common/main.c
```

common/main.c

```
 if (cli_process_fdt(&s))
        cli_secure_boot_cmd(s);

+               setenv("fdt_high", "0x1E000000");
+               setenv("sdboot", "echo Importing environment from SD... && mmcinfo && fatload mmc 0 0x2000000 uEnv.txt &&
env import -t 0x2000000 ${filesize} && boot");

    autoboot_command(s);
```

u-boot Compile

```
$ cp ../zynq-zyboc.dts arch/arm/dts
$ cp ../zynq_zyboc.h include/configs
$ cp ../zynq_zyboc_defconfig configs
```

arch/arm/dts/zynq-zyboc.dts

```
/dts-v1/;
#include "zynq-7000.dtsi"

/ {
        model = "Zynq ZYBOC Development Board";
        compatible = "inipro,zynq-zyboc", "xlnx,zynq-7000";

        aliases {
                ethernet0 = &gem0;
                serial0 = &uart1;
        };

        memory {
                device_type = "memory";
                reg = <0x0 0x20000000>;
        };

        chosen {
                bootargs = "earlyprintk";
                linux,stdout-path = &uart1;
                stdout-path = &uart1;
        };

};
```

```
&clkc {
        ps-clk-frequency = <50000000>;
};

&gem0 {
        status = "okay";
        phy-mode = "rgmii-id";
        phy-handle = <&ethernet_phy>;

        ethernet_phy: ethernet-phy@0 {
                reg = <0>;
        };
};

&sdhci0 {
        status = "okay";
};

&uart1 {
        status = "okay";
};
```

u-boot Compile

include/configs/zynq_zyboc.h

```
#ifndef __CONFIG_ZYNQ_ZYBOC_H
#define __CONFIG_ZYNQ_ZYBOC_H

#define CONFIG_SYS_SDRAM_SIZE (512 * 1024 * 1024)

#define CONFIG_ZYNQ_SERIAL_UART1
#define CONFIG_ZYNQ_GEM0
#define CONFIG_ZYNQ_GEM_PHY_ADDR0  0

#define CONFIG_SYS_NO_FLASH

#define CONFIG_ZYNQ_SDHCI0
#define CONFIG_ZYNQ_I2C0
#define CONFIG_SYS_I2C_EEPROM_ADDR_LEN 1
#define CONFIG_CMD_EEPROM
#define CONFIG_ZYNQ_GEM_EEPROM_ADDR    0x50
#define CONFIG_ZYNQ_GEM_I2C_MAC_OFFSET 0xFA
#define CONFIG_ZYNQ_BOOT_FREEBSD

/* Define ZYBO PS Clock Frequency to 50MHz */
#define CONFIG_ZYNQ_PS_CLK_FREQ       50000000UL

#include <configs/zynq-common.h>

#endif /* __CONFIG_ZYNQ_ZYBOC_H */
```

u-boot Compile

include/configs/zynq_zyboc.h

```
CONFIG_ARM=y
CONFIG_ARCH_ZYNQ=y
CONFIG_TARGET_ZYNQ_ZYBOC=y
CONFIG_DEFAULT_DEVICE_TREE="zynq-zyboc"
# CONFIG_SYS_MALLOC_F is not set
CONFIG_SPL=y
CONFIG_FIT=y
CONFIG_FIT_VERBOSE=y
CONFIG_FIT_SIGNATURE=y
# CONFIG_CMD_IMLS is not set
# CONFIG_CMD_FLASH is not set
# CONFIG_CMD_SETEXPR is not set
CONFIG_OF_EMBED=y
```

```
$ nano arch/arm/dts/Makefile
```

```
dtb-$(CONFIG_ARCH_ZYNQ) += zynq-zc702.dtb \
    zynq-zc706.dtb \
    zynq-zed.dtb \
    zynq-zybo.dtb \
    zynq-microzed.dtb \
    zynq-cc108.dtb \
    zynq-afx-nand.dtb \
    zynq-afx-nor.dtb \
    zynq-afx-qspi.dtb \
    zynq-cse-nand.dtb \
    zynq-cse-nor.dtb \
    zynq-cse-qspi.dtb \
    zynq-picozed.dtb \
    zynq-zc770-xm010.dtb \
    zynq-zc770-xm011.dtb \
    zynq-zc770-xm012.dtb \
-   zynq-zc770-xm013.dtb
+    zynq-zc770-xm013.dtb \
+    zynq-zyboc.dtb
```

u-boot Compile

INIPRO

$ nano arch/arm/mach-zynq/Kconfig

```
config TARGET_ZYNQ_ZYBO
    bool "Zynq Zybo Board"
    select ZYNQ_CUSTOM_INIT

config TARGET_ZYNQ_AFX
    bool "Zynq AFX Board"
    select ZYNQ_CUSTOM_INIT

config TARGET_ZYNQ_CSE
    bool "Zynq CSE Board"
    select ZYNQ_CUSTOM_INIT

config TARGET_ZYNQ_CC108
    bool "Zynq CC108 Board"
    select ZYNQ_CUSTOM_INIT

+config TARGET_ZYNQ_ZYBOC
+    bool "Zynq Zyboc Board"
+    select ZYNQ_CUSTOM_INIT
.....
.....
config SYS_CONFIG_NAME
    default "zynq_zed" if TARGET_ZYNQ_ZED
    default "zynq_microzed" if TARGET_ZYNQ_MICROZED
    default "zynq_picozed" if TARGET_ZYNQ_PICOZED
    default "zynq_zc70x" if TARGET_ZYNQ_ZC702 || TARGET_ZYNQ_ZC706 \
                || TARGET_ZYNQ_ZC70X
    default "zynq_zc770" if TARGET_ZYNQ_ZC770
    default "zynq_zybo" if TARGET_ZYNQ_ZYBO
    default "zynq_cse" if TARGET_ZYNQ_CSE
    default "zynq_afx" if TARGET_ZYNQ_AFX
    default "zynq_cc108" if TARGET_ZYNQ_CC108
+   default "zynq_zyboc" if TARGET_ZYNQ_ZYBOC

endif
```

u-boot Compile

```
$ make arch=ARM zynq_zyboc_defconfig
$ make arch=ARM CROSS_COMPILE=arm-linux-gnueabihf- CFLAGS="-O2
-mtune=cortex-a9 -mfpu=neon -mfloat-abi=hard" all
$ cp u-boot ~/work/embedded_linux/vivado/u-boot.elf
```

- **Kernel driver** for platform devices

  = Kernel source code + Device Tree

  Hierarchy of Devices

  Provide register address, irq number, so on as property of device.

- **Platform device**

  Instead of being dynamically detected, must be statically described in either:

  Kernel source code or Device Tree

  The devices on I2C buses or SPI buses, or the devices directly part of the system-on-chip.

Device Tree Compile

```
$ cd ~/work/embedded_linux
$ cp vivado/embedded_linux/embedded_linux.tree/system.dts .
$ nano system.dts
```

system.dts

```
&clkc {
    fclk-enable = <0x0>;
    ps-clk-frequency = <50000000>;
};

+&gem0 {
+    phy-handle = <&phy0>;
+    ps7_ethernet_0_mdio: mdio {
+        #address-cells = <0x1>;
+        #size-cells = <0x0>;
+        phy0: phy@0 {
+            compatible = "realtek,RTL8211E";
+            device_type = "ethernet-phy";
+            reg = <0>;
+        };
+    };
+};
```

```
+&i2c0 {
+    eeprom@50 {
+        /* Microchip 24AA02E48 */
+        compatible = "microchip,24c02";
+        reg = <0x50>;
+        pagesize = <8>;
+    };
+};
+/ {
+    usb_phy0: phy0 {
+        compatible = "ulpi-phy";
+        #phy-cells = <0>;
+        reg = <0xe0002000 0x1000>;
+        view-port = <0x0170>;
+        drv-vbus;
+    };
+};
+&usb0 {
+    usb-phy = <&usb_phy0>;
+};
```

```
$ dtc -O dtb -I dts -i vivado/embedded_linux/embedded_linux.tree/ -o devicetree.dtb system.dts
```

Linux Kernel Compile

```
$ cd ~/work/embedded_linux
$ wget https://github.com/Xilinx/linux-xlnx/archive/xilinx-v2015.4.01.tar.gz -O
dl/linux-xlnx-xilinx-v2015.4.01.tar.gz
$ cd kernel
$ tar xvzf ../dl/linux-xlnx-xilinx-v2015.4.01.tar.gz
$ cd linux-xlnx-xilinx-v2015.4.01
$ cp -r ../drivers/rtl8192cu drivers/net/wireless/
$ nano drivers/net/wireless/Kconfig
```

drivers/net/wireless/Kconfig

```
source "drivers/net/wireless/mwifiex/Kconfig"
source "drivers/net/wireless/cw1200/Kconfig"
source "drivers/net/wireless/rsi/Kconfig"
+source "drivers/net/wireless/rtl8192cu/Kconfig"

endif # WLAN
```

```
$ nano drivers/net/wireless/Makefile
```

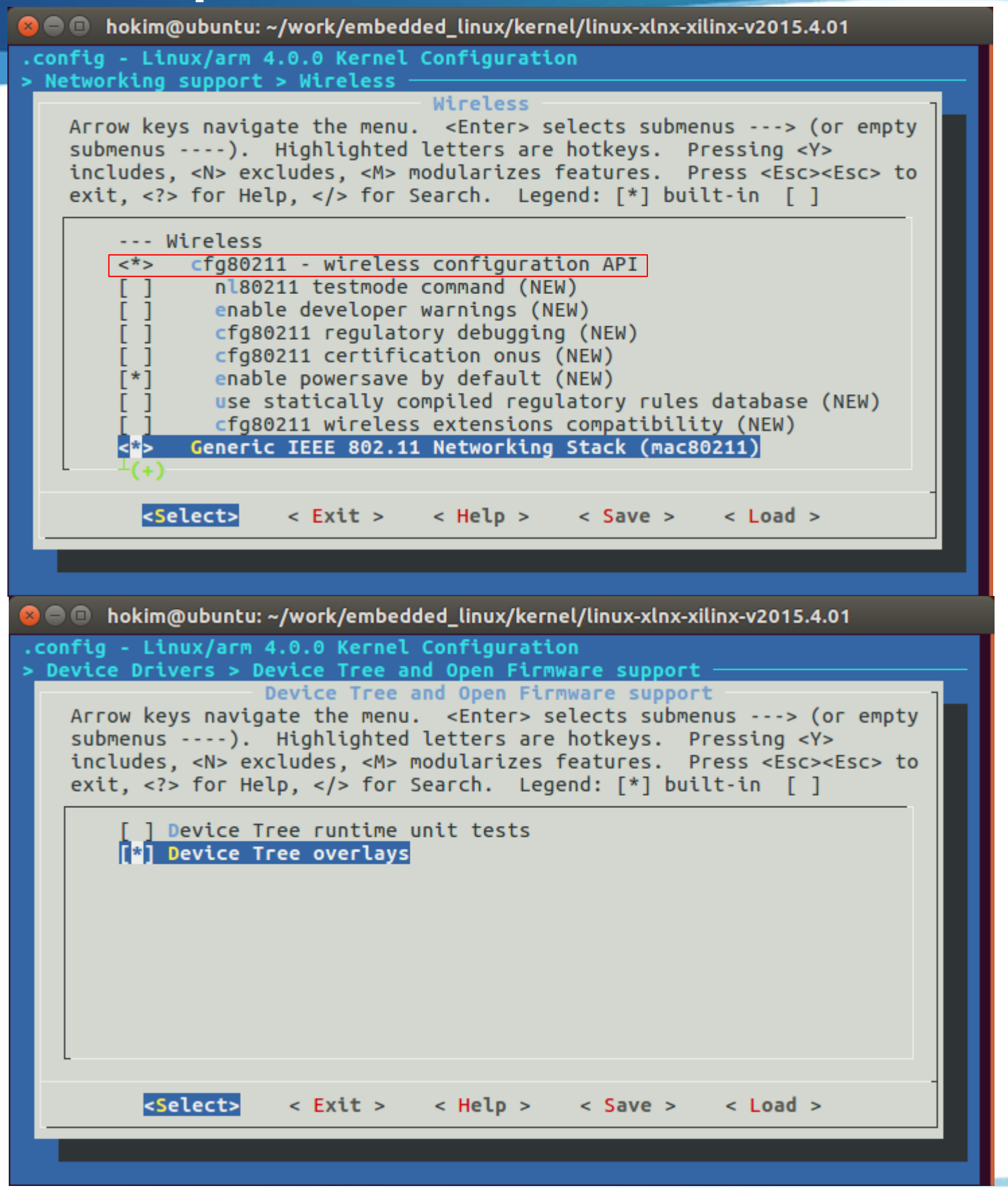
drivers/net/wireless/Makefile

```
obj-$(CONFIG_CW1200)    += cw1200/
obj-$(CONFIG_RSI_91X)   += rsi/
+obj-$(CONFIG_RTL8192CU)    += rtl8192cu/
```

```
$ make ARCH=arm xilinx_zynq_defconfig
$ make ARCH=arm menuconfig
```

Linux Kernel Compile

INIPRO



Linux Kernel Compile

INIPRO

hokim@ubuntu: ~/work/embedded_linux/kernel/linux-xlnx-xilinx-v2015.4.01

```
.config - Linux/arm 4.0.0 Kernel Configuration
[...] rivers > Network device support > PHY Device support and infrastructure
                PHY Device support and infrastructure
  Arrow keys navigate the menu.  <Enter> selects submenus ---> (or empty
  submenus ----).  Highlighted letters are hotkeys.  Pressing <Y>
  includes, <N> excludes, <M> modularizes features.  Press <Esc><Esc> to
  exit, <?> for Help, </> for Search.  Legend: [*] built-in  [ ]
      ^(-)
      < >   Drivers for the Intel LXT PHYs
      < >   Drivers for the Cicada PHYs
      <*>   Drivers for the Vitesse PHYs
      < >   Drivers for SMSC PHYs
      < >   Drivers for Broadcom PHYs
      < >   Drivers for Broadcom 7xxx SOCs internal PHYs
      < >   Driver for Broadcom BCM8706 and BCM8727 PHYs
      < >   Drivers for ICPlus PHYs
      <*>   Drivers for Realtek PHYs
      < >   Drivers for National Semiconductor PHYs
      v(+)

         <Select>    < Exit >    < Help >    < Save >    < Load >
```

hokim@ubuntu: ~/work/embedded_linux/kernel/linux-xlnx-xilinx-v2015.4.01

```
.config - Linux/arm 4.0.0 Kernel Configuration
> Device Drivers > Network device support > Wireless LAN
                Wireless LAN
  Arrow keys navigate the menu.  <Enter> selects submenus ---> (or empty
  submenus ----).  Highlighted letters are hotkeys.  Pressing <Y>
  includes, <N> excludes, <M> modularizes features.  Press <Esc><Esc> to
  exit, <?> for Help, </> for Search.  Legend: [*] built-in  [ ]
      ^(-)
      < >   Hermes chipset 802.11b support (Orinoco/Prism2/Symbol) (NEW
      < >   Softmac Prism54 support (NEW)
      < >   Ralink driver support (NEW)  ----
      < >   Realtek rtlwifi family of devices  ----
      [ ]   TI Wireless LAN support  ----
      < >   ZyDAS ZD1211/ZD1211B USB-wireless support (NEW)
      < >   Marvell WiFi-Ex Driver (NEW)
      < >   CW1200 WLAN support (NEW)
      < >   Redpine Signals Inc 91x WLAN driver support (NEW)
      <*>   Realtek 8192C USB WiFi

