香港中文大學
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CENG3430 Rapid Prototyping of Digital Systems

Lecture 08:
Rapid Prototyping (II) – Embedded Operating System

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Prototyping Styles with Zynq ZedBoard

ZYNQ®

	Style 1) FPGA (PL)	Style 2) ARM + FPGA	Style 3) Embedded OS	
Xilinx SDK (C/C++)		**Bare-metal Applications**	**Applications**	**SDK** (Shell, C, Java, …)
			Operating System	**Process System (PS)**
		Board Support Package	Board Support Package	
				software
				hardware
Xilinx Vivado (HDL)	**Programmable Logic Design**	**Hardware Base System**	Hardware Base System	**Program Logic (PL)**

Style 1)
FPGA (PL)
VHDL or Verilog Programming
(*Lec. 01~06 & 10*)

Style 2)
ARM + FPGA
ARM Programming & IP Block Design
(*Lec. 07 & 09*)

Style 3)
Embedded OS
Shell Script & `sysfs` EMIO GPIO
(*Lec. 08*)

Outline

- Embedded Operating System
  - Why Embedded Operating Systems
  - Types of Operating Systems
  - Zynq Operating Systems
- Case Study: Embedded Linux
  - Linux System Overview
  - Linux Kernel
  - Linux GPIO Driver: GPIO sysfs Interface
  - Shell Script
  - Lab 09: Linux GPIO Stopwatch

Why Embedded Operating Systems

- An embedded OS is not necessary for all digital systems, but it has the following advantages:
  - **Reducing Time to Market**
    - OS vendors provide support for various architectures and platforms.
      - If a software is mainly developed for an OS rather than a device, it is easy to be moved to another new architecture or device.
  - **Make Use of Existing Features**
    - Embedded OSs offer support for many validated features which would otherwise have to be developed by the system designer.
      - **Driver-level support** provides the low-level drivers that makes the connection between the embedded processor and the device.
      - **Graphical interface-level** support deals with the high-level graphical content that is to be displayed.
  - **Reduce Maintenance and Development Costs**
    - By making use of an embedded OS, the amount of custom code that needs to be developed and tested can be reduced.

Types of Operating Systems

- There are a number of possibilities when determining the type of OS to use on an embedded system:
  - **Standalone Operating Systems** (a.k.a., **Bare-metal OS**)
    - A simple OS that provides a very low-level of software modules that the system can use to access processor-specific functions.
    - A standalone OS enables close control over code execution but is fairly limited in terms of functionality.
  - **Real-Time Operating Systems (RTOS)**
    - The defining feature of a RTOS is the degree of determinism that is guaranteed by the scheduler.
    - The purpose of a RTOS is ***NOT*** to achieve a high throughput, but instead to respond both quickly and predictably for a given task.
  - Other Embedded Operating Systems
    - For applications that require high system performance, another type of OS is usually required, such as Linux and Android.

Zynq Operating Systems

- There're many Zynq-compatible embedded OSs:
  - **Xilinx Zynq-Linux**: An open source OS based on the 3.0 Linux kernel with additions such as BSP and device drivers.
  - **Petalogix® - Petalinux**: It provides a complete package to build, test, develop and deploy embedded Linux systems.
  - **Xillybus – Xillinux**: A desktop distribution of Linux that can run a full graphical desktop environment on the Zedboard.
    - A keyboard and mouse can be attached via the USB On-The-Go port, while a monitor can be connected to the provided VGA port.
  - **FreeRTOS**: a lightweight real-time OS that is available for a wide range of devices and processor architectures.
  - **Further Operating Systems**: There are a large number of OSs for Zynq which are provided by Xilinx partners:
    - E.g., Adeneo Embedded Windows CE 7.0, Linux, Android and QNX.

