Embedded Operating System

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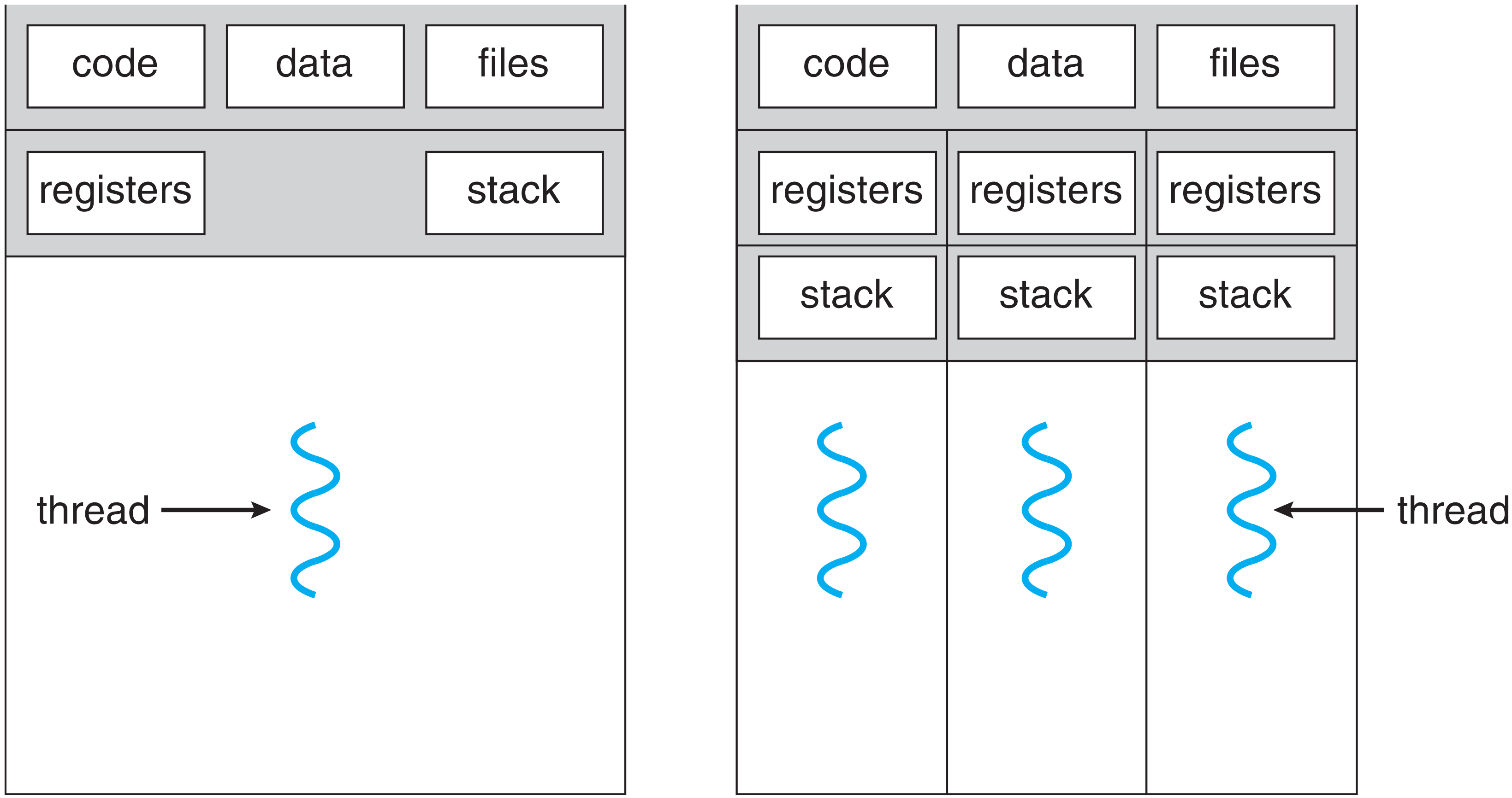
Concepts of Pthread

Single and Multithreaded Processes



single-threaded process

multithreaded process

Definition of Threads

- A thread is defined as an independent stream of instructions that can be scheduled to run
- To the software developer, the concept of a "procedure" that runs independently from its main program may best describe a thread
- To go one step further, imagine a main program that contains a number of procedures
  - Then imagine all of these procedures being able to be scheduled to run simultaneously and/or independently by the operating system
  - That would describe a "multi-threaded" program

Reference: https://computing.llnl.gov/tutorials/pthreads/

A Process

- A UNIX process is created by the operating system
- It requires a fair amount of overhead for the creation and context switch among processes
- Processes contain information about program resources and program execution state, including:
  - Process ID, process group ID, user ID, and group ID
  - Working directory
  - Program instructions
  - Registers, stack, heap
  - File descriptors
  - Signal actions
  - Shared libraries
  - Inter-process communication tools
    - Message queues, pipes, semaphores, and shared memory

A Thread

- Threads use and exist within the process resources
- Threads are able to be scheduled by the operating system and run as independent entities
- Threads duplicate only the bare essential resources that enable them to exist as executable code
  - Stack pointer
  - Registers
  - Scheduling properties (such as policy or priority)
  - Set of pending and blocked signals
  - Thread specific data