         <Select>    < Exit >    < Help >    < Save >    < Load >
```

Linux Kernel Compile

INIPRO

hokim@ubuntu: ~/work/embedded_linux/kernel/linux-xlnx-xilinx-v2015.4.01

```
.config - Linux/arm 4.0.0 Kernel Configuration
> Device Drivers > SPI support
                              SPI support
  Arrow keys navigate the menu.  <Enter> selects submenus ---> (or empty
  submenus ----).  Highlighted letters are hotkeys.  Pressing <Y>
  includes, <N> excludes, <M> modularizes features.  Press <Esc><Esc> to
  exit, <?> for Help, </> for Search.  Legend: [*] built-in  [ ]
      ^(-)
      < >   NXP SC18IS602/602B/603 I2C to SPI bridge
      < >   Analog Devices AD-FMCOMMS1-EBZ SPI-I2C-bridge driver
      <*>   Xilinx SPI controller common module
      <*>   Xilinx Zynq QSPI controller
      [ ]     Xilinx Zynq QSPI Dual stacked configuration
      < >   Xilinx ZynqMP GQSPI controller
      < >   DesignWare SPI controller core support
            *** SPI Protocol Masters ***
      <*>   User mode SPI device driver support
      < >   Infineon TLE62X0 (for power switching)

          <Select>    < Exit >    < Help >    < Save >    < Load >
```

hokim@ubuntu: ~/work/embedded_linux/kernel/linux-xlnx-xilinx-v2015.4.01

```
.config - Linux/arm 4.0.0 Kernel Configuration
> Device Drivers > GPIO Support
                               GPIO Support
  Arrow keys navigate the menu.  <Enter> selects submenus ---> (or empty
  submenus ----).  Highlighted letters are hotkeys.  Pressing <Y>
  includes, <N> excludes, <M> modularizes features.  Press <Esc><Esc> to
  exit, <?> for Help, </> for Search.  Legend: [*] built-in  [ ]
      ^(-)
      < >   GPIO driver for 74xx-ICs with MMIO access
      -*-   Generic memory-mapped GPIO controller support (MMIO platfor
      < >   Synopsys DesignWare APB GPIO driver
      < >   Emma Mobile GPIO
      [ ]   LSI ZEVIO SoC memory mapped GPIOs
      [ ]   PrimeCell PL061 GPIO support
      < >   SMSC SCH311x SuperI/O GPIO
      < >   GPIO based on SYSCON
      <*>   Xilinx GPIO support
      <*>   Xilinx Zynq GPIO support
      v(+)

          <Select>    < Exit >    < Help >    < Save >    < Load >
```

Linux Kernel Compile

INIPRO

```
$ make ARCH=arm CROSS_COMPILE=arm-linux-gnueabihf- CFLAGS="-O2
-mtune=cortex-a9 -mfpu=neon -mfloat-abi=hard" -j $(nproc)
UIMAGE_LOADADDR=0x8000 uImage
$ cp arch/arm/boot/uImage ../..
```

Root File System Build

INIPRO

```
$ cd ~/work/embedded_linux
$  sudo sh ./image.sh
```

image.sh

```
mkdir -p dl

UBUNTU_URL=http://cdimage.ubuntu.com/ubuntu-base/releases/16.04/release
UBUNTU=ubuntu-base-16.04-core-armhf.tar.gz
if [ ! -f dl/$UBUNTU ]; then
        wget $UBUNTU_URL/$UBUNTU -O dl/$UBUNTU
fi

ARCH=armhf
SIZE=3500
mkdir -p img
IMAGE=img/ubuntu-core_${ARCH}_16.04.img
dd if=/dev/zero of=$IMAGE bs=1M count=$SIZE
DEVICE=$(losetup -f)
losetup $DEVICE $IMAGE
parted -s $DEVICE mklabel msdos
parted -s $DEVICE mkpart primary fat16 4MB 128MB
parted -s $DEVICE mkpart primary ext4 128MB 100%
BOOT_DEV=/dev/$(lsblk -lno NAME $DEVICE | sed '2!d')
ROOT_DEV=/dev/$(lsblk -lno NAME $DEVICE | sed '3!d')
mkfs.vfat -v $BOOT_DEV
mkfs.ext4 -F -j $ROOT_DEV
ROOT_DIR=root
mkdir -p $ROOT_DIR
mount $ROOT_DEV $ROOT_DIR
cd $ROOT_DIR
tar xvf ../dl/$UBUNTU
rm -fr boot
cd ..
```

Root File System Build

INIPRO

image.sh

```
cat > $ROOT_DIR/etc/fstab << EOF_CAT
# /etc/fstab: static file system information.
# <file system> <mount point>   <type>  <options>             <dump>  <pass>
/dev/mmcblk0p1  /boot           vfat    errors=remount-ro      0       0
/dev/mmcblk0p2  /               ext4    errors=remount-ro      0       1
EOF_CAT

cp /etc/resolv.conf         $ROOT_DIR/etc/
cp /usr/bin/qemu-arm-static $ROOT_DIR/usr/bin/
chroot $ROOT_DIR << EOF_CHROOT
sed -i 's/^# deb http:\/\/ports\.ubuntu\.com\/ubuntu-ports\/ xenial universe.*/deb http:\/\/ports\.ubuntu\.com\/ubuntu-ports\/
xenial universe/' /etc/apt/sources.list
sed -i 's/^# deb http:\/\/ports\.ubuntu\.com\/ubuntu-ports\/ xenial-updates universe.*/deb http:\/\/ports\.ubuntu\.com\/ubuntu-
ports\/ xenial-updates universe/' /etc/apt/sources.list
apt-get update
apt-get -y upgrade
DEBIAN_FRONTEND=noninteractive apt-get -y install vim nano sudo openssh-server udev usbutils u-boot-tools device-tree-
compiler kmod net-tools wpasupplicant parted rfkill lshw wireless-tools gcc g++ cmake git i2c-tools iputils-ping
echo "Asia/Seoul" > /etc/timezone
ln -fs /usr/share/zoneinfo/Asia/Seoul /etc/localtime
locale-gen "en_US.UTF-8"
DEBIAN_FRONTEND=noninteractive dpkg-reconfigure locales
EOF_CHROOT
rm $ROOT_DIR/etc/resolv.conf
rm $ROOT_DIR/usr/bin/qemu-arm-static

mkdir -pv $ROOT_DIR/etc/systemd/system/serial-getty\@ttyPS0.service.d
cat > $ROOT_DIR/etc/systemd/system/serial-getty\@ttyPS0.service.d/autologin.conf << EOF_CAT
[Service]
ExecStart=
ExecStart=-/sbin/agetty --autologin root -s %I 115200,38400,9600 linux
EOF_CAT
umount -l $ROOT_DIR
rmdir $ROOT_DIR
losetup -d $DEVICE
```

File Transfer (Ubuntu → Windows)

INIPRO

using WinSCP

Ubuntu	Windows
~/work/embedded_linux/ devicetree.dtb, uImage	C:₩Users₩hokim₩work₩embedded_linux
~/work/embedded_linux/vivado/ u-boot.elf	C:₩Users₩hokim₩work₩embedded_linux₩vivado
~/work/embedded_linux/img/ ubuntu-core_armhf_16.04.img	C:₩Users₩hokim₩work

Boot.bin Build

INIPRO

bootbin.tcl

```
# tclsh bootbin.tcl

set project_name embedded_linux

set fileId [open $project_name/boot.bif "w"]
puts $fileId "img:{\[bootloader\] $project_name/$project_name.fsbl/executable.elf
$project_name/$project_name.runs/impl_1/system_wrapper.bit u-boot.elf}"
close $fileId

file delete -force boot.bin

exec bootgen -image $project_name/boot.bif -w -o i boot.bin >&@stdout
```

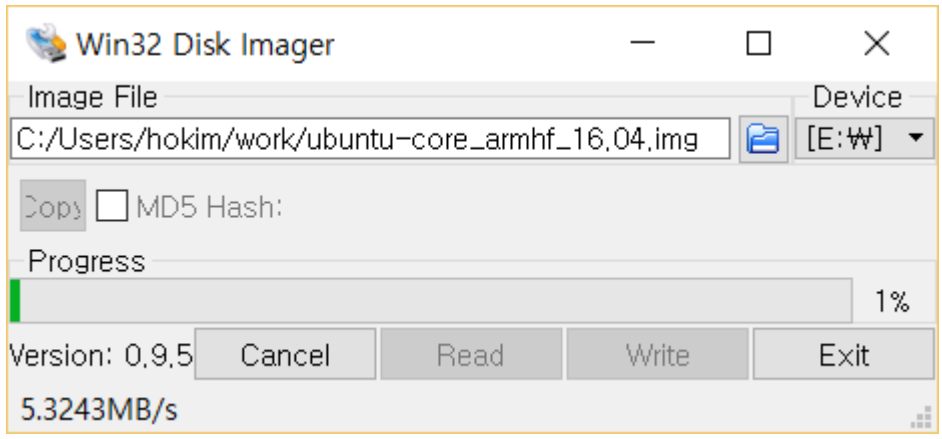
In cmd window for Vivado

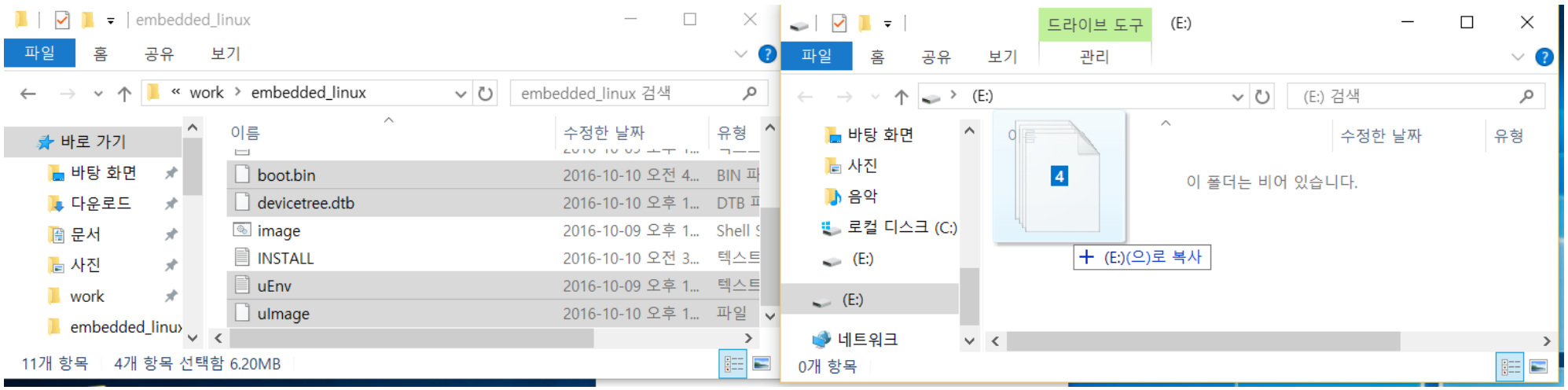
```
C:\  cd c:\Users\hokim\work\embedded_linux\vivado
C:\ tclsh bootbin.tcl
C:\ copy boot.bin ..
```

output : boot.bin

SD Card

https://sourceforge.net/projects/win32diskimager/

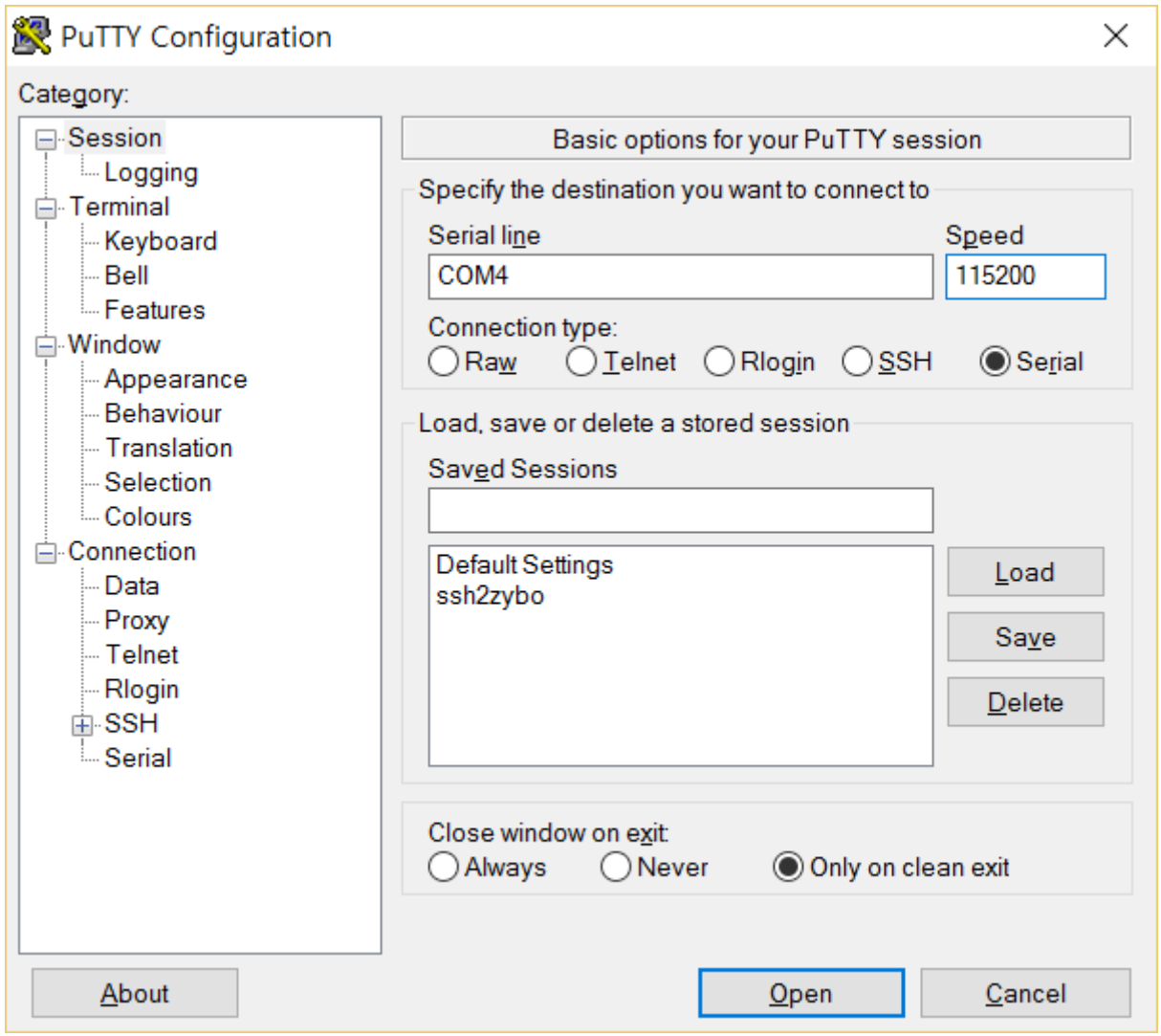




Boot zybo with SD card

Post install

Log in through UART console using putty



Post install