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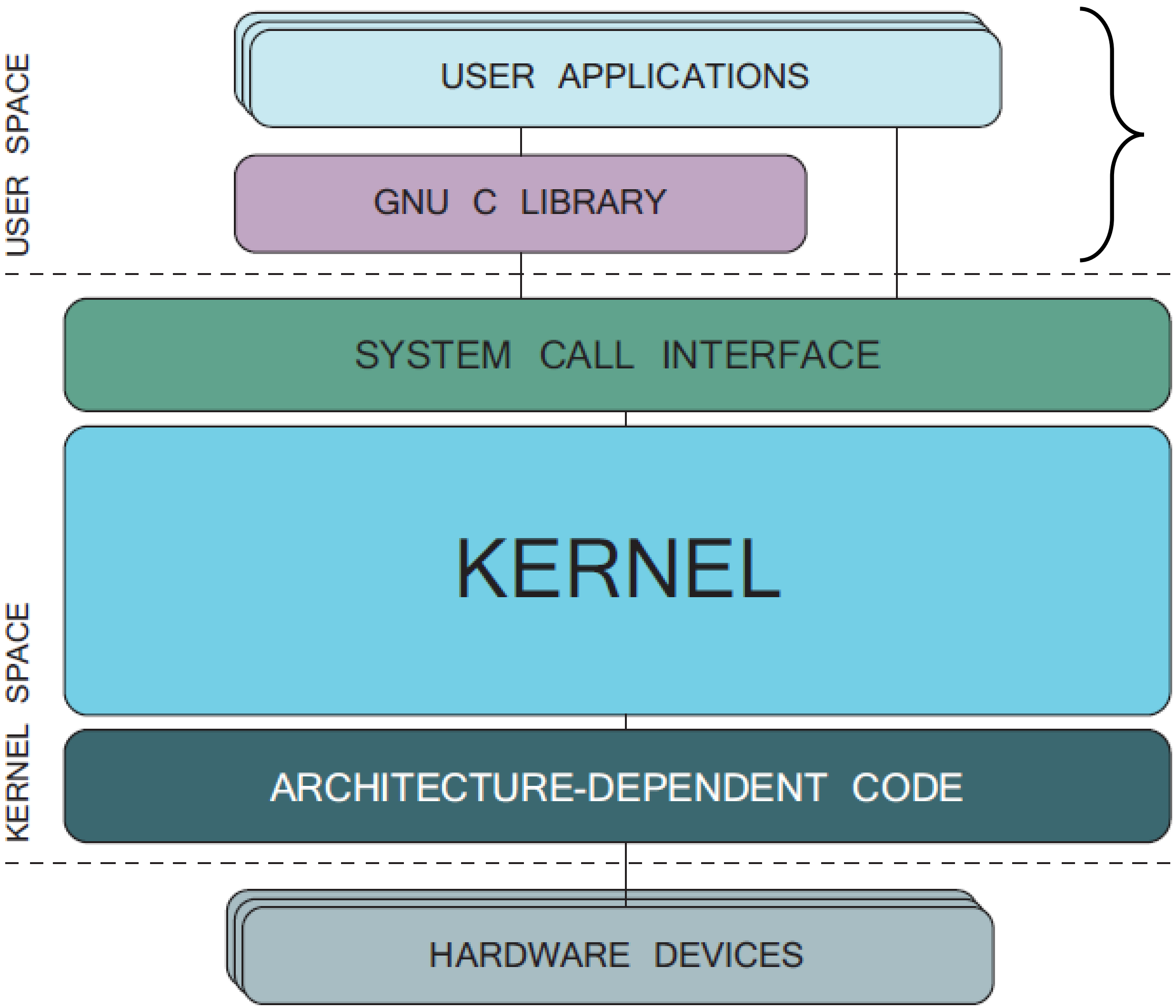
Linux System Overview

- Below shows a generalized GNU/Linux System:



Applications run on top of the kernel in user-space.

SCI facilitates function calls from the user space to the kernel of system.