User Threads and Kernel Threads

- User threads
  - Management done by user-level threads library
  - Three primary thread libraries:
    - POSIX Pthreads
    - Win32 threads
    - Java threads
- Kernel threads
  - Supported by the Kernel
  - Examples – virtually all general purpose operating systems, including: Windows, Solaris, Linux, Tru64 UNIX, Mac OS X
  - Linux supports one-to-one mapping for a Pthread to a kernel thread, which is the environment for this lab exercise

History of Pthread

- Historically, hardware vendors have implemented their own proprietary versions of threads which are not portable
- In order to take full advantage of the capabilities provided by threads, a standardized programming interface was required
- For UNIX systems, this interface has been specified by the IEEE POSIX 1003.1c standard (1995)

  ➔ Thus, it is called Pthread (POSIX thread)

Pthreads vs Processes

- For 50,000 process/thread creations, the time is measured in seconds

Platform	fork()			pthread_create()		
	real	user	sys	real	user	sys
Intel 2.6 GHz Xeon E5-2670 (16 cores/node)	8.1	0.1	2.9	0.9	0.2	0.3
Intel 2.8 GHz Xeon 5660 (12 cores/node)	4.4	0.4	4.3	0.7	0.2	0.5
AMD 2.3 GHz Opteron (16 cores/node)	12.5	1.0	12.5	1.2	0.2	1.3
AMD 2.4 GHz Opteron (8 cores/node)	17.6	2.2	15.7	1.4	0.3	1.3
IBM 4.0 GHz POWER6 (8 cpus/node)	9.5	0.6	8.8	1.6	0.1	0.4
IBM 1.9 GHz POWER5 p5-575 (8 cpus/node)	64.2	30.7	27.6	1.7	0.6	1.1
IBM 1.5 GHz POWER4 (8 cpus/node)	104.5	48.6	47.2	2.1	1.0	1.5
INTEL 2.4 GHz Xeon (2 cpus/node)	54.9	1.5	20.8	1.6	0.7	0.9
INTEL 1.4 GHz Itanium2 (4 cpus/node)	54.5	1.1	22.2	2.0	1.2	0.6

Source: https://computing.llnl.gov/tutorials/pthreads/

Considerations for Designing Parallel Programs

- Problem partitioning
- Load balancing
- Communications
- Data dependencies
- Synchronization and race conditions
- Memory issues
- I/O issues
- Debugging efforts

Pthreads API

- Thread Management:
  - Routines that work directly on threads, such as creating, detaching, joining
- Mutex:
  - Routines that deal with synchronization, called a "mutex", which is an abbreviation for "mutual exclusion"
  - Mutex functions are provided for creating, destroying, locking and unlocking mutexes
- Condition Variable:
  - Routines to create, destroy, wait and signal based upon specified variable values
  - Functions to set/query condition variable attributes are also included

Tools for Using Pthread

Compiling Threaded Programs

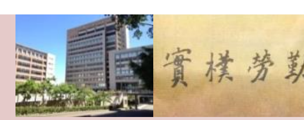
Compiler / Platform	Compiler Command	Description
INTEL **Linux**	**icc -pthread**	C
	icpc -pthread	C++
PGI **Linux**	**pgcc -lpthread**	C
	pgCC -lpthread	C++
GNU **Linux, Blue Gene**	**gcc -lpthread**	GNU C
	g++ -lpthread	GNU C++
IBM **Blue Gene**	**bgxlc_r / bgcc_r**	C (ANSI / non-ANSI)
	bgxlC_r, bgxlc++_r	C++

Creating and Terminating

- Routines
  - pthread_create (thread,attr,start_routine,arg)
  - pthread_exit (status)
  - pthread_cancel (thread)
  - pthread_attr_init (attr)
  - pthread_attr_destroy (attr)
- Initially, your main() program comprises a single, default thread
- All other threads must be explicitly created by the programmer
- The function pthread_create() creates a new thread and makes it executable
  - Return 0 for success

pthread_create() Arguments

- thread:
  - An identifier for the new thread returned by the subroutine
- attr:
  - An opaque attribute object that may be used to set thread attributes
  - You can specify a thread attributes object, or use NULL for the default values
- start_routine:
  - The C routine that the thread will execute once it is created
- arg:
  - A single argument that may be passed to the start_routine
  - It must be passed by reference as a pointer cast of type void
  - NULL may be used if no argument is to be passed.



An Example pthread_create()