```
# groupadd -g 1000 hokim
# groupadd -g 1001 admin
# useradd -u 1000 -g 1000 -G adm,dialout,cdrom,audio,dip,video,plugdev,admin
-d /home/hokim -m -s /bin/bash hokim
# passwd hokim
# nano /etc/network/interfaces.d/eth0
```

/etc/network/interfaces.d/eth0

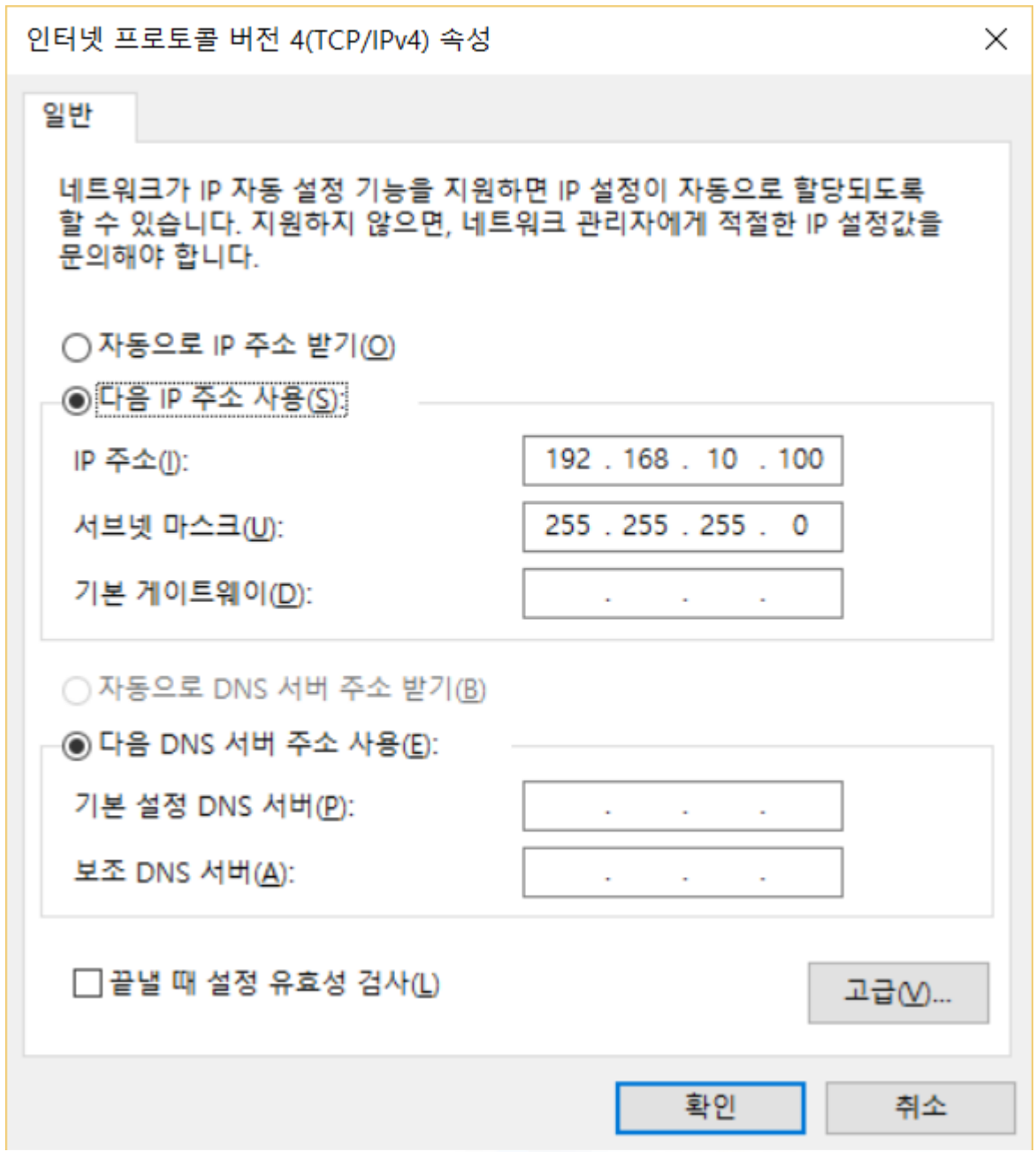
```
allow-hotplug eth0
iface eth0 inet static
address 192.168.10.10
netmask 255.255.255.0
```

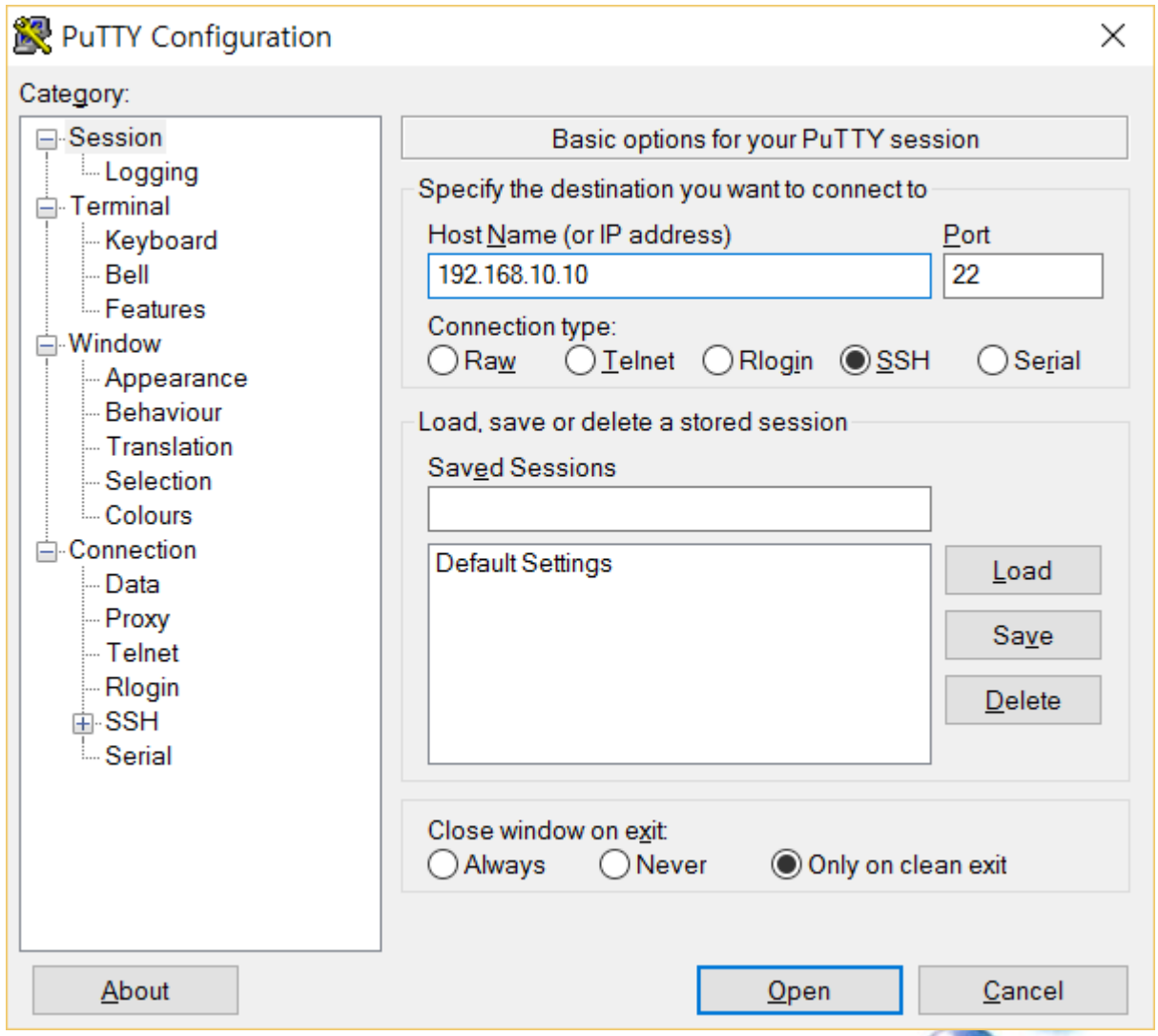
```
# halt
```

Turn off/on zybo

Post install

Log in through ethernet using putty





Post install

```
$ sudo nano /etc/hostname
```

/etc/hostname

```
-localhost.localdomain
+zybo
```

```
$ sudo nano /etc/hosts
```

/etc/hosts

```
127.0.0.1       localhost
127.0.1.1       zybo

# The following lines are desirable for IPv6 capable hosts
::1             ip6-localhost ip6-loopback
fe00::0         ip6-localnet
ff00::0         ip6-mcastprefix
ff02::1         ip6-allnodes
ff02::2         ip6-allrouters
```

```
$ ls /sys/class/net
```

output:

```
enx74da38422193  eth0  lo
```

Post install

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```
$ sudo nano /etc/network/interfaces.d/enx74da38422193
```

/etc/network/interfaces.d/enx74da38422193

```
allow-hotplug enx74da38422193
iface enx74da38422193 inet dhcp
        pre-up wpa_supplicant -B -D wext -i enx74da38422193 -c /etc/wpa_supplicant.conf
        post-down killall -q wpa_supplicant
        udhcpc_opts -t7 -T3
```

```
$ sudo nano /etc/wpa_supplicant.conf
```

/etc/wpa_supplicant.conf

```
ctrl_interface=DIR=/var/run/wpa_supplicant GROUP=netdev
update_config=1

network={
                ssid="INIPRO"
                key_mgmt=WPA-PSK
                psk="20471047"
}
```

```
$ sudo halt
```

Turn off/on zybo

Post install

```
$ sudo nano /etc/network/interfaces.d/enx74da38422193
```

/etc/network/interfaces.d/enx74da38422193

```
allow-hotplug enx74da38422193
iface enx74da38422193 inet dhcp
        pre-up wpa_supplicant -B -D wext -i enx74da38422193 -c /etc/wpa_supplicant.conf
        post-down killall -q wpa_supplicant
        udhcpc_opts -t7 -T3
```

```
$ sudo nano /etc/wpa_supplicant.conf
```

/etc/wpa_supplicant.conf

```
ctrl_interface=DIR=/var/run/wpa_supplicant GROUP=netdev
update_config=1

network={
                ssid="INIPRO"
                key_mgmt=WPA-PSK
                psk="20471047"
}
```

```
$ sudo -s
# echo -e "d\n2\nw" | fdisk /dev/mmcblk0
# parted -s /dev/mmcblk0 mkpart primary ext4 128M 100%
# halt
```

Post install

Turn off / on zybo
Log in through ethernet using putty

```
$ sudo resize2fs /dev/mmcblk0p2
$ df -h
```

output:

```
Filesystem      Size  Used Avail Use% Mounted on
/dev/root       7.0G  632M  6.0G  10% /
devtmpfs        242M     0  242M   0% /dev
tmpfs           250M     0  250M   0% /dev/shm
tmpfs           250M  6.5M  244M   3% /run
tmpfs           5.0M     0  5.0M   0% /run/lock
tmpfs           250M     0  250M   0% /sys/fs/cgroup
/dev/mmcblk0p1  118M  6.3M  112M   6% /boot
```

Post install

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$ ifconfig

output:

```
enx74da38422193 Link encap:Ethernet  HWaddr 74:da:38:42:21:93
          inet addr:192.168.0.148  Bcast:192.168.0.255  Mask:255.255.255.0
          UP BROADCAST RUNNING MULTICAST  MTU:1500  Metric:1
          RX packets:418 errors:0 dropped:3 overruns:0 frame:0
          TX packets:12 errors:0 dropped:0 overruns:0 carrier:0
          collisions:0 txqueuelen:1000
          RX bytes:77995 (77.9 KB)  TX bytes:1772 (1.7 KB)

eth0      Link encap:Ethernet  HWaddr d8:80:39:5c:48:82
          inet addr:192.168.10.10  Bcast:192.168.10.255  Mask:255.255.255.0
          UP BROADCAST RUNNING MULTICAST  MTU:1500  Metric:1
          RX packets:437 errors:0 dropped:1 overruns:0 frame:0
          TX packets:448 errors:0 dropped:0 overruns:0 carrier:0
          collisions:0 txqueuelen:1000
          RX bytes:33219 (33.2 KB)  TX bytes:57605 (57.6 KB)
          Interrupt:145 Base address:0xb000

lo        Link encap:Local Loopback
          inet addr:127.0.0.1  Mask:255.0.0.0
          UP LOOPBACK RUNNING  MTU:65536  Metric:1
          RX packets:80 errors:0 dropped:0 overruns:0 frame:0
          TX packets:80 errors:0 dropped:0 overruns:0 carrier:0
          collisions:0 txqueuelen:0
          RX bytes:5920 (5.9 KB)  TX bytes:5920 (5.9 KB)
```

Linux Architecture

- **Virtual memory management is a key aspect of Linux**

The Memory Management Unit(MMU) of the processor translates virtual address to physical addresses

- **Linux divides virtual memory into kernel space and user space**

Kernel space is the memory area for the kernel and device drivers

kernel space is the top 1 GB of memory, 0xC0000000 to 0xFFFFFFFF

User space is the memory area for user application software

User space is the bottom 3 GB of memory, 0 to 0xBFFFFFFF

Other kernel/user space memory configurations are configurable in the kernel such as 2 GB kernel and 2GB user space

Kernel space virtual address 0xC0000000 maps to physical address zero

Linux Architecture

- **Linux uses the processor modes to create privilege levels**

The kernel executes at a higher privilege level than user space code such that it can access any resources in the system

Applications execute at a lower privilege level such that they must use the kernel to get to the restricted resources in the system

- **Library functions run in user space and provide a more convenient interface for the programmer**

Linux applications require a C library to build which is provided by the tools

The Xilinx Linux GNU tools are based on the GNU C Library(glibc)