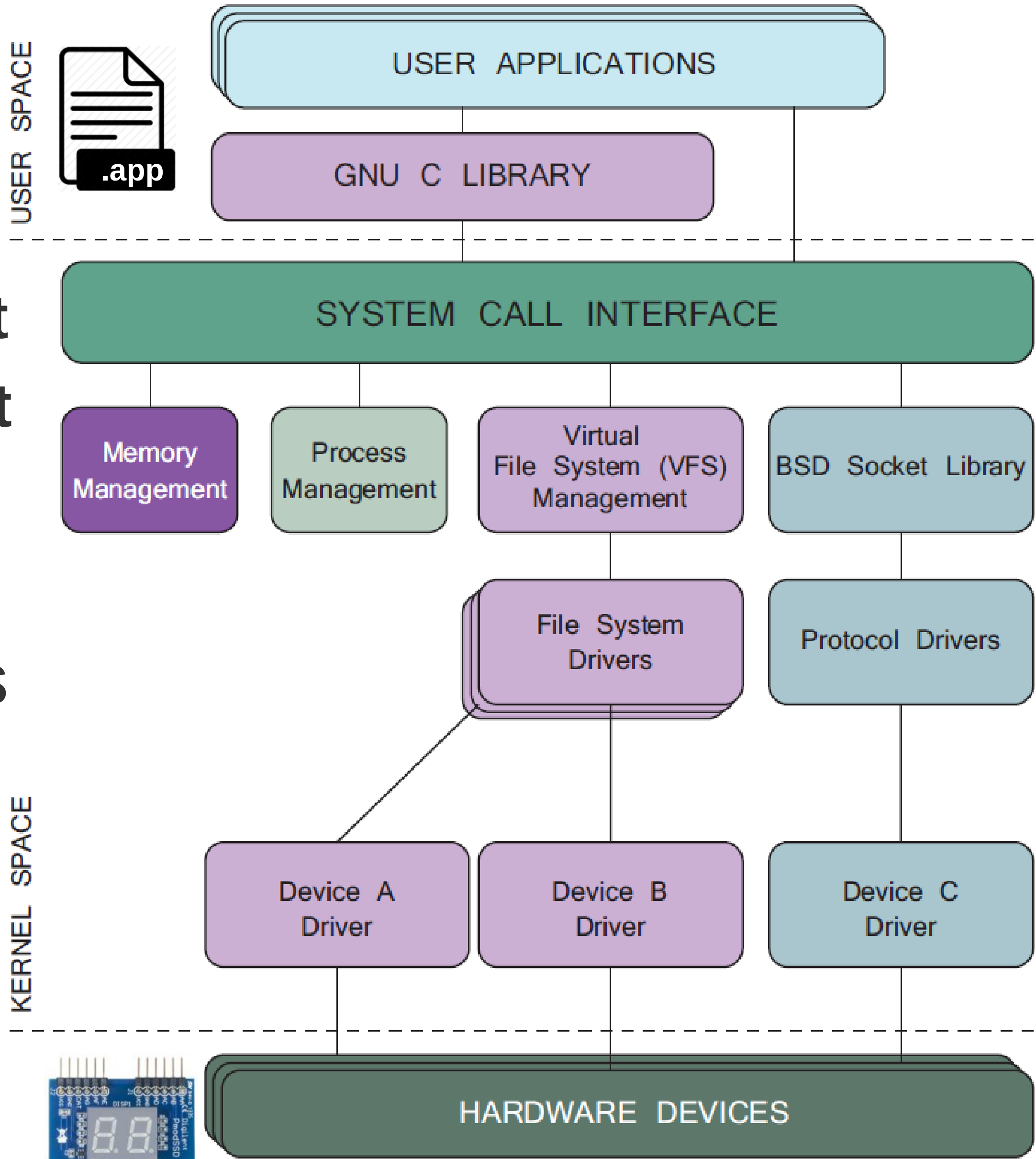
Kernel provides a set of tools with which the user can interact with hardware.

Platform-specific code: BSP (board support package).

Hardware devices are abstracted from the user-level by the kernel space.