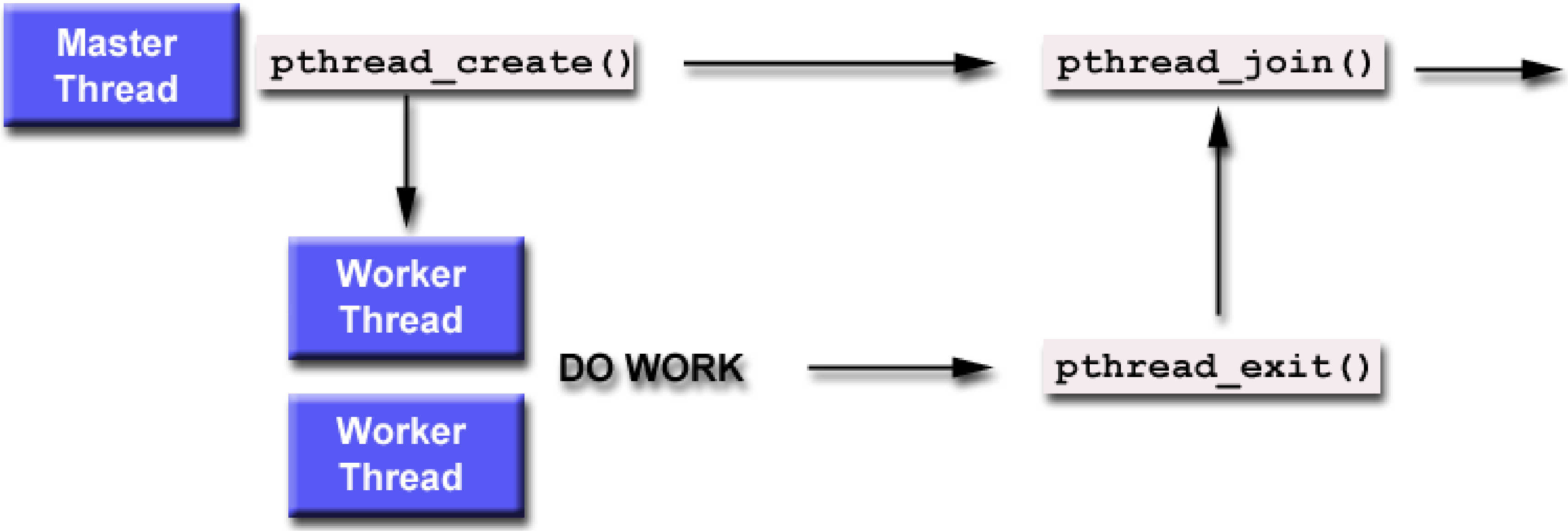
```
#include <pthread.h>
#include <stdio.h>
#define NUM_THREADS     5

void *PrintHello(void *threadid)
{
   printf("\n%d: Hello World!\n", threadid);
   pthread_exit(NULL);
}

int main (int argc, char *argv[])
{
   pthread_t threads[NUM_THREADS];
   int rc, t;
   for(t=0; t<NUM_THREADS; t++){
      printf("Creating thread %d\n", t);
      rc = pthread_create(&threads[t], NULL, PrintHello, (void *)t);
      if (rc){
         printf("ERROR; return code from pthread_create() is %d\n", rc);
         exit(-1);
      }
   }
   pthread_exit(NULL);
}
```

Function pointer for the routine

The type of threads

Thread: thread[t], attribute: default, function: PrintHello, input: t

Joining Threads



Function pthread_join()

- The Format:
  - ➔int pthread_join(pthread_t thread, void **value_ptr);
- pthread_t thread is for the thread to wait
- void ** value_ptr is for the return value of the thread
- The int return value:
  - 0 is for success
  - Others are for errors

Mutex

- Create a mutex:
  - pthread_mutex_t   count_mutex = PTHREAD_MUTEX_INITIALIZER;
- Lock a mutex:
  - pthread_mutex_lock(&count_mutex);
    - It is a blocking lock
  - pthread_mutex_trylock ((&count_mutex);
    - It is a non-blocking lock
- Release a mutex:
  - pthread_mutex_unlock(&count_mutex);

An Example with Mutex (1/2)

```
#include <stdio.h>
#include <pthread.h>
#define TCOUNT 10
#define NUM_THREADS 3
int count = 0;
pthread_mutex_t count_mutex = PTHREAD_MUTEX_INITIALIZER;
int thread_ids[3] = {0, 1, 2};

int inc_count(void *idp)
{
    int i;
    for(i=0; i < TCOUNT; i++)
    {
        pthread_mutex_lock(&count_mutex);
        count++;
        pthread_mutex_unlock(&count_mutex);
        printf("inc_counter():thread %d, old count %d, new count %d, \n", (int)idp, count-1, count);
        sleep(1);
    }
    return 0;
}
```

Initialize a mutex

count++ should be protected by a mutex

An Example with Mutex (2/2)

Thread ID

Default Attribute

Function Pointer

Input Value

```
int main()
{
    int i;
    pthread_t threads[3];
    pthread_create(&threads[0], NULL, (void *)&inc_count, (void *)thread_ids[0]);
    pthread_create(&threads[1], NULL, (void *)&inc_count, (void *)thread_ids[1]);
    pthread_create(&threads[2], NULL, (void *)&inc_count, (void *)thread_ids[2]);

    for(i=0; i<NUM_THREADS; i++)
    {
        pthread_join(threads[i], NULL);
    }
    printf("done ... terminate with kill command or CRTL+C\n");
    return 0;
}
```

Wait the previous three threads

Preparation

Notices

- No food, no drink
- The evaluation boards are quite expensive
- Do not do anything else to crash the PC
- Do not update the OS nor tools to keep the consistency
- Remember the number of your evaluation board
  - Check the items before you use them
  - Check the items before you return them
- No rubbish