The Xilinx standalone GNU tools are based on newlib library rather than glibc

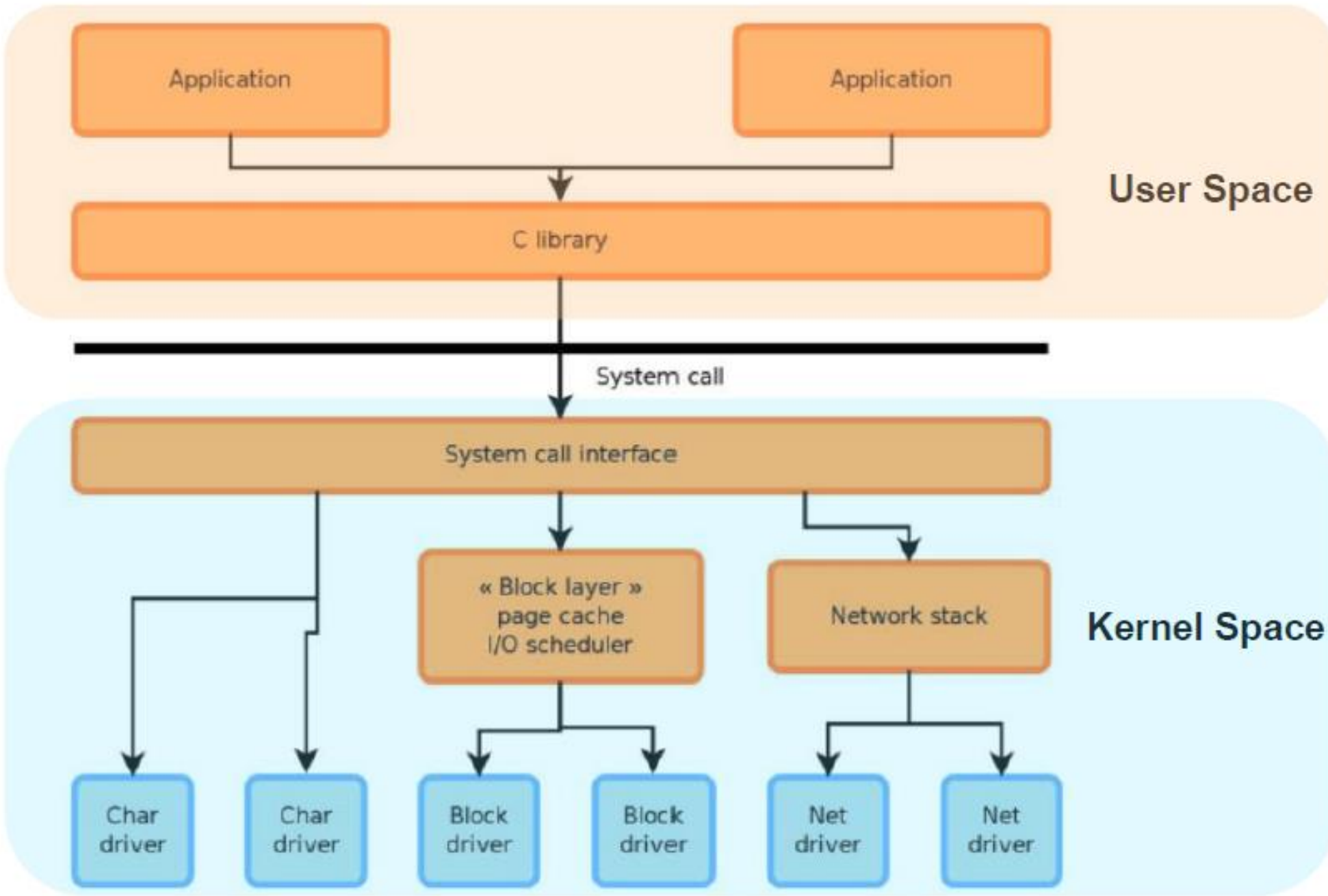
- **System calls run in kernel mode on the user's behalf and are provided by the kernel itself**

Linux Architecture

INIPRO

- A library function calls one or more system calls, and these system calls execute in supervisor mode since they are part of kernel itself
- Once the system call complete its task, it returns an execution is transferred back to user mode
- The user space application is typically blocked until the library function and system call return (just like a function call)
- System calls may interact with the kernel property, or with specific drivers and frameworks of the kernel

Linux Architecture



Linux Device Model

- You don’t have to be a kernel expert, but understanding some terms will help a lot
- The Linux Device model is built around the concept of buses, devices and drivers
- All devices in the system are connected to a bus of some kind
- A bus may be a software abstraction rather than a real bus
- Buses primarily exist to gather similar devices together and coordinate initialization, shutdown and power management
- When a device in the system is found to match a driver, they are bound together. The specifics about how to match devices and drivers are bus-specific

Linux Device Types

- **Network devices**

These are represented as network interfaces, visible in userspace using the ifconfig utility

- **Block devices**

These are used to provide userspace applications access to raw storage devices (hard disks, USB keys)

Visible to the applications as device files in /dev

- **Character devices**

These are used to provide userspace applications access to all other types of devices (input, sound, graphics, serial, etc.)

They are also visible to the applications as device files in /dev

Many devices are character devices and a lot of user IP could be accessed as a character device

Linux Kernel Frameworks

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- **Many device drivers are not directly implemented as character devices or block devices. They are implemented under a framework, specific to a device type (framebuffer, V4L, serial, etc.)**
- **The framework factors out the common parts of drivers for the same type of devices to reduce code duplication**
- **From userspace, many are still seen as normal character devices**
- **The frameworks provide a coherent userspace interface (ioctl numbering and semantics, etc.) for every type of device, regardless of the driver**

The network framework of Linux provides a socket API such that an application can connect to a network using any network driver without knowing the details of the network driver

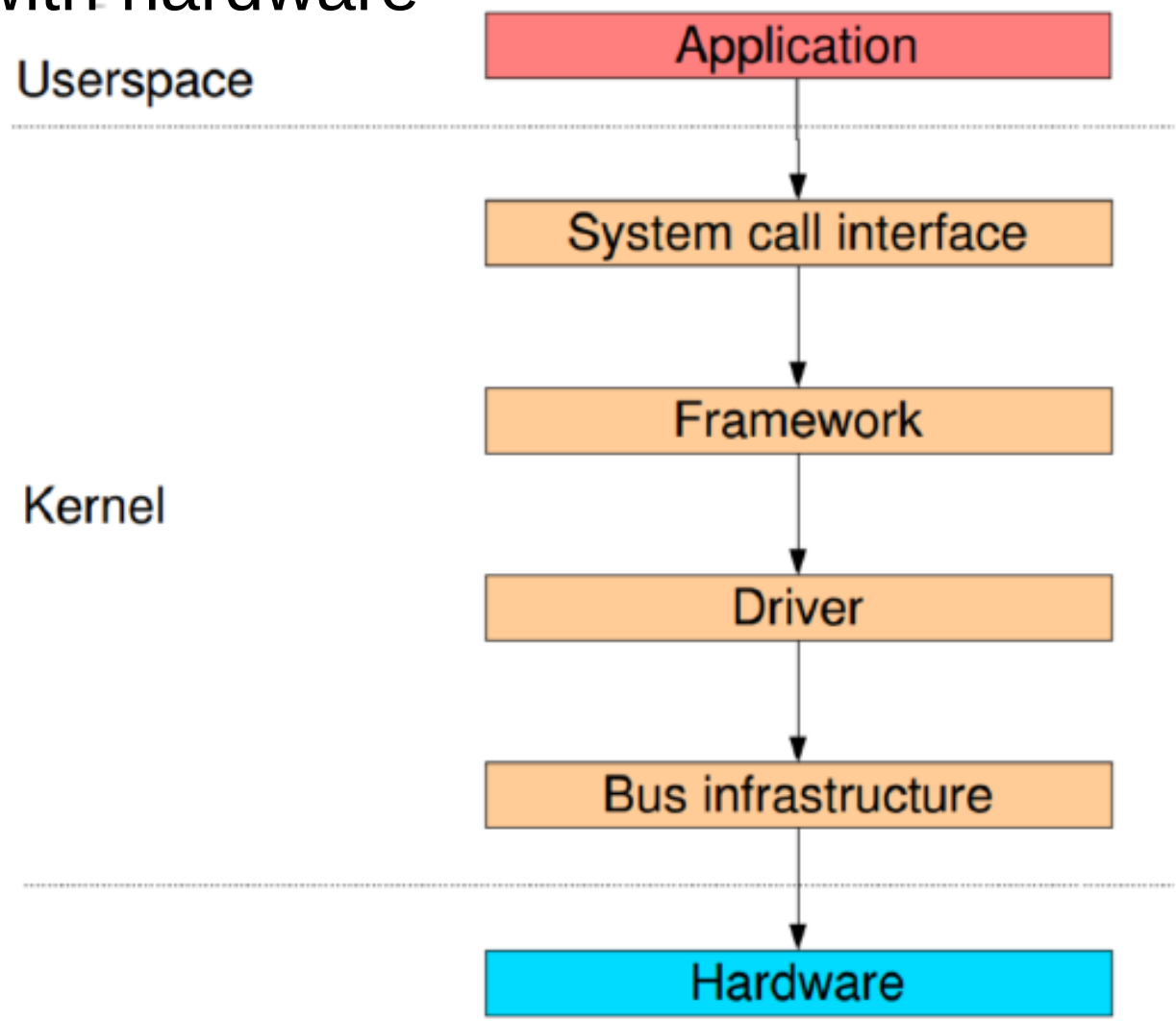
- sockfd = socket(AF_INET, SOCK_STREAM, 0)

Linux Kernel Layers Focused on Frameworks

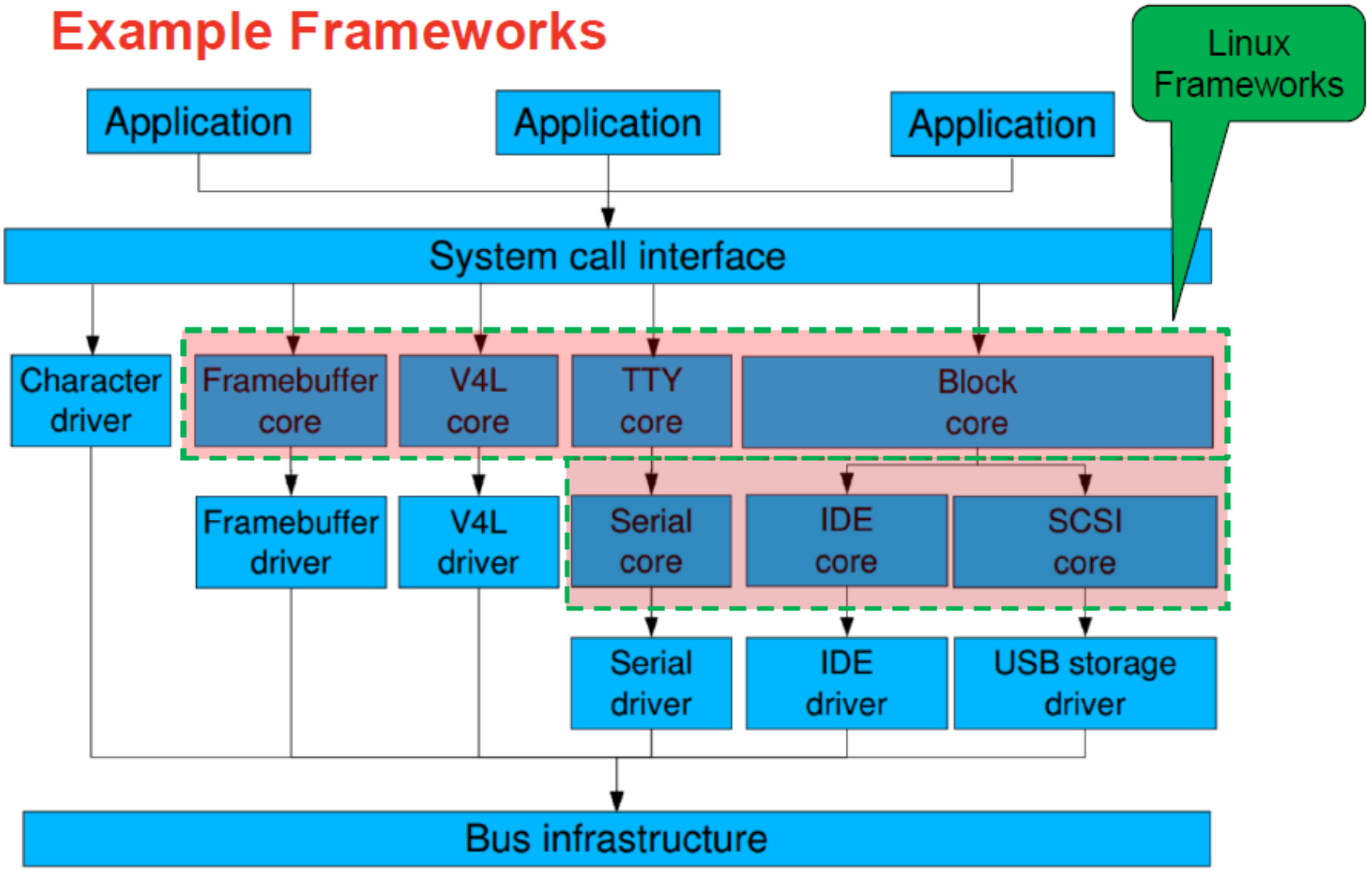
- **A driver is always interfacing with:**

A framework that allows the driver to expose the hardware features to userspace applications

A bus infrastructure (part of the device model), to detect /communicate with hardware



Example Frameworks



Virtual File Systems - Overview

- **System and kernel information**

  Presented to user space application as virtual file systems

  Created dynamically and only exist in memory

- **Two virtual filesystems most known to users**

  proc, mounted on /proc, contains operating system related information (processes, memory management parameters…)

  This is an older mechanism that became somewhat chaotic

  sysfs, mounted on /sys, contains representation of the system as a set of devices and buses together with information about these devices

  This is the newer mechanism and is the preferred place to add system information

Virtual File Systems - sysfs

- **The sysfs virtual filesystem is a mechanism for the kernel to export operating details to user space**
- **The kernel exports the following items to userspace**

The bus, device, drivers, etc. structures internal to the kernel

/sys/bus/ contains the list of buses

/sys/devices/ contains the list of devices

/sys/class/ enumerates devices by class (net, input, block…), whatever the bus they are connected to

- **Used for example by udev to provide automatic module loading, firmware loading, device file creation, etc.**

Device Tree In A Nutshell

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- The principle of the Device Tree is to separate a large part of the hardware description from the kernel sources
- Device Tree allows a single kernel image to run on different boards with the differences being described in the device tree
- This mechanism takes its roots from OpenFirmware (OF) used on PowerPC platforms. This is why the “of” is part of some kernel functions.
- Device Tree is a tree of nodes that models the hierarchy of devices in the system, from the devices inside the processor to the devices on the board
- Each node can have a number of properties describing various properties of the devices: address, interrupts, clocks, etc.
- Written in a specialized language, the Device Tree source code is compiled into a Device Tree Blob by the Device Tree Compiler (DTC)

Device Tree In A Nutshell

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- **The DTC checks the device tree syntax but the semantics of the device tree are checked at runtime by the kernel and drivers**
- **At boot time, the kernel is given a compiled device tree, referred to as a Device Tree Blob, which is parsed to instantiate all the devices described in the device tree**
- **Device trees are located in ~~the kernel tree at arch/<arm or microblaze>/boot/dts~~ https://github.com/Xilinx/device-tree-xlnx**
- **The device tree compiler is part of the Linux kernel tree**
- **Some key properties in a device tree node, referred to as bindings**

  The compatible property is used to bind a device with a device driver

  The interrupts property contains the interrupt number used by the device

  The reg property contains the memory range used by the device
- **There is limited documentation for the device tree bindings for each device such that driver code inspection may be necessary**

  The docs are in the kernel tree at Documentation/devicetree/bindings

Device Tree Details and A Simple Example

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- **A simple example below illustrates a node of device tree**

An AMBA bus with GPIO that has registers mapped to 0x4120000 and is using interrupt 91

91 – 32 = 59, where 32 is the first Shared Peripheral Interrupt

The device is compatible with a driver containing a matching compatible string of “xlnx,simple”

The device driver source code may be the only way to really understand what properties it is expecting from the device tree

```
ps7_axi_interconnect_0: amba@0 {
        #address-cells = <1>;
        #size-cells = <1>;
        compatible = "xlnx,ps7-axi-interconnect-1.00.a", "simple-bus";
        ranges ;
        axi_gpio_0: gpio@41200000 {
                #gpio-cells = <2>;
                compatible = "xlnx,simple";
                gpio-controller ;
                interrupt-parent = <&ps7_scugic_0>;
                interrupts = <0 59 4>;
                reg = <0x41200000 0x10000>;
                xlnx,is-dual = <0x1>;
        } ;
};
```

Device Tree In A Nutshell

- The dtsi files are included files while the dts file is the final device tree
- A dts file includes dtsi files and the inclusion process works by overlaying the tree of the including file over the tree of the included file
- When properties are repeated in dtsi files the last one is the final
- The PL and PS are separate DTSI files while there is top level dts file that includes them
- The device tree compiler can be used to create the final device tree which is handy for debug (by specifying DTS input and output)

Device Tree – Inclusion Example

ps.dtsi (included file)

```
ps7_ttc_1: ps7-ttc@0xf8002000 {
  clocks = <&clkc 6>;
  compatible = "xlnx,ps7-ttc-1.00.a";
  interrupt-parent = <&ps7_scugic_0>;
  interrupts = <0 37 4>,<0 38 4>,<0 39 4>;
  reg = <0xF8002000 0x1000>;
  status = "disabled";
} ;
```

+

system-top.dts (including file)

```
/include/ "ps.dtsi"

&ps7_ttc_1 {
  compatible = "xlnx,psttc", "generic-uio";
  status = "okay";
};
```

Note the "&" used to reference an existing node (rather than creating a new node

=

```
ps7_ttc_1: ps7-ttc@0xf8002000 {
  clocks = <&clkc 6>;
  compatible = "xlnx,psttc", "generic-uio";
  interrupt-parent = <&ps7_scugic_0>;
  interrupts = <0 37 4>, <0 38 4>, <0 39 4>;
  reg = <0xF8002000 0x1000>;
  status = "okay";
} ;
```

The result for the duplicated (red) properties is the same as the including file.