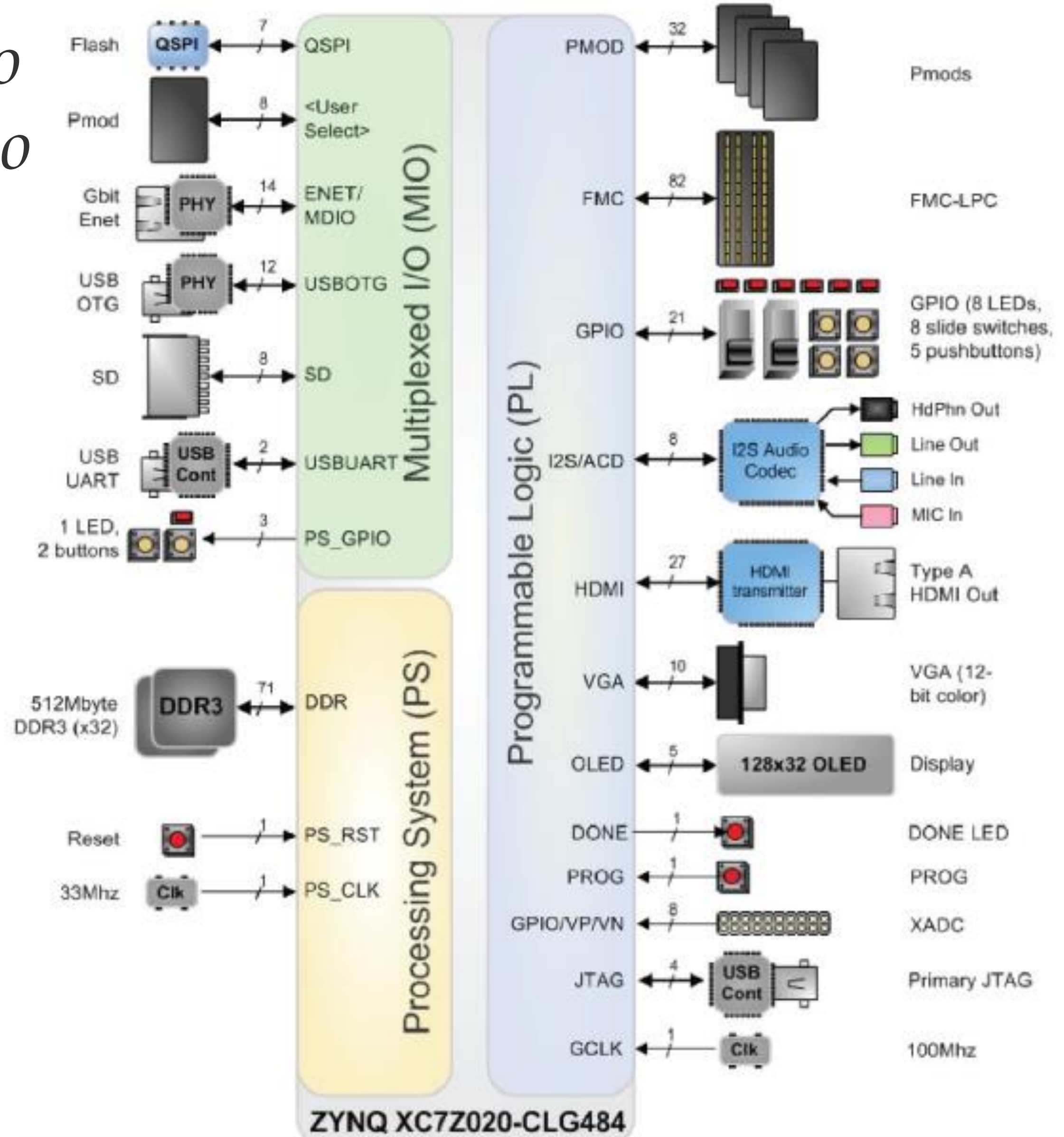
Linux Kernel

- **Linux kernel** is of subsystems providing required services:
  - **Memory Management**
  - **Process Management**
  - **Virtual File System**
  - **Device Drivers**
- A system call provides *interaction between user application and kernel services*.
  - Where direct calls are ***NOT*** allowed.



Software Stopwatch with Zynq-Linux?

- ***Question***: *Can we also design an application to realize a software stopwatch on top of Zynq-Linux?*
- ***Answer***: *Yes, through the GPIO interface.*



The Zynq-Linux can be performed on the ARM CPU (PS) of ZedBoard.