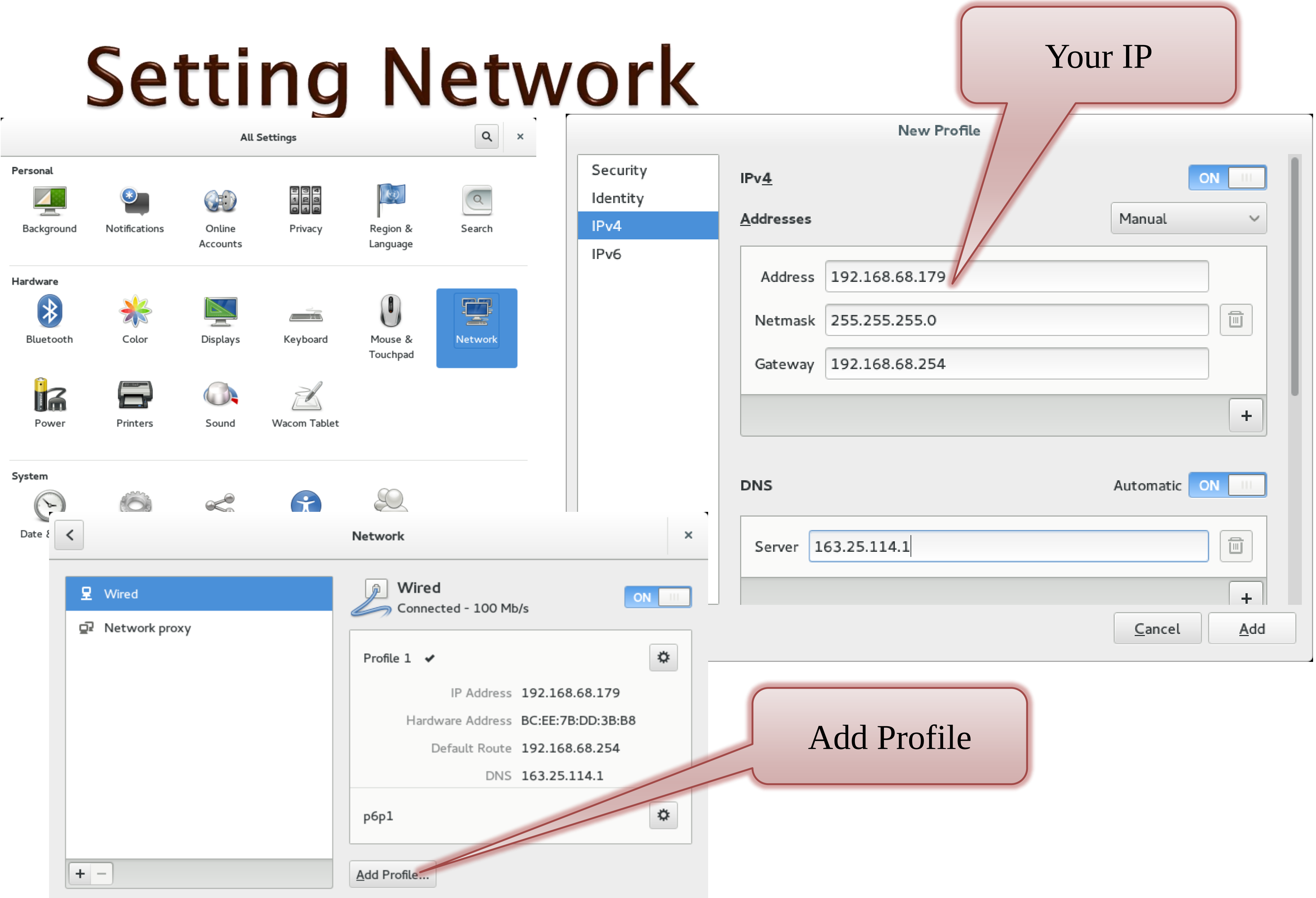
What are We Going to Do?

- Build the Cross Development Toolchain
- Build the Linux Kernel
  ➔Check Point 1: uImage
- Setup a TFTP Server
- Setup NFS Server
  ➔Check Point 2: Test the Services
- Setup the Target Board
- Download the Linux Kernel
  ➔Check Point 3: Try the Linux Kernel
- Write Multi-thread programs on TI OMAP Evaluation Booard
  ➔Check Point 4: Test it
  ➔Check Point 5: Modify the program
  ➔Final Check Point: Use Mutex to protect your program

Fedora Linux

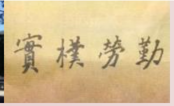
- The Fedora Project was created in late 2003
- We are using the version 20
- Package manager: RPM
- Update method Yum
- Default user interface: GNOME 3
  - Password: 123456
  - Select the language: Taiwan
  - WindowsKey+Space to change the input language
  - Ativeties ➔ Search: terminal ➔ to get the terminal
    - Edit →Profile Preferences → Colors →Uncheck “use colors from system theme”
  - Click the icon at the right-top corner for network setting

Setting Network



vi— A Screen-Oriented Text Editor

- vi is widely supported by Unix-like operating system
- Normal mode
  - Move, search, copy, paste, delete,…
  - Press i, I, a, A, o, O,… to change to the insert mode
  - Press : for the command mode
- Command mode
  - Save, quit, load, split,…
  - After enter the command, it will be back to the normal mode
- Insert mode
  - Move and input anything
  - Press ESC to go back to the normal mode