Linux GPIO

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- **General Purpose Input/Output**
- **Pin connection two electronic components (chips)**
- **Voltage is held at one of two level to indicate 1 or 0 logic**
- **Controlled by one chip, sensed by the other**
- **Usually grouped in banks**
- **Per GPIO pin configuration**
- **Configure pin direction mode to input or output**
- **Input mode**

  Sense the logic level

  Interrupt source (asynchronous notification)
- **Output mode**

  Set voltage logic level to 0 or 1

Linux GPIO Userspace Interface

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- **Documented in Documentation/gpio.txt**
- **gpiolib framework**
- **Gpio drivers : drivers/gpio/(gpio-zynq.c, gpio-xilinx.c)**
- **GPIO control interface is via sysfs under /sys/class/gpio, and includes following control files:**

export Make a specific GPIO pin available for userspace control. Write the pin number N (e.g. “55”, ASCII); the gpioN directory should appear.

unexport Make a specific GPIO pin unavailable. Write the pin number; the gpioN directory should disappear

gpioN/direction Write “in” or “out” to set pin direction

gpioN/value Read the current pin status in input. For output, write “0” or “1” to set the pin status.

Linux GPIO Userspace Interface

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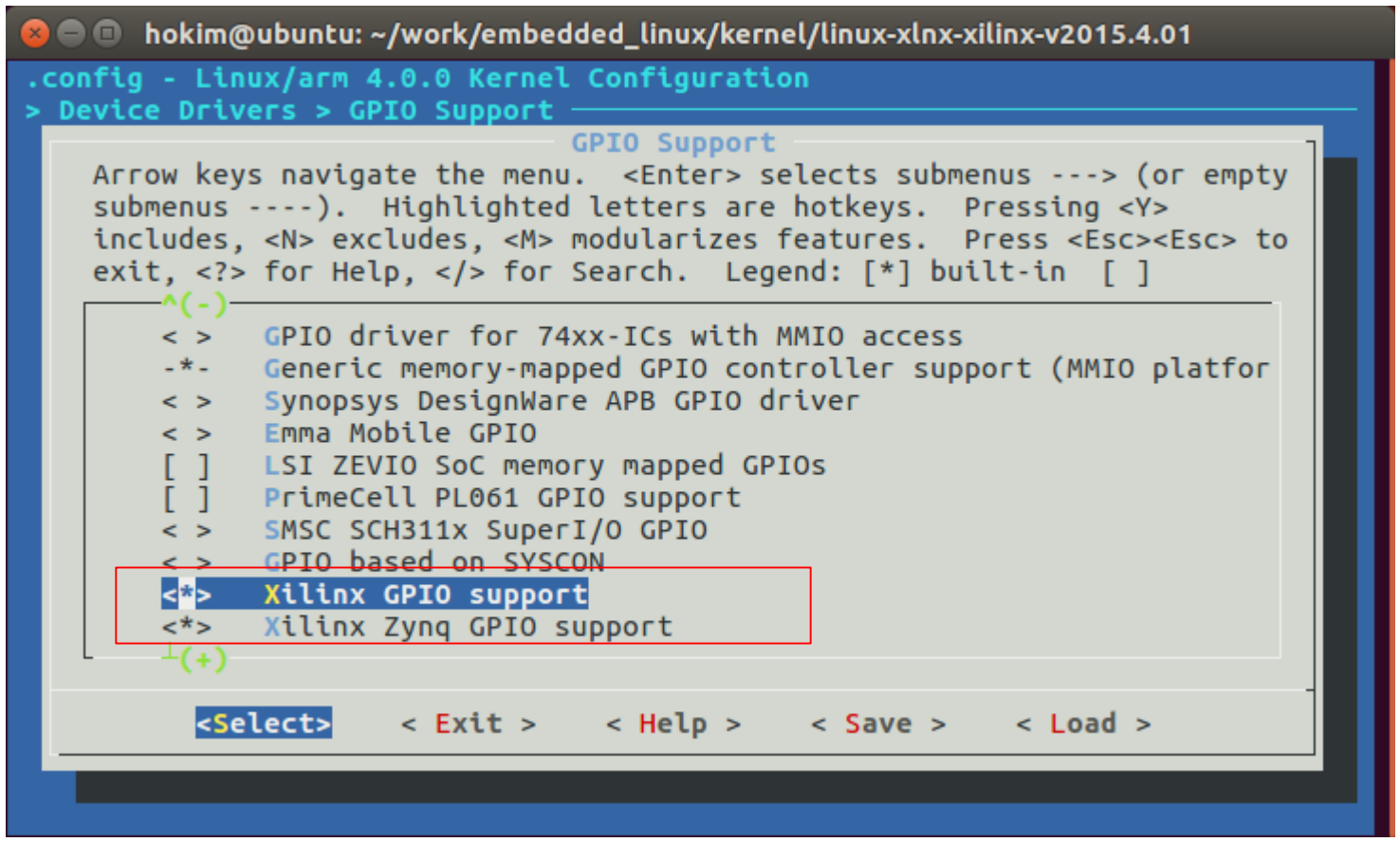
Kernel Configuration



Linux GPIO Userspace Interface

INIPRO

gpio_sw/driver/*gpio.c*

```
#include <fcntl.h>
#include <stdio.h>
#include <string.h>
#include <stdlib.h>
#include <unistd.h>

#include "gpio.h"

int setGpio(unsigned int index, const char *direction){
    int fd;
    char buf[50];
    sprintf(buf, "/sys/class/gpio/gpio%d/direction", index);
    if(access(buf, F_OK) != -1)
        unsetGpio(index);
    if((fd = open("/sys/class/gpio/export", O_WRONLY)) == -1)
        return -1;
    sprintf(buf, "%d", index);
    if(write(fd, buf, strlen(buf)) == -1)
        return -1;
    close(fd);

    sprintf(buf, "/sys/class/gpio/gpio%d/direction", index);
    if((fd = open(buf, O_WRONLY)) == -1)
        return -1;
    if(write(fd, direction, strlen(direction)) == -1)
        return -1;
    close(fd);
    return 0;
}
```

```
int unsetGpio(unsigned int index){
    int fd;
    char buf[50];
    if((fd = open("/sys/class/gpio/unexport", O_WRONLY)) == -
1)
        return -1;
    sprintf(buf, "%d", index);
    if(write(fd, buf, strlen(buf)))
        return -1;
    close(fd);
    return 0;
}

int writeGpio(unsigned int index, int value){
    int fd;
    char buf[50];
    sprintf(buf, "/sys/class/gpio/gpio%d/value", index);
    if((fd = open(buf, O_WRONLY)) == -1)
        return -1;
    sprintf(buf, "%d", value);
    if(write(fd, buf, strlen(buf)) == -1)
        return -1;
    close(fd);
    return 0;
}

int readGpio(unsigned int index){
    int fd;
    char buf[50];
    sprintf(buf, "/sys/class/gpio/gpio%d/value", index);
    if((fd = open(buf, O_RDONLY)) == -1)
        return -1;
    if(read(fd, buf, 10) == -1)
        return -1;
    close(fd);
    return atoi(buf);
}
```

Legacy UserSpace Driver Methods (/dev/mem)

INIPRO

- A character driver referred to as /dev/mem exists in the kernel that will map device memory into userspace
- With this driver userspace applications can access device memory
- Must be root user
- A great tool for prototyping or maybe testing new hardware, but is not considered to be an acceptable production solution for a userspace device driver
- Since it can map any address into userspace, a buggy userspace driver could crash the kernel

Linux GPIO Userspace Interface

INIPRO

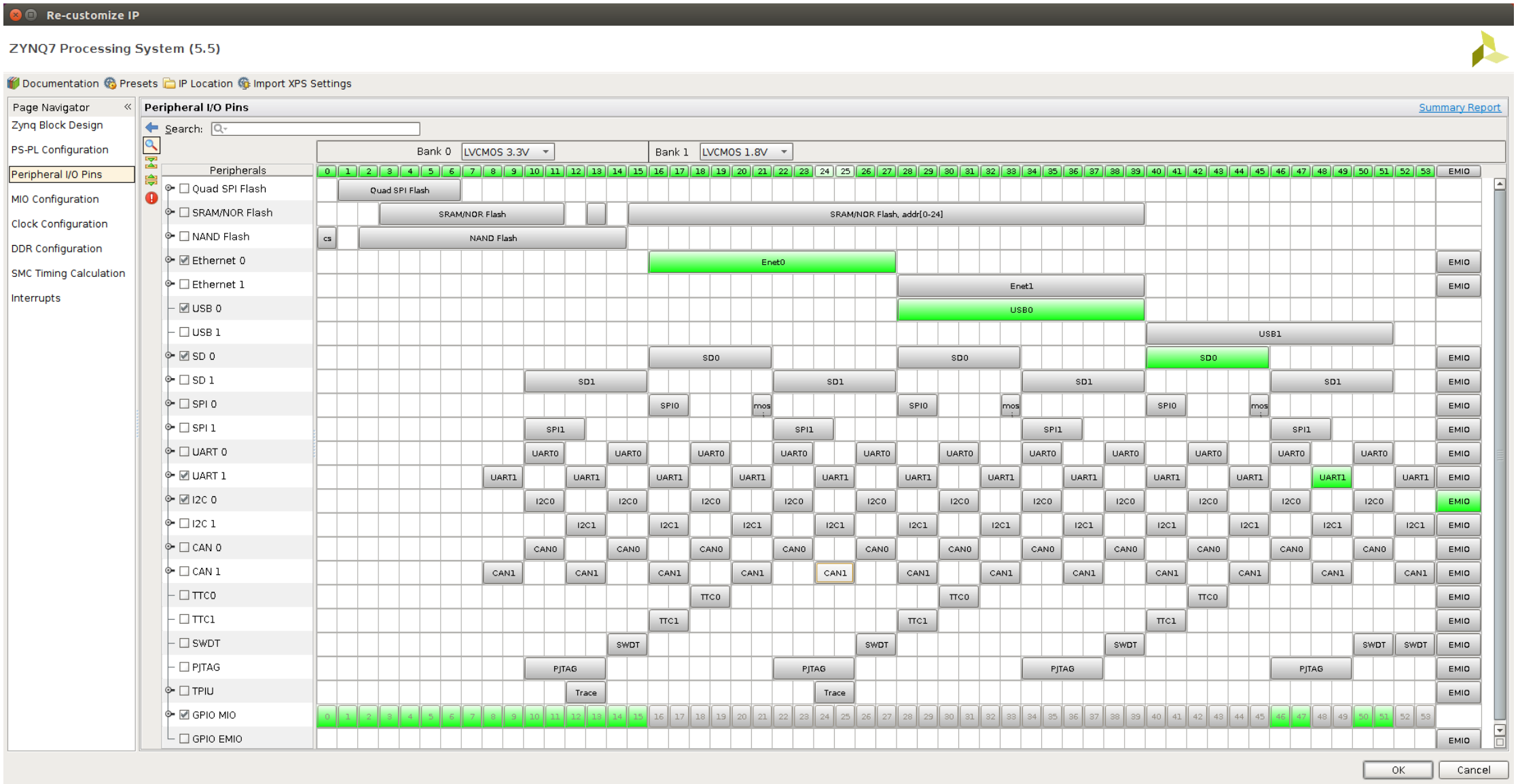
gpio_sw/mmap/*main.c*

```
#include <stdio.h>
#include <stdint.h>
#include <unistd.h>
#include <fcntl.h>
#include <sys/mman.h>
#include <signal.h>
#include "xgpio.h"

XGpio_Config XGpio_ConfigTable[3] = {
        { 0, 0, 1, 0 },
        { 1, 0, 1, 0 },
        { 2, 0, 1, 0 }
};

static int loop_exit;

void sig_handler(int signo)
{
        if (signo == SIGINT)
                loop_exit = 1;
}

int main()
{
        int fd;
        uint32_t btns, leds, sws;

        if ((fd = open("/dev/mem", O_RDWR)) < 0)
{
                perror("open");
                return 1;
        }
```

```
        btns =  (uint32_t)mmap(NULL, sysconf(_SC_PAGESIZE),
PROT_READ|PROT_WRITE, MAP_SHARED, fd, 0x40001000);
        leds =  (uint32_t)mmap(NULL, sysconf(_SC_PAGESIZE),
PROT_READ|PROT_WRITE, MAP_SHARED, fd, 0x40000000);
        sws =  (uint32_t)mmap(NULL, sysconf(_SC_PAGESIZE),
PROT_READ|PROT_WRITE, MAP_SHARED, fd, 0x40002000);

        XGpio_ConfigTable[0].BaseAddress = btns;
        XGpio_ConfigTable[1].BaseAddress = leds;
        XGpio_ConfigTable[2].BaseAddress = sws;

        if (signal(SIGINT, sig_handler) == SIG_ERR) {
                fprintf(stderr, "can't catch SIGINT\n");
                return 1;
        }

        XGpio Gpio;
        int Status;
        Status = XGpio_Initialize(&Gpio, 1);
        if (Status != XST_SUCCESS) {
                return XST_FAILURE;
        }

        loop_exit = 0;
        while (1) {
                XGpio_DiscreteWrite(&Gpio, 1, 0xF);
                sleep(1);
                XGpio_DiscreteWrite(&Gpio, 1, 0x0);
                sleep(1);
                if (loop_exit == 1) break;
        }
        munmap((void*)btns, sysconf(_SC_PAGESIZE));
        munmap((void*)leds, sysconf(_SC_PAGESIZE));
        munmap((void*)sws, sysconf(_SC_PAGESIZE));
        close(fd);
        return 0;
}
```