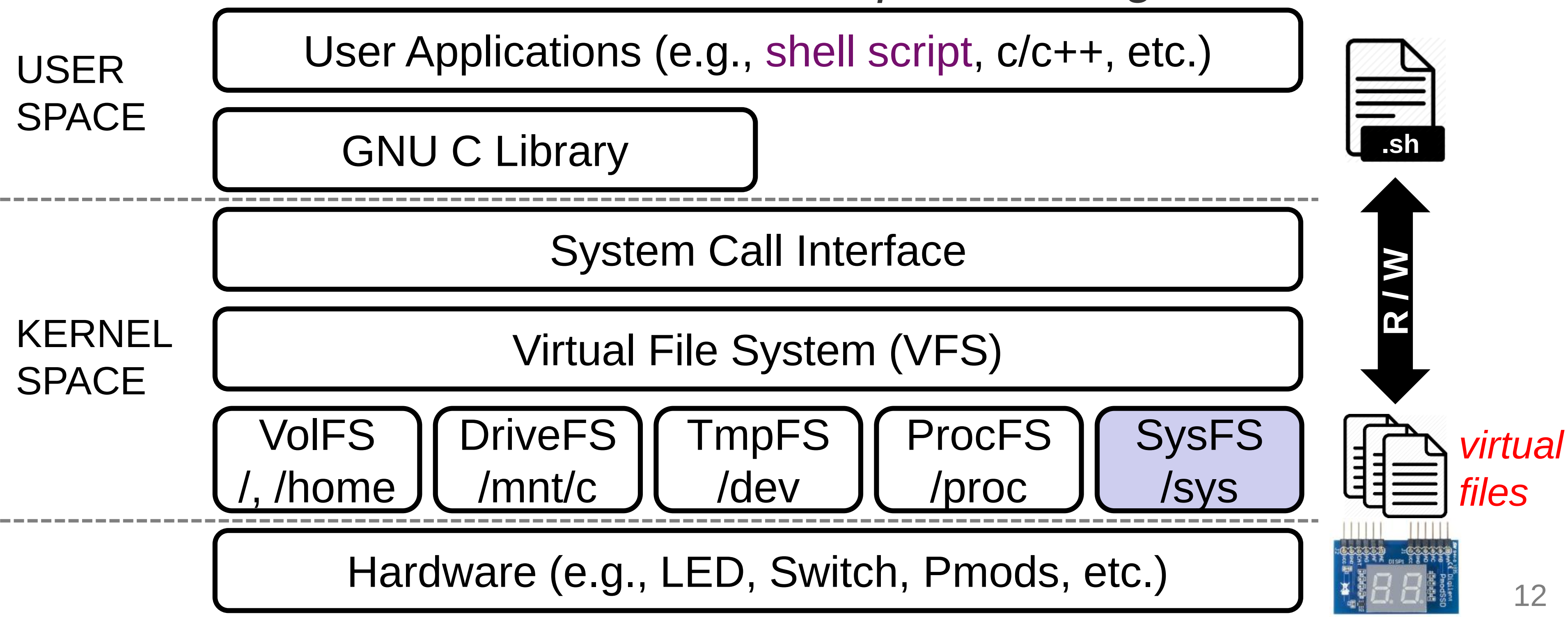
General-Purpose Input/Output (GPIO)

- **General-purpose input/output (GPIO)**:
  - *Uncommitted digital signal pins on an integrated circuit or board whose behavior—including whether it acts as input or output—is controllable by the user at run time.*
- Zynq-Linux defines **60** GPIO signals between PS and PL via the extended multiplexed I/O (EMIO) interface to control the pins on the board (see `system.ucf`):
  - USB OTG Reset: `processing_system7_0_GPIO<0>`
  - OLED: `processing_system7_0_GPIO<1>~<6>`
  - LED: `processing_system7_0_GPIO<7>~<14>`
  - Switches: `processing_system7_0_GPIO<15>~<22>`
  - Buttons: `processing_system7_0_GPIO<23>~<27>`
  - Pmod (JA~JD): `processing_system7_0_GPIO<28>~<59>`

(Note: These IDs should be shifted by 54 which is for MIO GPIOs.)

GPIO sysfs Interface

- One easiest way to control GPIO in Linux is through the **`sysfs`** interface (`/sys/class/gpio`):
  - ***`sysfs`*** *is a pseudo file system provided by the Linux kernel that exports information about various kernel subsystems, hardware devices, and associated device drivers from the kernel's device model to user space through virtual files.*



Dash Shell Script (`#/bin/sh`)

- A **shell script** is a list of commands that can run by the Unix shell directly in a sequential manner.
  - Unix shell is a command line (or terminal) interpreter.
- Common commands of a shell script:
  - Comment: `#` *comment*
  - Arguments: `$0, $1, $2,` …
  - Variable: `$`*var*
  - Command: `$(`*command*`)` or `` ` ``*command*`` ` ``
  - Expression: `$((`*expression*`))`
  - Loop: `for` *i* `in $(seq` *1 n*`) do` … `done;`
  - Function Call: *function_name parameters*
  - Read from File: `` `cat `` *file_path*`` `; ``
  - Write to File: `echo $`*value* `>` *file_path*`;`