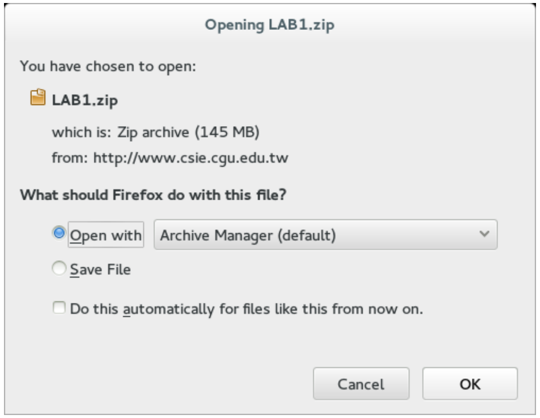
vi Commands

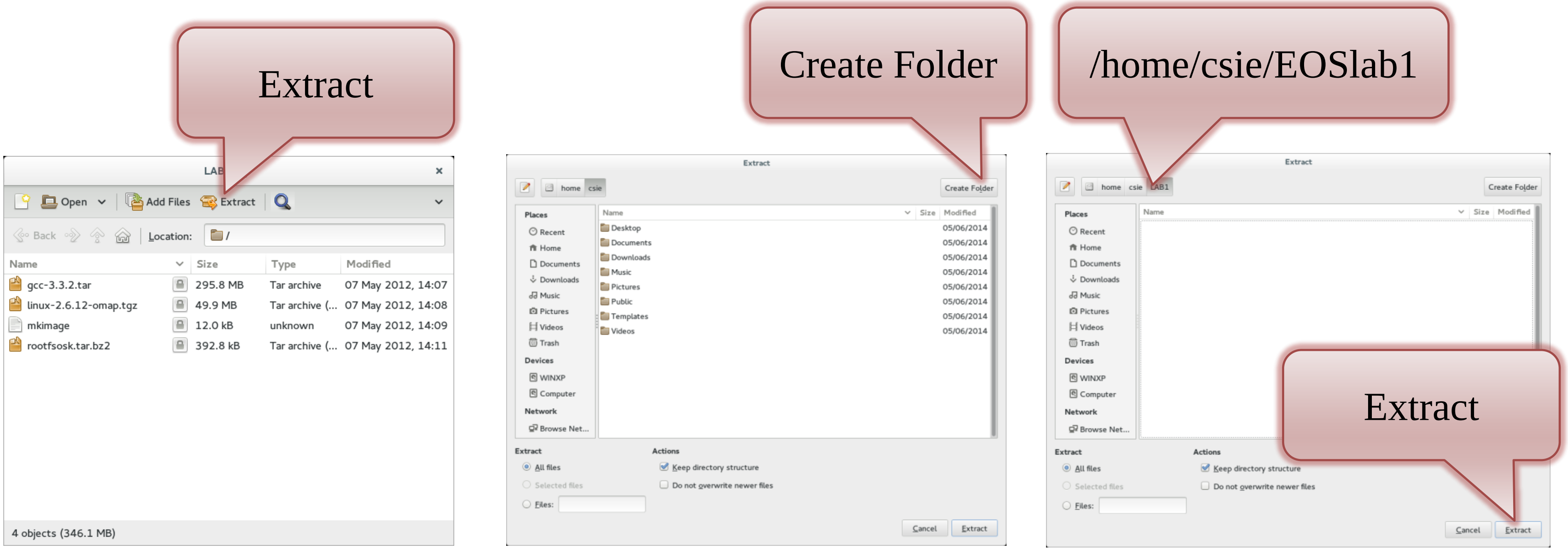
- Press ‘i’ to get the insert mode
- Key-in anything
- Press ‘ESC’ to go back the normal mode
- Press ‘:→w→q→ENTER” to save and quit
- Please search for some tutorial of vi and study by yourself

Build the Linux Kernel and Setup Services on TI OMAP

Download Files

- Download the tools from the course website and extract the files





Download Files

- You will need the following files
  - linux-2.6.12-omap.tgz ➔ the kernel source code
  - gcc-3.3.2.tar ➔ some gcc extension for this lab
  - mkimage ➔ some script which is used when compiling kernel
  - rootfsosk.tar.bz2 ➔ the content of the root filesystem
- You need the root privilege for the following actions
  - *su* (the password is 123456) ➔ change to root
  - *cd /home/csie/LAB1*
  - *cp linux-2.6.12-omap.tgz /opt/linux-2.6.12-omap.tgz*
  - *cp gcc-3.3.2.tar /opt/gcc-3.3.2.tar*
  - *chmod +x mkimage*
  - *cd /opt*
  - *tar xvf gcc-3.3.2.tar*
  - *tar zxvf linux-2.6.12-omap.tgz*
  - *cp /home/csie/LAB1/mkimage /opt/usr/local/arm/3.3.2/bin/mkimage*

Prepare the Compiling Environment

- Set Path
  - *export PATH=$PATH:/opt/usr/local/arm/3.3.2/bin* ➔ for every terminal session, before you compile the kernel
  - *export LANG=en*
- Install Tools
  - *yum -y install gcc* ➔ compiler tools
  - *yum -y install glibc.i686* ➔ library for 32bit Linux kernel
  - *yum -y install minicom* ➔ minicom is the utility for the serial port connection