Zynq7 PS Re-customize IP for GPIO

INIPRO



Zynq7 PS Re-customize IP for GPIO

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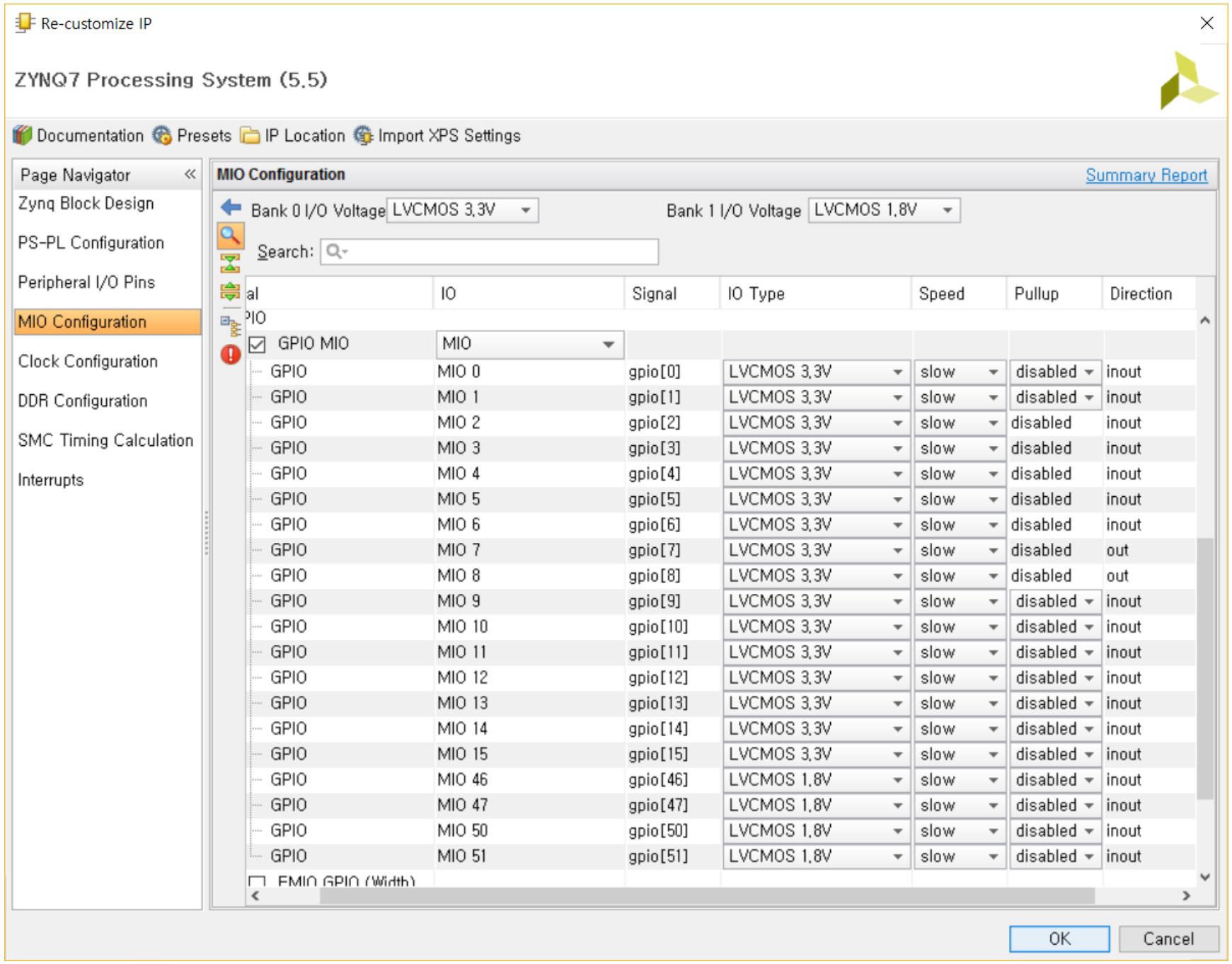

Zynq7 PS Re-customize IP for GPIO

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Re-customize IP

ZYNQ7 Processing System (5.5)

Documentation | Presets | IP Location | Import XPS Settings

Page Navigator

- Zynq Block Design
- PS-PL Configuration
- Peripheral I/O Pins
- MIO Configuration
- Clock Configuration
- DDR Configuration
- SMC Timing Calculation
- Interrupts

PS-PL Configuration — Summary Report

Search:

Name	Select	Description
FTM Trace buffer FIFO size	128	FTM Trace buffer FIFO size
FTM Trace buffer clock delay	12	Number of clock cycles interval for a trace data output from FIF
Include ACP transaction checker	☐	Enables ACP transaction checker.
Trace data/control signal pipeline width	8	Enables configurable number of pipeline stages on the TRACE
Power-on reset(POR) 4k timer	☐	Enables power-on reset(POR) 4k timer. By default, 64k timer is
Processor event interface	☐	Enables event bus which provides a low-latency and direct me
Address Editor		
Enable Clock Triggers		
Enable Clock Resets		
FCLK_RESET0_N	☑	Enables general purpose reset signal 0 for PL logic
FCLK_RESET1_N	☐	Enables general purpose reset signal 1 for PL logic
FCLK_RESET2_N	☐	Enables general purpose reset signal 2 for PL logic
FCLK_RESET3_N	☐	Enables general purpose reset signal 3 for PL logic
AXI Non Secure Enablement	0	Enable AXI Non Secure Transaction
GP Master AXI Interface		
M AXI GP0 interface	☑	Enables General purpose AXI master interface 0
M AXI GP1 interface	☐	Enables General purpose AXI master interface 1
GP Slave AXI Interface		
HP Slave AXI Interface		
ACP Slave AXI Interface		
DMA Controller		

OK Cancel

Zynq7 PS Re-customize IP for GPIO

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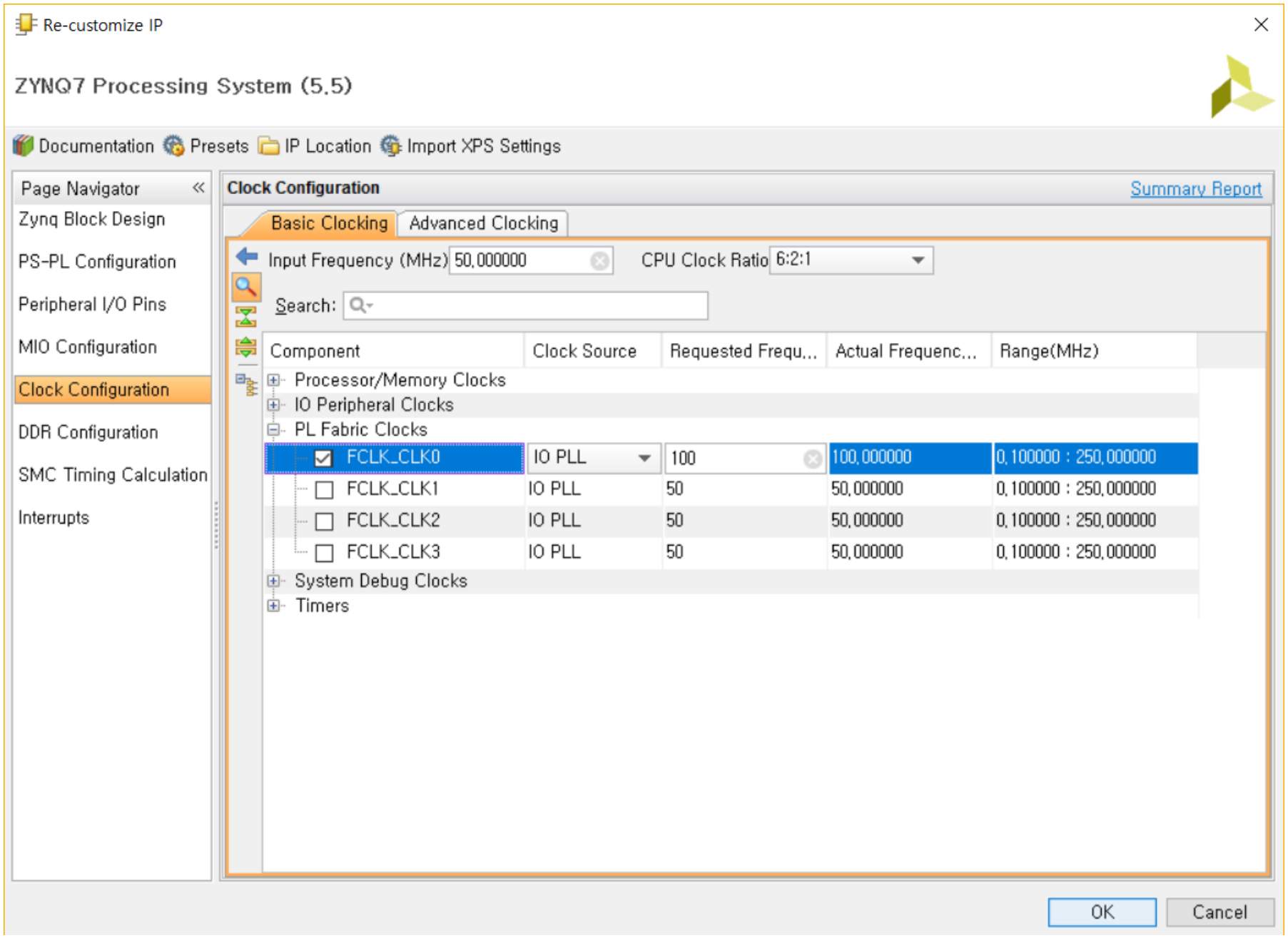

Zynq7 PS Re-customize IP for GPIO

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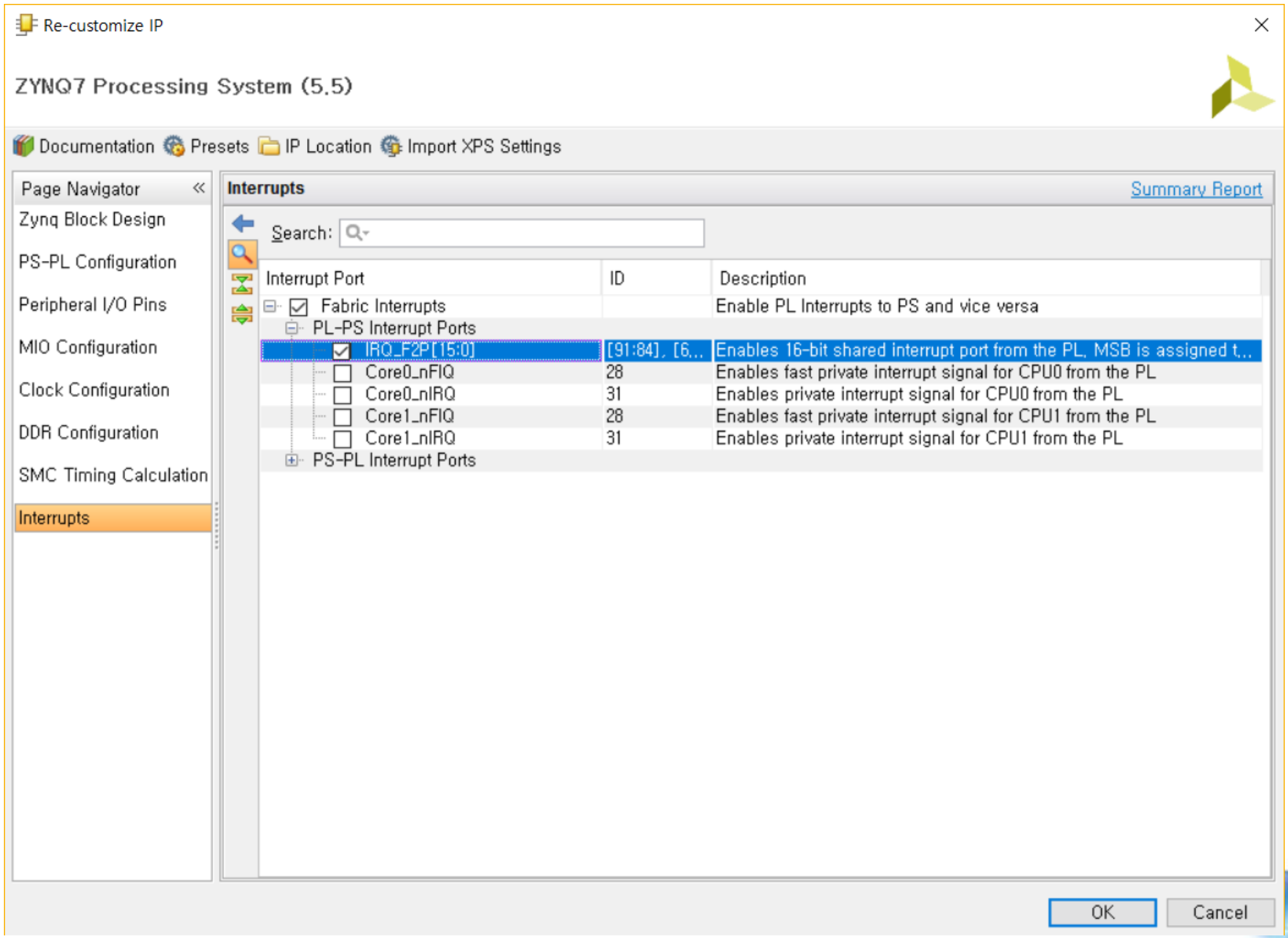

Zynq7 PS Re-customize IP for GPIO

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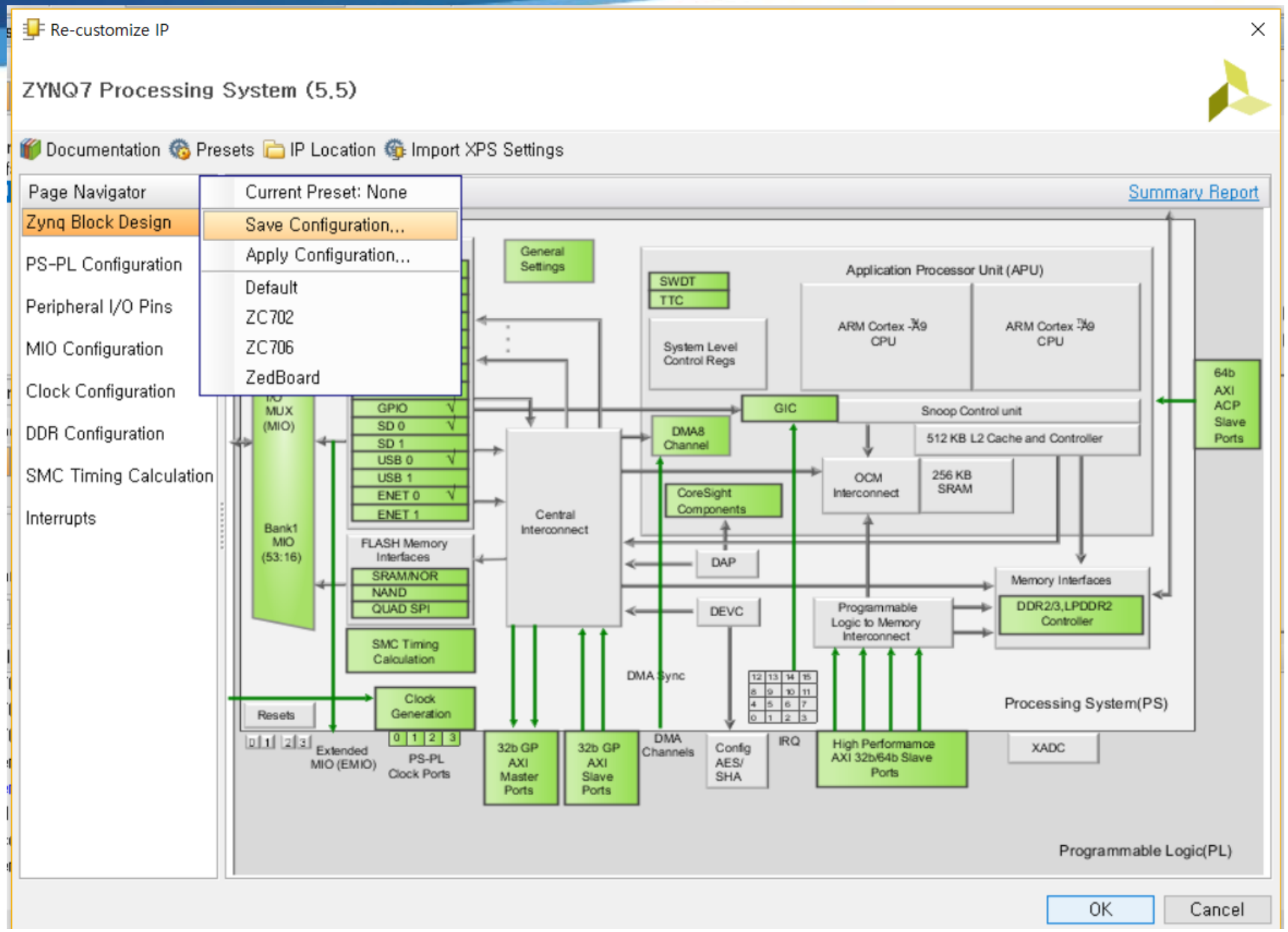