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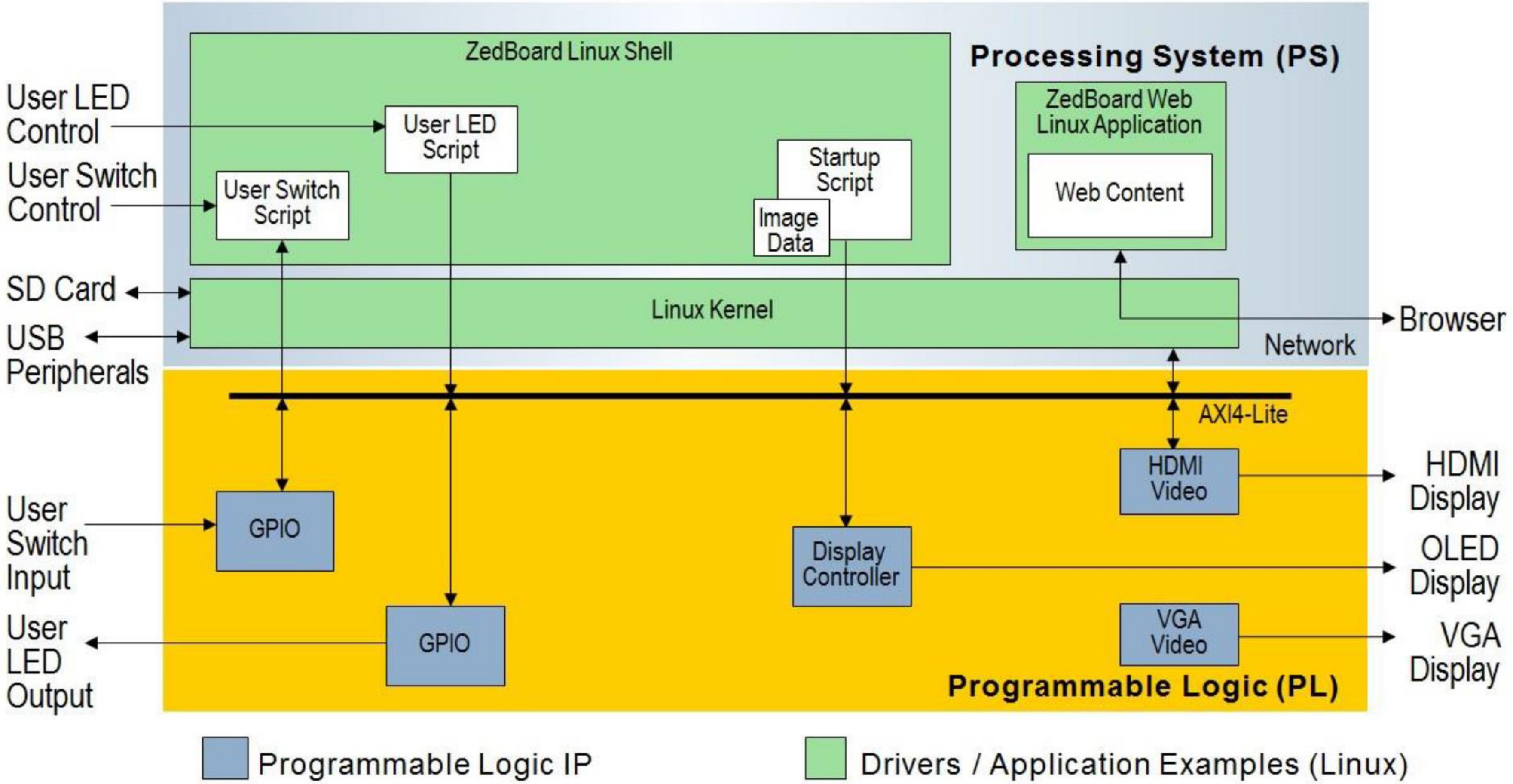
Lab 09: Linux GPIO Stopwatch

- In Lab 09, we will implement a software stopwatch by controlling LED, Switch and Pmod seven-segment display using the shell script language.

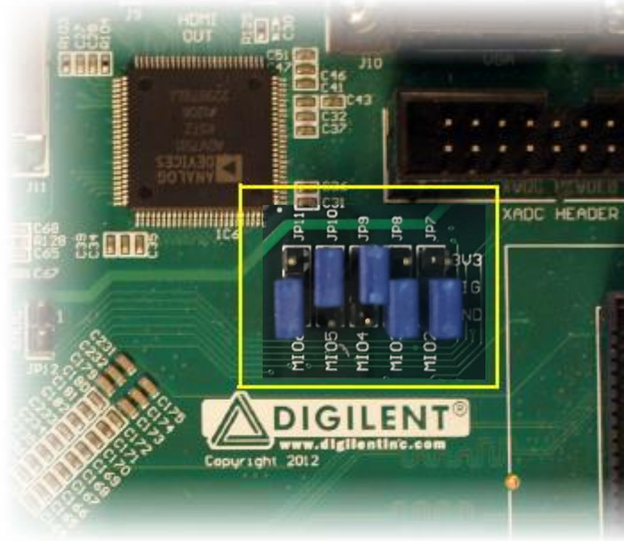


Booting the ZedBoard from SD Card

- The ZedBoard user specifies the method of booting / programming via a set of jumper pins.
  - The middle three are for specifying programming source.