Build the Linux Kernel

- Go to the kernel source directory (be the root)
  - *cd /opt/linux-2.6.12*
- Set the kernel configuration
  - *make omap_osk_5912_defconfig*
- Compile the kernel
  - *make uImage*
- Prepare the root filesystem
  - *cp /home/csie/LAB1/rootfsosk.tar.bz2 /tmp/rootfsosk.tar.bz2*
  - *cd /tmp*
  - *tar jxvf rootfsosk.tar.bz2*

Check Point 1

- Now, you should have the compiled kernel
- The kernel image is at:
  /opt/linux-2.6.12/arch/arm/boot/uImage
- The root filesystem for the evaluation board is at:
  /tmp/roorfs2.6

Set the Network Services

- Disable the Firewall (it is not a good idea, only for this lab exercise)
  - *systemctl stop firewalld*
  - *systemctl disable firewalld*
- Set the TFTP Service
  - *yum –y install tftp-server tftp* ➔ tftp is used to download the kernel image
  - *vi /etc/xinetd.d/tftp*
    - Find disable = yes
    - Change it to disable = no
  - ~~*/sbin/chkconfig xinetd on*~~
  - *systemctl start tftp.socket*
  - ~~*/sbin/service xinetd start*~~
  - *systemctl enable tftp.socket*
- Set the NFS Service
  - *yum -y install nfs-utils* ➔ nfs for the root filesystem
  - *vi /etc/exports*
    - Add the line /tmp/rootfs2.6 *(rw,fsid=1,no_root_squash)
  - *exportfs –rv*
  - *systemctl start rpcbind.service*
  - *systemctl start nfs-mountd.service*

Test the Network Services

- You need a friend for the following test
  - One be the server and the other be the client
  - Switch the roles and do it again
- Test TFTP
  - Server side:
    - *vi /var/lib/tftpboot/testfile* ➔ and then key something
  - Client side:
    - *tftp 192.168.68.xxx* (xxx is for the server IP)
    - *get testfile*
    - *quit*
    - *cat testfile*
- Test NFS
  - Server side:
  - Client side:
    - *mkdir /home/csie/nfstest*
    - *mount -t nfs 192.168.68.xxx:/tmp/rootfs2.6 /home/csie/nfstest*
    - *cd /home/csie/nfstest*
    - *ls*
    - *cd /*
    - *umount /home/csie/nfstest*

Check Point 2

- Now, you have enabled the TFTP and NFS services on your PC
- TFTP and NFS are properly working now

Set the Minicom (1/3)

- Enter the setting menu
  - *minicom -s*

```
+-----[configuration]------+
| Filenames and paths      |
| File transfer protocols  |
| Serial port setup        |
| Modem and dialing        |
| Screen and keyboard      |
| Save setup as dfl        |
| Save setup as..          |
| Exit                     |
| Exit from Minicom        |
+--------------------------+
```

- Serial port setup ➔ press the letter to change it

```
+-----------------------------------------------------------------------+
| A -    Serial Device      : /dev/ttyS0                                |
|                                                                       |
| C -   Callin Program      :                                           |
| D -  Callout Program      :                                           |
| E -    Bps/Par/Bits       : 115200 8N1                                |
| F - Hardware Flow Control : No                                        |
| G - Software Flow Control : No                                        |
|                                                                       |
|    Change which setting?                                              |
+-----------------------------------------------------------------------+
```

Set the Minicom (2/3)

- Modem and dialing

```
+------------------[Modem and dialing parameter setup]-------------------+
|                                                                        |
| A - Init string .........                                              |
| B - Reset string ........                                              |
| C - Dialing prefix #1....                                              |
| D - Dialing suffix #1....                                              |
| E - Dialing prefix #2.... ATDP                                         |
| F - Dialing suffix #2.... ^M                                           |
| G - Dialing prefix #3.... ATX1DT                                       |
| H - Dialing suffix #3.... ;X4D^M                                       |
| I - Connect string ...... CONNECT                                      |
| J - No connect strings .. NO CARRIER            BUSY                   |
|                           NO DIALTONE           VOICE                  |
| K - Hang-up string ...... ~~+++~~ATH^M                                 |
| L - Dial cancel string .. ^M                                           |
|                                                                        |
| M - Dial time ........... 45      Q - Auto bps detect ..... No         |
| N - Delay before redial . 2       R - Modem has DCD line .. Yes        |
| O - Number of tries ..... 10      S - Status line shows ... DTE speed  |
| P - DTR drop time (0=no). 1       T - Multi-line untag .... No         |
|                                                                        |
| Change which setting?     Return or Esc to exit. Edit A+B to get defaults. |
+------------------------------------------------------------------------+
```

```
+-----[configuration]------+
| Filenames and paths      |
| File transfer protocols  |
| Serial port setup        |
| Modem and dialing        |
| Screen and keyboard      |
| Save setup as dfl        |
| Save setup as..          |
| Exit                     |
| Exit from Minicom        |
+--------------------------+
```


Set the Minicom (3/3)