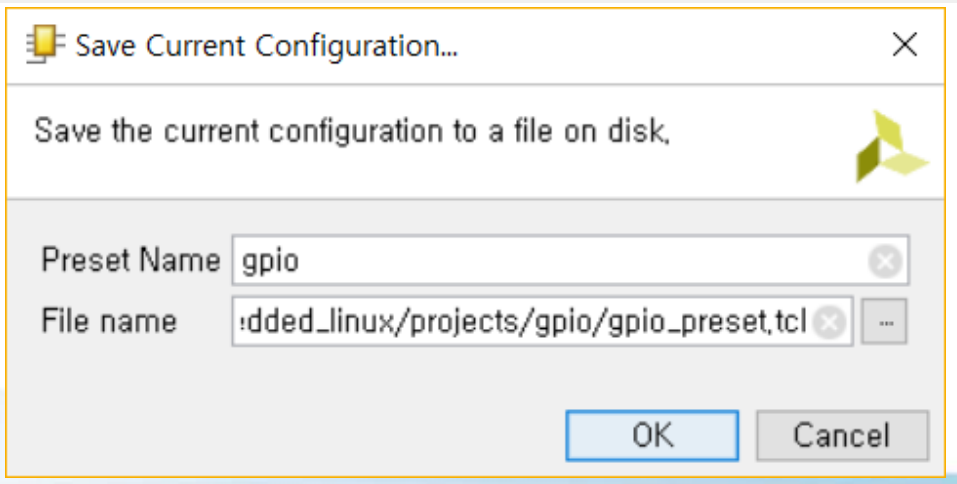

IP Integrator Diagram for GPIO

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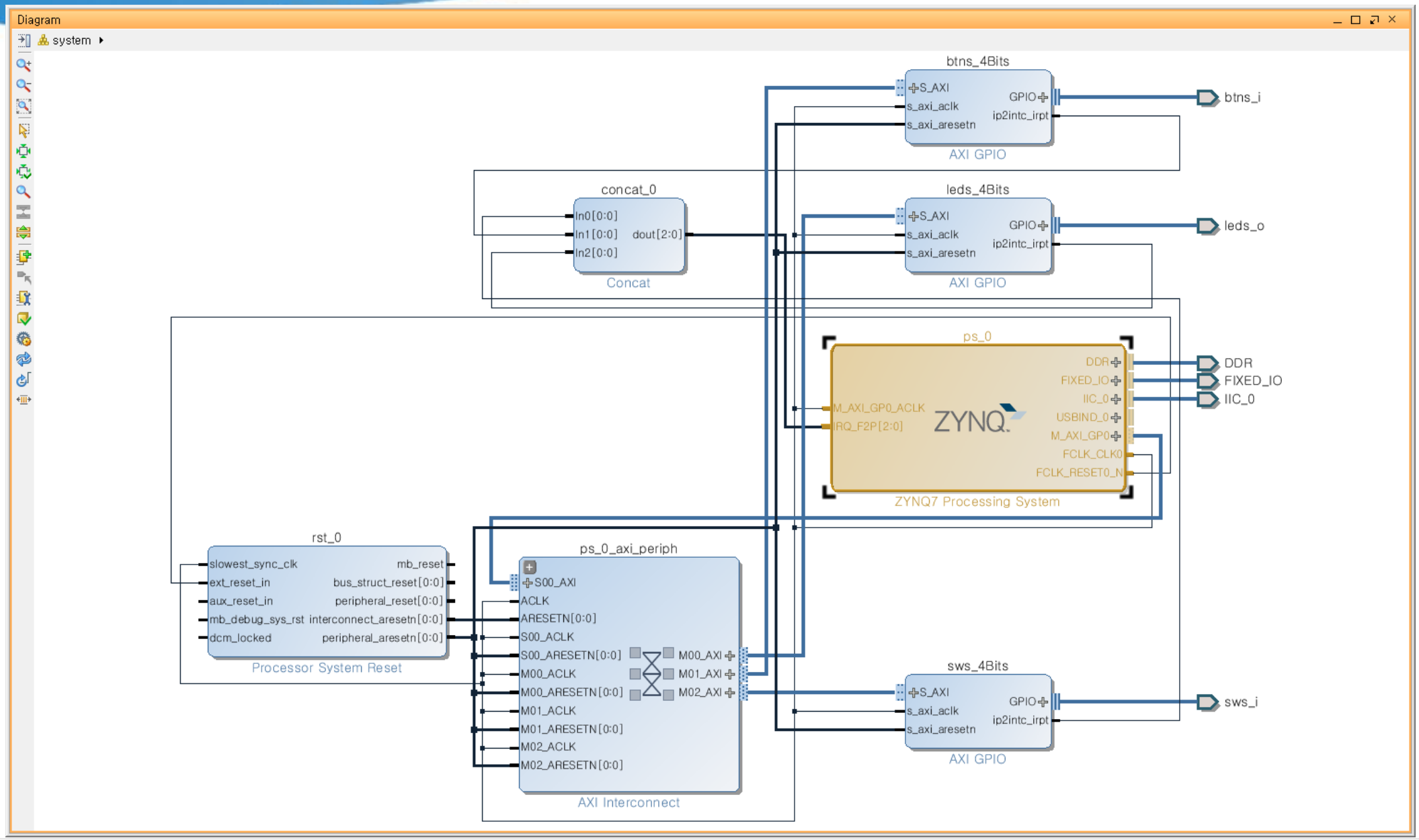
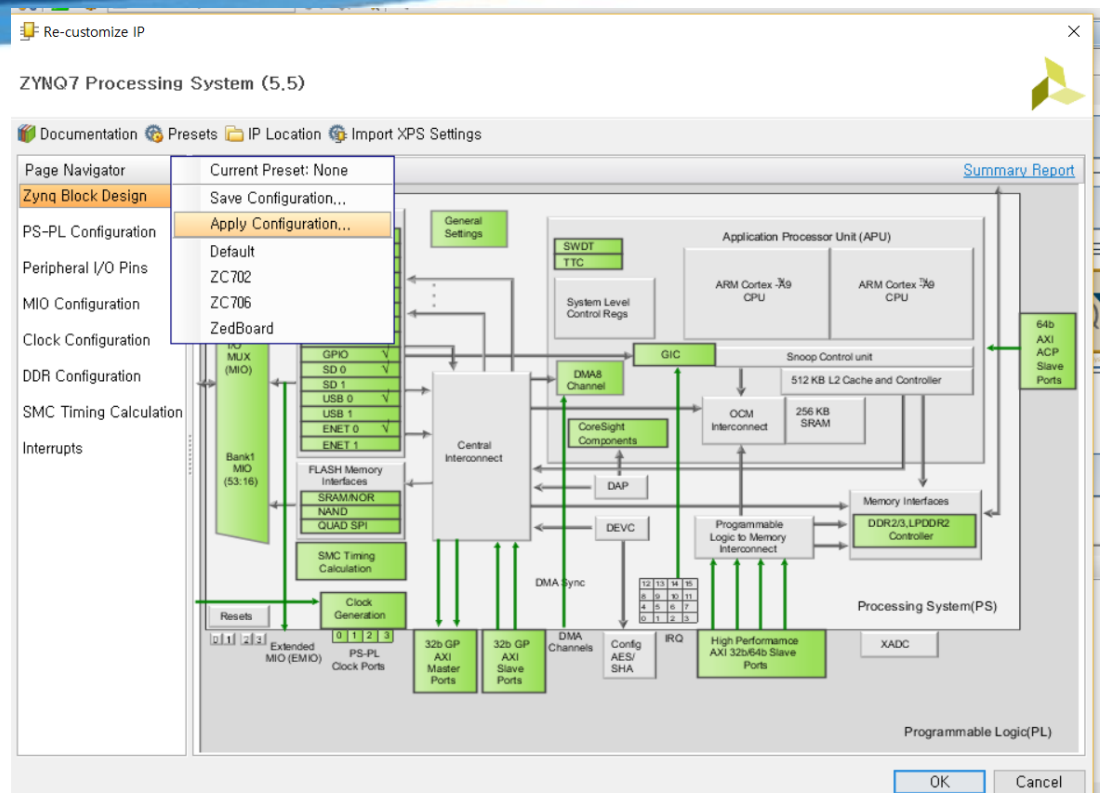
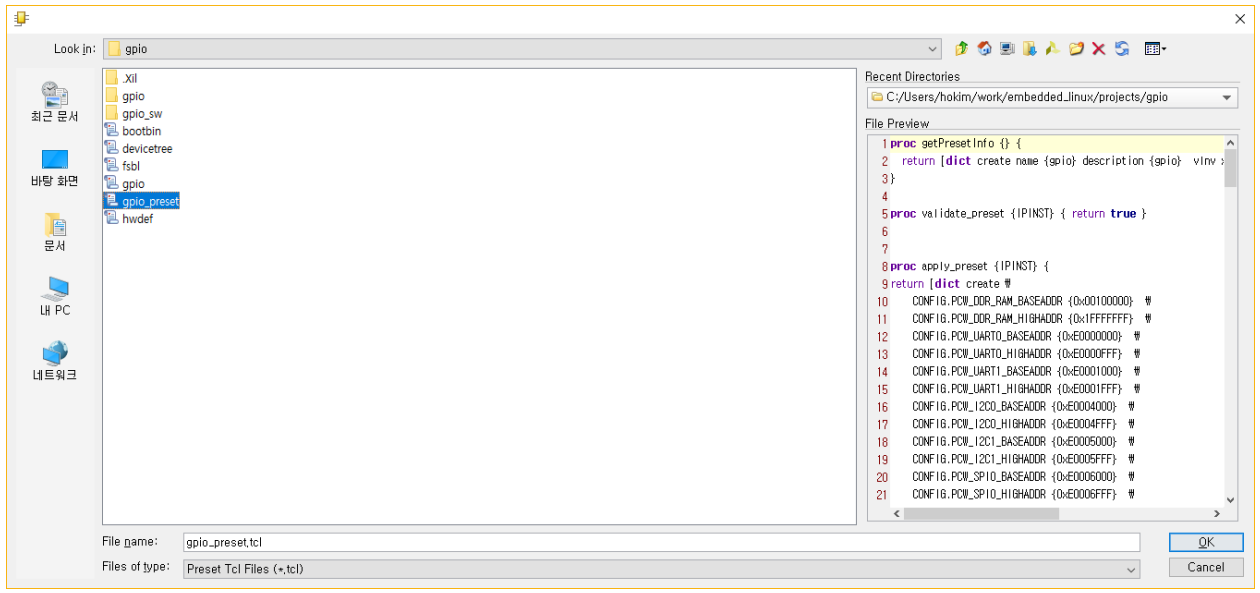


Address Editor

Cell	Slave Interface	Base Name	Offset Address	Range	High Address
ps_0					
Data (32 address bits : 0x40000000 [1G])					
leds_4Bits	S_AXI	Reg	0x4000_0000	4K	0x4000_0FFF
btns_4Bits	S_AXI	Reg	0x4000_1000	4K	0x4000_1FFF
sws_4Bits	S_AXI	Reg	0x4000_2000	4K	0x4000_2FFF

IP Integrator Diagram for GPIO





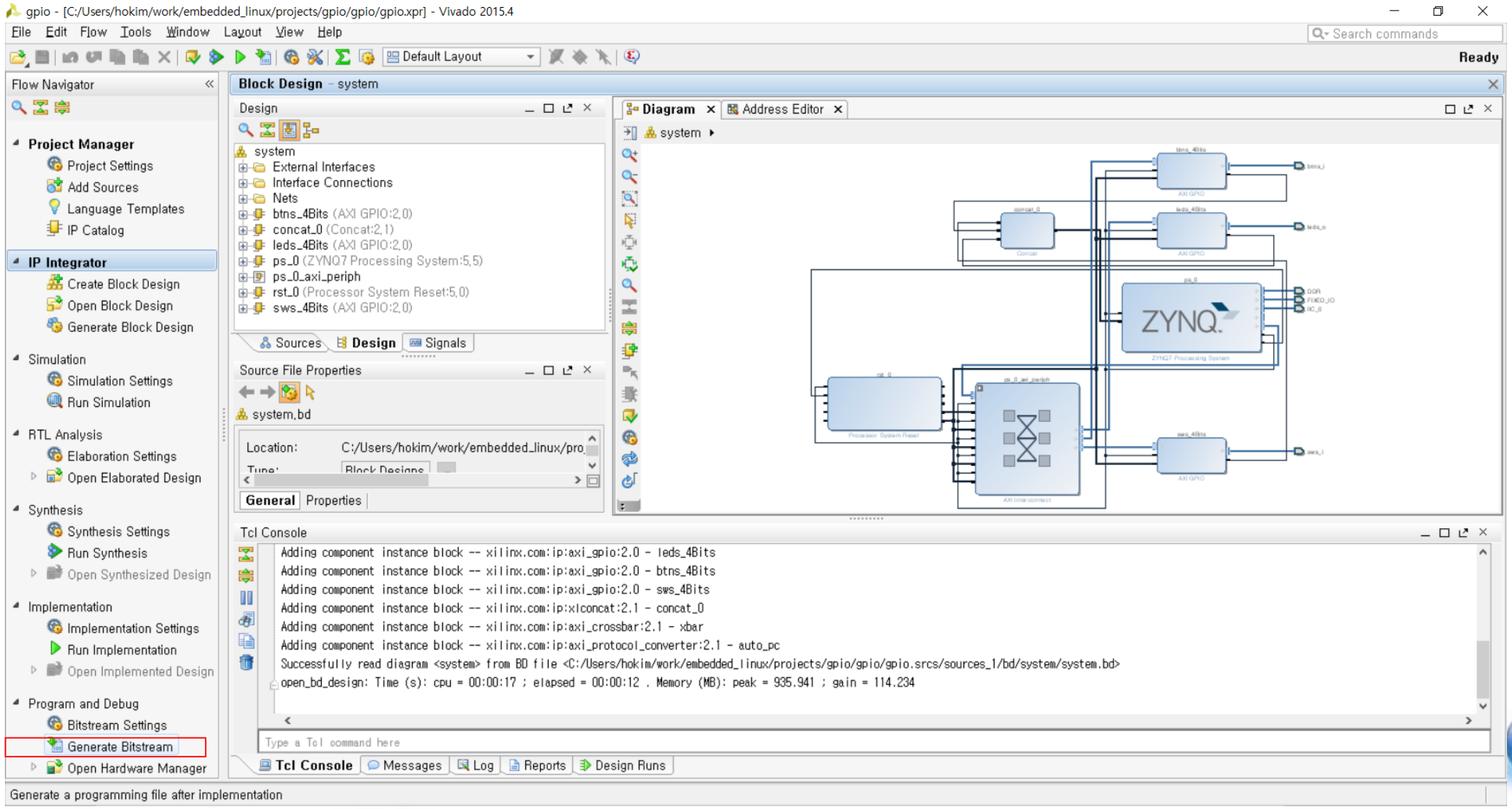
Bit Generation for GPIO

https://github.com/inipro/embedded_linux/projects/gpio

In cmd window for Vivado

```
C:\ cd C:\Users\hokim\work\embedded_linux\projects\gpio
C:\ vivado  -nolog -nojournal -mode batch -source gpio.tcl
```