	MIO[6]	MIO[5]	MIO[4]	MIO[3]	MIO[2]
In Xilinx Technical Reference Manual...	Boot_ Mode[4]	Boot_ Mode[0]	Boot_ Mode[2]	Boot_ Mode[1]	Boot_ Mode[3]
		JTAG Mode			
Cascaded JTAG[a]	-	-	-	-	0
Independent JTAG	-	-	-	-	1
		Boot Device			
JTAG	-	0	0	0	-
Quad-SPI (flash)	-	1	0	0	-
SD Card[a]	-	1	1	0	-
		PLL Mode			
PLL Used[a]	0	-	-	-	-
PLL Bypassed	1	-	-	-	-

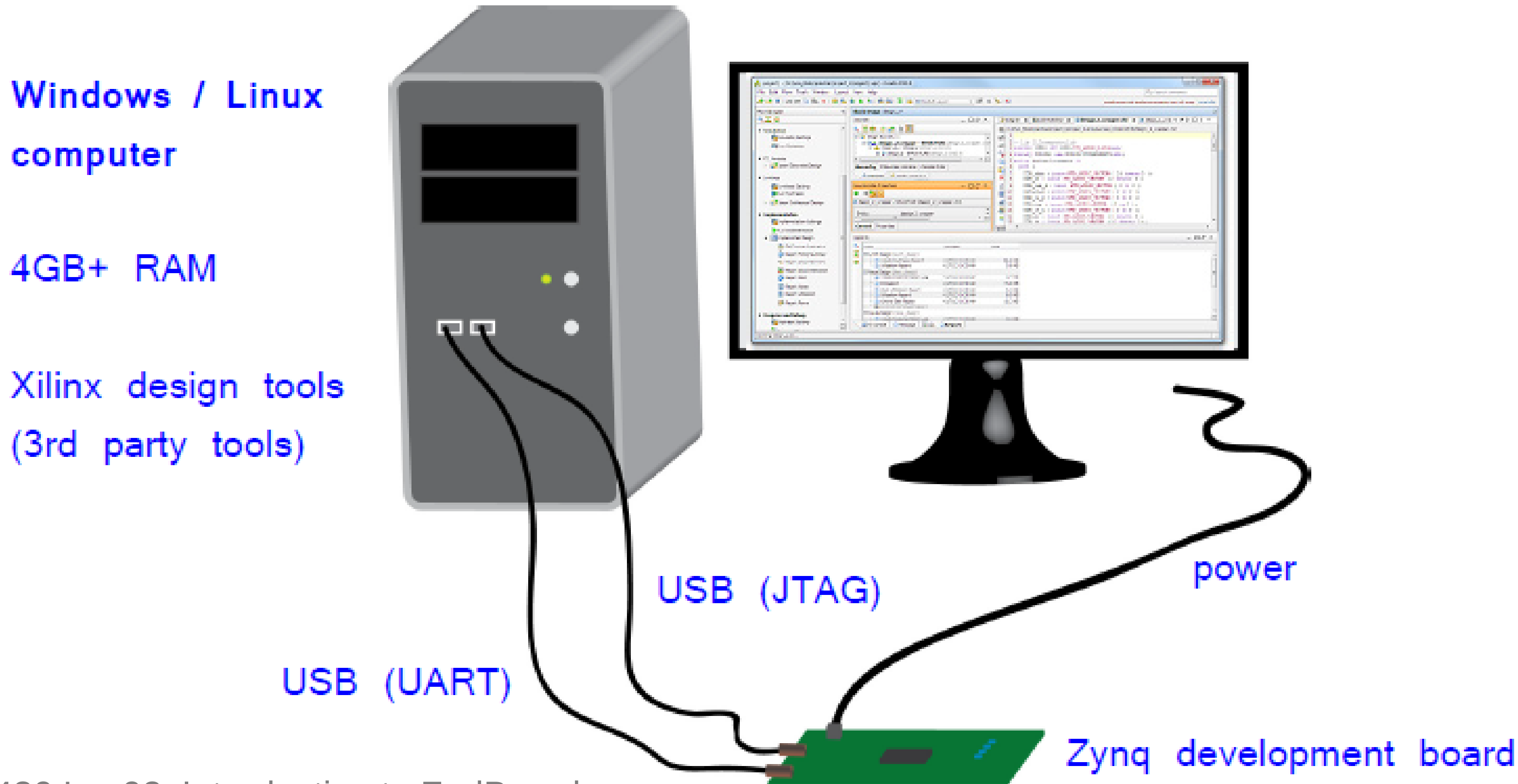
Cascaded: A single JTAG connection is used to interface to the debug access ports in both the PS and PL.