- Save and leave the setting interface

```
+-----[configuration]------+
| Filenames and paths      |
| File transfer protocols  |
| Serial port setup        |
| Modem and dialing        |
| Screen and keyboard      |
| Save setup as dfl        |
| Save setup as..          |
| Exit                     |
| Exit from Minicom        |
+--------------------------+
```

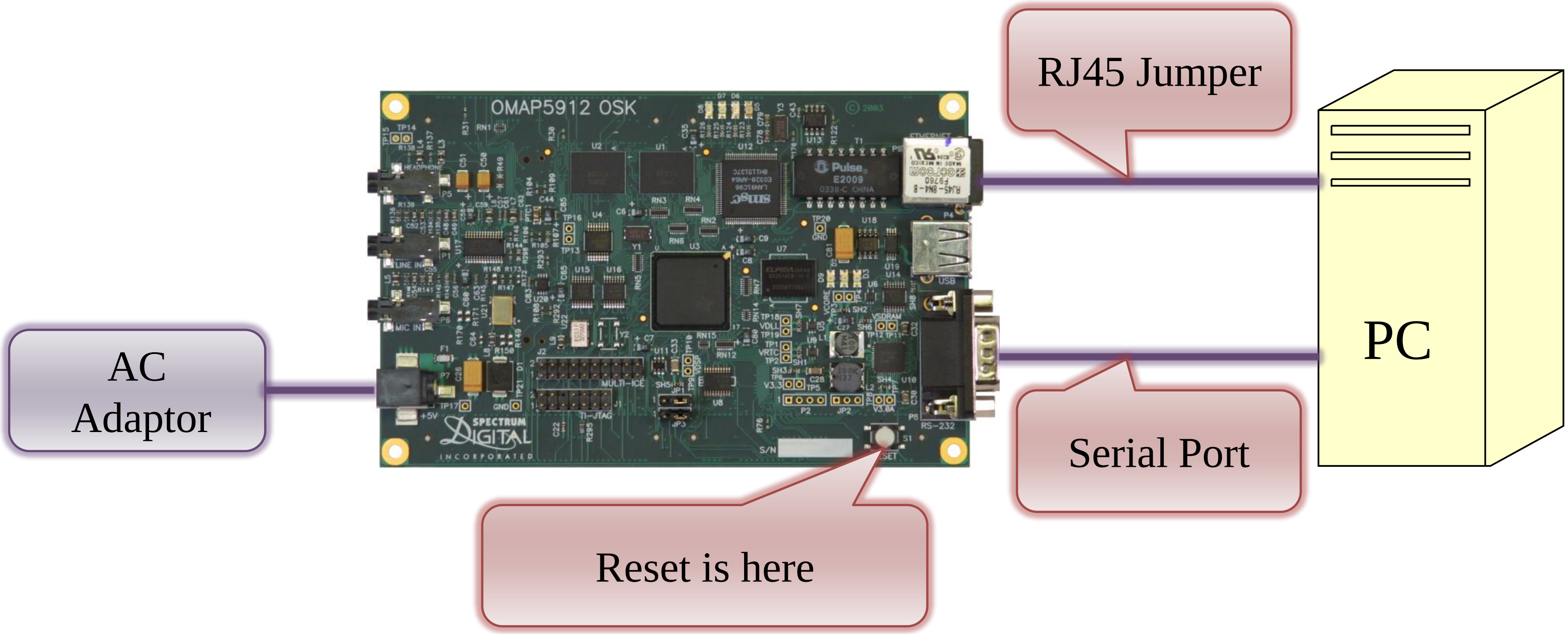
```
+-----[configuration]------+
| Filenames and paths      |
| File transfer protocols  |
| Serial port setup        |
| Modem and dialing        |
| Screen and keyboard      |
| Save setup as dfl        |
| Save setup as..          |
| Exit                     |
| Exit from Minicom        |
+--------------------------+
```

- Start and quit minicom
  - Start *minicom*
  - Quit *CTRL+A → Q*

```
Welcome to minicom 2.6.2

OPTIONS: I18n
Compiled on Aug  7 2013, 13:32:48.
Port /dev/ttyS0, 21:18:16

Press CTRL-A Z for help on special keys
```

Prepare for the Booting

- Copy the boot image for TFTP booting
  - *cp /opt/linux-2.6.12/arch/arm/boot/uImage /var/lib/tftpboot/uImage*
- Set the evaluation board as follows



Boot the Evaluation Board

- Start mimicom
  - *minicom*
- Press the reset button on the board
  - After the reset, immediately press any key on minicom terminal
  - You will get the following prompt

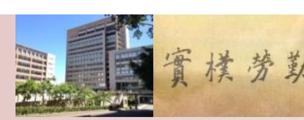
```
OMAP5912 OSK #
```

Download the New Kernel

- Set the boot configuration
  - *set ipaddr 192.168.68.yy* (evaluation board IP)
  - *set serverip 192.168.68.zz* (PC IP)
  - *set netmask 255.255.255.0*
  - *set gatewayip 192.168.68.254*
  - *set ethaddr 00-0e-99-xx-xx-xx*
  - *set bootargs console=ttyS0,115200n8 rw ip=192.168.68.yy root=/dev/nfs nfsroot=192.168.68.zz:/tmp/rootfs2.6,v3*
  - *printenv* ➔ double check the setting

```
OMAP5912 OSK # printenv
bootdelay=3
baudrate=115200
bootfile="uImage"
bootcmd=bootm 0x100000
ipaddr=192.168.68.123
serverip=192.168.68.186
netmask=255.255.255.0
gatewayip=192.168.68.254
ethaddr=00-0e-99-02-0d-0b
stdin=serial
stdout=serial
stderr=serial
bootargs=console=ttyS0,115200n8 rw ip=192.168.68.123 root=/dev/nfs nfsroot=192.168.68.186:/tmp/rootfs2.6,v3

Environment size: 337/131068 bytes
OMAP5912 OSK #
```