output : gpio\gpio.xpr…



Boot.bin Build/DT Generation for GPIO

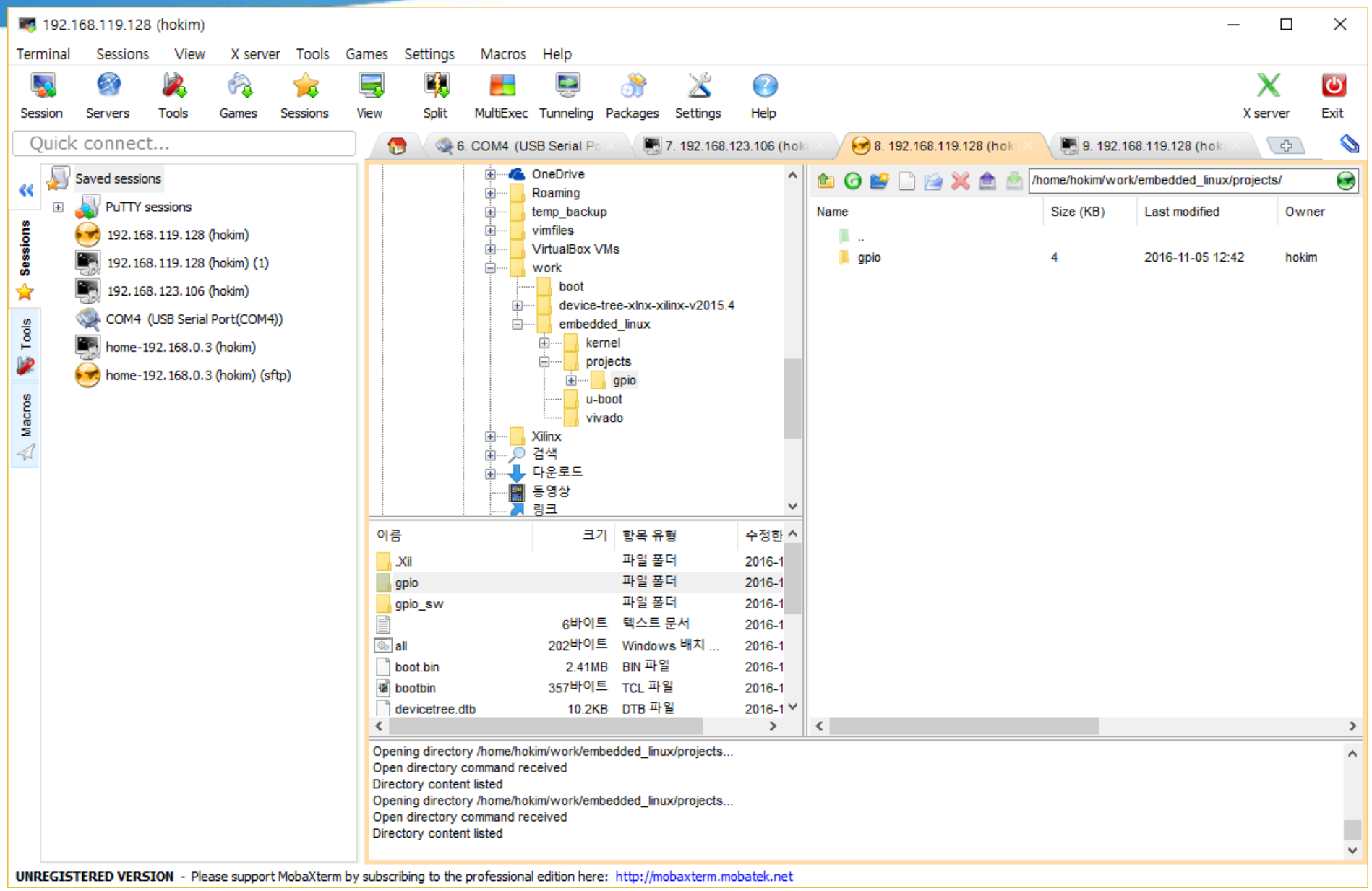
C:\Users\hokim\work\embedded_linux\projects\gpio\all.bat

```
call vivado -nolog -nojournal -mode batch -source hwdef.tcl
call hsi -nolog -nojournal -mode batch -source fsbl.tcl
call tclsh bootbin.tcl

call hsi -nolog -nojournal -mode batch -source devicetree.tcl
```

```
C:\ cd C:\Users\hokim\work\embedded_linux\projects\gpio
C:\ all
```

Device Tree Compile for GPIO




```
$ cd ~/work/embedded_linux/projects
$ cp ~gpio/gpio.tree/system.dts  system_gpio.dts
$ nano system_gpio.dts
```

Device Tree Compile for GPIO

INIPRO

system_gpio.dts

```
/dts-v1/;
/include/ "zynq-7000.dtsi"
/include/ "pl.dtsi“
…….
…….
&clkc {
    fclk-enable = <0x1>;
    ps-clk-frequency = <50000000>;
};

+&gem0 {
+    phy-handle = <&phy0>;
+    ps7_ethernet_0_mdio: mdio {
+        #address-cells = <0x1>;
+        #size-cells = <0x0>;
+        phy0: phy@0 {
+            compatible = "realtek,RTL8211E";
+            device_type = "ethernet-phy";
+            reg = <0>;
+        };
+    };
+};
```

```
+&i2c0 {
+    eeprom@50 {
+        /* Microchip 24AA02E48 */
+        compatible = "microchip,24c02";
+        reg = <0x50>;
+        pagesize = <8>;
+    };
+};
+/ {
+    usb_phy0: phy0 {
+        compatible = "ulpi-phy";
+        #phy-cells = <0>;
+        reg = <0xe0002000 0x1000>;
+        view-port = <0x0170>;
+        drv-vbus;
+    };
+};
+&usb0 {
+    usb-phy = <&usb_phy0>;
+};
```

Device Tree Compile for GPIO

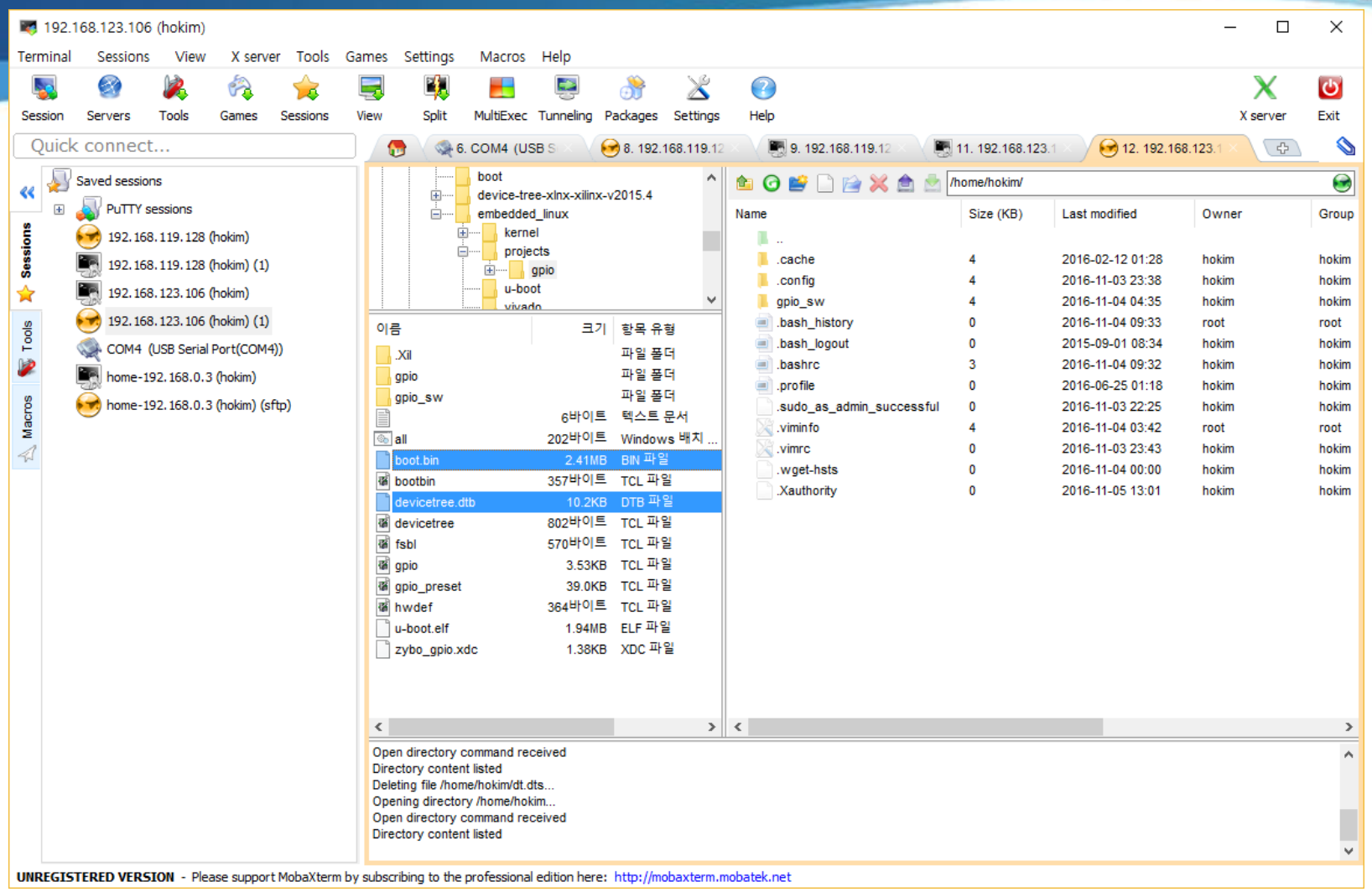
gpio/gpio.tree/*pl.dtsi*

```
/ {
        amba_pl: amba_pl {
                #address-cells = <1>;
                #size-cells = <1>;
                compatible = "simple-bus";
                ranges ;
                btns_4Bits: gpio@40001000 {
                        #gpio-cells = <2>;
                        compatible = "xlnx,xps-
gpio-1.00.a";
                        gpio-controller ;
                        interrupt-parent = <&intc>;
                        interrupts = <0 30 4>;
                        reg = <0x40001000
0x1000>;
.....
……
                };
                leds_4Bits: gpio@40000000 {
                        #gpio-cells = <2>;
                        compatible = "xlnx,xps-
gpio-1.00.a";
                        gpio-controller ;
                        interrupt-parent = <&intc>;
                        interrupts = <0 31 4>;
                        reg = <0x40000000
0x1000>;
.....
……
                };
```

```
                sws_4Bits: gpio@40002000 {
                        #gpio-cells = <2>;
                        compatible = "xlnx,xps-
gpio-1.00.a";
                        gpio-controller ;
                        interrupt-parent = <&intc>;
                        interrupts = <0 29 4>;
                        reg = <0x40002000
0x1000>;
.....
……
                };
        };
};
```

```
$ dtc -O dtb -I dts -i gpio/gpio.tree/ -o devicetree.dtb system_gpio.dts
```

Update boot.bin, devicetree.dtb for GPIO



login into zybo

```
$ sudo –s
# cd /boot
# rm boot.bin devicetree.dtb
# mv ~hokim/boot.bin .
# mv ~hokim/devicetree.dtb
# sync
# reboot
```

GPIO investigation

```
hokim@zybo:/sys/class/gpio$ ls
export  gpiochip894  gpiochip898  gpiochip902  gpiochip906  unexport

hokim@zybo:/sys/class/gpio$ ls gpiochip906
base  device  label  ngpio  power  subsystem  uevent

hokim@zybo:/sys/class/gpio$ cat gpiochip906/base
906

hokim@zybo:/sys/class/gpio$ cat gpiochip906/label
zynq_gpio

hokim@zybo:/sys/class/gpio$ cat gpiochip906/ngpio
118

hokim@zybo:/sys/class/gpio$ ls gpiochip894
base  label  ngpio  power  subsystem  uevent

hokim@zybo:/sys/class/gpio$ cat gpiochip894/base
894

hokim@zybo:/sys/class/gpio$ cat gpiochip894/label
/amba_pl/gpio@40002000

hokim@zybo:/sys/class/gpio$ cat gpiochip894/ngpio
4
```

```
hokim@zybo:/sys/class/gpio$ cat gpiochip898/base
898

hokim@zybo:/sys/class/gpio$ cat gpiochip898/label
/amba_pl/gpio@40000000

hokim@zybo:/sys/class/gpio$ cat gpiochip898/ngpio
4

hokim@zybo:/sys/class/gpio$ cat gpiochip902/base
902

hokim@zybo:/sys/class/gpio$ cat gpiochip902/label
/amba_pl/gpio@40001000

hokim@zybo:/sys/class/gpio$ cat gpiochip902/ngpio
4
```

GPIO sw & test

```
hokim@zybo:~$ cd gpio_sw/
hokim@zybo:~/gpio_sw$ ls
driver  mmap
hokim@zybo:~/gpio_sw$ cd driver
hokim@zybo:~/gpio_sw/driver$ ls
CMakeLists.txt  build  gpio.c  gpio.h  main.c
hokim@zybo:~/gpio_sw/driver$
hokim@zybo:~/gpio_sw/driver$ mkdir build
hokim@zybo:~/gpio_sw/driver$ cd build
hokim@zybo:~/gpio_sw/driver/build$ cmake ..
hokim@zybo:~/gpio_sw/driver/build$ sudo ./gpio_test
```

```
hokim@zybo:~$ cd gpio_sw
hokim@zybo:~/gpio_sw$ ls
driver  mmap
hokim@zybo:~/gpio_sw$ cd mmap
hokim@zybo:~/gpio_sw/mmap$ ls
CMakeLists.txt  lib  main.c
hokim@zybo:~/gpio_sw/mmap$ mkdir build
hokim@zybo:~/gpio_sw/mmap$ cd build
hokim@zybo:~/gpio_sw/mmap/build$ cmake ..
hokim@zybo:~/gpio_sw/mmap/build$ make
hokim@zybo:~/gpio_sw/mmap/build$ sudo ./gpio_test
```