The PLL mode determines whether the process of configuring the device includes a phase of waiting for the PLL to lock

Zynq Development Setup

- Joint Test Action Group (JTAG): Downloading designs onto the development board over JTAG
- Universal Asynchronous Receiver/Transmitter (UART) and Terminal Applications: Interfacing and debugging



Sample Script 1) read_sw.sh

```
#!/bin/sh
value=0;

for i in 0 1 2 3 4 5 6 7; # total 8 switches, GPIO ID from 69~76.
do
  sw=$((76-$i));
  sw_tmp=`cat /sys/class/gpio/gpio$sw/value`; # read the value from the sw using corresponding gpioID

  value=$(($value*2)); # adding the value in order, since we read the binary value so using 2 instead of 10 here
  value=$(($value+$sw_tmp));
done;

printf "0x%x %d\n" $value $value; # print out value in both hexadecimal & decimal format
```

Sample Script 2) write_led.sh

```
#!/bin/sh
value=$(($1)); # arguments of the script (e.g., write_led 0xFF)

if [ $value -ge 0 ]; then
  for i in 0 1 2 3 4 5 6 7; # total 8 led, GPIO ID from 61~68
  do
    led=$(($i+61)); # i-th gpioID corresponding to led_i

    echo $(($value&0x01)) > /sys/class/gpio/gpio$led/value; # use bit-wise and '&' to get the right-most bit and write to i-th gpio

    value=$(($value/2)); # using divide operation to remove the previous right-most bit
  done;
fi;
```

Sample Script 3) single_count_down.sh

```
#!/bin/sh
display() { # display function
  value=$1 # the first argument is the number will be show in seven-segment
  echo $2 > /sys/class/gpio/gpio93/value; # the second argument defines which seven-segment will be used (gpio id 93 is ssdcat)
  for i in 0 1 2 3 4 5 6;
    do
      pin=$((92-$i));
      if [ $i -gt 2 ];
      then
        pin=$(($pin-4));
        # JA:82~85 / JB: 90~92
      fi;
      echo $(($value&0x01)) > /sys/class/gpio/gpio$pin/value; # output one segment
        value=$(($value/2)); # move to next segment
    done;
}
```

```
# seven-segment display patterns, refer to Lab sheet 6, here we represent them in decimal values
p0=126;
p1=48;
p2=109;
…
p15=71;

for i in $(seq 0 15); # display 0~15
do
    idx=$((15-$i)); # count down the number to be shown on the SSD

    display $((p$idx)) 0; # invoke the display function, argument #1 is the pattern of the i-th number, argument #2 is the ssdcat for selecting the left/right seven-segment

    sleep 1; # delay one sec
done;
```

How to Run .sh Files?

- Give execute permission to your script:

```
chmod +x /path/to/yourscript.sh
```

- Run your script (“.” refers to current directory):

```
/path/to/yourscript.sh
./yourscript.sh
```

COM13:115200baud - Tera Term VT

File Edit Setup Control Window Help

```
[    1.320000] Freeing init memory: 152K
Starting rcS...
++ Mounting filesystem
++ Setting up mdev
++ Configure static IP 192.168.1.10
[    1.510000] GEM: lp->tx_bd ffdfb000 lp->tx_bd_dma 18a36000 lp->tx_skb d8ab56c
0
[    1.510000] GEM: lp->rx_bd ffdfc000 lp->rx_bd_dma 18a44000 lp->rx_skb d8ab57c
0
[    1.520000] GEM: MAC 0x00350a00, 0x00002201, 00:0a:35:00:01:22
[    1.520000] GEM: phydev d8b6b400, phydev->phy_id 0x1410dd1, phydev->addr 0x0
[    1.530000] eth0, phy_addr 0x0, phy_id 0x01410dd1
[    1.530000] eth0, attach [Marvell 88E1510] phy driver
++ Starting telnet daemon
++ Starting http daemon
++ Starting ftp daemon
++ Starting dropbear (ssh) daemon
++ Starting OLED Display
[    1.570000] pmodoled-gpio-spi [zed_oled] SPI Probing
++ Exporting LEDs & SWs
rcS Complete
zynq> read_sw
0x55 85
zynq>
```

← Not necessary to have the file extension in Linux

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