  - *saveenv* ➔ if everything is correct ➔ be careful, do not crash the entire system



Boot the New Kernel and Mount the NFS Root Filesystem

- Download the kernel: *tftpboot 0x10000000 uImage*

```
OMAP5912 OSK # tftpboot 0x10000000 uImage
TFTP from server 192.168.68.186; our IP address is 192.168.68.123
Filename 'uImage'.
Load address: 0x10000000
Loading: #################################################################
         #################################################################
         #################################################################
         ######################
done
Bytes transferred = 1110712 (10f2b8 hex)
OMAP5912 OSK #
```

- Boot the OS: *bootm 0x10000000*

```
Looking up port of RPC 100003/3 on 192.168.68.186
Looking up port of RPC 100005/3 on 192.168.68.186
VFS: Mounted root (nfs filesystem).
Freeing init memory: 112K
init started:  BusyBox v1.00-pre8 (2004.03.05-22:18+0000) multi-call binary

******************************************

Starting System Init for OMAP5912OSK
******************************************

Please press Enter to activate this console.
```

Check Point 3

Done!

Or Bugs!?

Common Mistakes

- *su* and *export* should be used whenever a new terminal is created
  - If you extract the root file system by the user csie, there will be an error when you boot the board to mount the NFS root file system
    - Reboot the computer and do everything again
  - If you do not export the path of the tools, you will get some error when you compile the kernel module
- Please read the error message if you type something wrong
- UART: it should be connected to the bottom port
- Ethernet: do check the IP is correct
- Some evaluation boards were tested to be good: 1, 5, 7, 10, 11, 12, 15, 19, 20

Pthread Programming on TI OMAP 5912

Cross Compile a Program

- Copy the file in cp4 to /tmp/rootfs2.6
- Make it: *make*
- The Makefile is like:

```
PREFIX=/opt/usr/local/arm/3.3.2
CC=$(PREFIX)/bin/arm-linux-gcc
CFLAGS= -I$(PREFIX)/include -L$(PREFIX)/lib
all:
	$(CC) -o cp4.out mutex_thd.c -static -lpthread $(CFLAGS)
```

- You now can *./cp4.out* on the OMAP evaluation board to execute the program on the board

Check Point 4

- Please read the source code and the make file
- The example code is executed on the board
- Dose it execute as you expect?

Exercise for Thread Creation and Join

- Copy the director cp5 to /tmp/rootfs2.6
- Now, you are a system programmer to improve the performance of a single-thread program
  - The main program is main_single_thread.c
  - The outsourcing program is in an object file format:
    - functionsARM.o is for ARM processor
    - functionsX86.o is for X86 processor
    - myFunctions.h is the header file
  - You have to write the Makefile and modify the program into a multi-thread version
- Hints
  - `$(CC) -o cp5.out objFile.o cFile.c -static -lpthread $(CFLAGS)`
  - `pthread_create(&thread[7],NULL,(void *)&function7,NULL);`
  - `pthread_join(thread[i],(void **)&results[i]);`

Check Point 5

- Do you understand the meaning of thread creation and join?
- Dose the program executes as you expect
- Measure execution time of the single-thread version and multi-thread version programs
- Is there any difference?

Exercise for Mutex

- Now copy the director final to /tmp/rootfs2.6
- Write the Makefile
- Change the program to use multiple threads
- Note that some functions use the same data
- Mutex should be used to protect the shared data
- Hints:
  - Create multiple threads → join them → use mutex to protect shared data
  - Minimized the code protected by mutex

Final Check Point

- Measure the time for the program
- Does the program works well
- Is it efficient?

Grading this Exercise

- Check point 1: 10%
- Check point 2: 10%
- Check point 3: 10%
- Check point 4: 10%
- Check point 5: 10%
- Final check point: 10%
- Bonus: test cp4 and cp5 on PC: 20%
- Report before the exercise: 20%
  - Two page A4, 12 pt font
  - Deadline is 23:59 2020/12/7
  - File name: EOS-Lab1-Study-Student_ID
  - File type: PDF or Word
  - Send it to my email: chewei@mail.cgu.edu.tw
  - Email title: EOS Lab1 Study Student_ID
- Report after the exercise: 20%
  - Bonus: test multiple thread programs on your PC: 20%
  - Two page A4, 12 pt font
  - Deadline is 23:59 2020/12/14
  - File name: EOS-Lab1-Report-Student_ID
  - File type: PDF or Word
  - Send it to my email: chewei@mail.cgu.edu.tw
  - Email title: EOS Lab1 Report Student_ID