

## Lab 4

### Outline

In Lab4, we will be exploring the PreemptRT kernel patch. Investigation into performance begins with the current installed version of Raspbian using some simple C-based signal generation techniques. Next, a new kernel will be built using the Raspbian 4.14.71 source and the corresponding PreemptRT patch. Once the patched kernel is running, we will explore signal generation using Real Time techniques provided by the patch.

In a bit more detail, we will follow the steps:

- On the current system:
  - Install utilities for managing GPIO in C
  - Implement a square wave signal in C
  - Measure the performance of the C code
- Install a new kernel, patched with PreemptRT
  - Download the Linux source files
  - Download the PreemptRT patch
  - Merge the patch with the Linux source
  - Configure the Linux code
  - Compile the Linux kernel
  - Copy the kernel to the SD card and boot the R-Pi
- On the new system
  - Install utilities for managing GPIO in C
  - Run the square wave code to check this install
  - Convert this system to a real time code
  - Test performance of the real time system

There are several new packages to install along the way. Most are straightforward. The Linux patch application is a bit complex; however, these techniques are good to know for general knowledge in altering a Linux kernel; something that will be common in embedded systems.

The following packages will be installed throughout steps in the lab:

- Cyclicttest
- Perf
- wiringPi
- kernel source
- Preempt-RT patch

The following will be used to verify system performance:

- Perf using the sort programs
- The Cyclicttest utility
- Measurement of signals using the oscilloscope

Canvas links

- Cyclicttest
- wiringPi install
- wiringPi C code example
- wiringPi pin numbering
- RaspberryPi.org link for kernel building
- PreemptRT how to build applications, code skeleton

## Before we start

In this lab, we will be replacing the current kernel on the SD card. This will ERASE everything on the card. There are important tasks you should perform before you do anything else:

1. **As a first step, Backup your SD card** using the instructions on Canvas. This will preserve the entire card image so that you can restore it as needed
2. Use your favorite cloud/USB stick copy/ ece5725\_f19 server method to save your programs from previous labs. Having these in a handy location will make them easy to restore onto the newly formatted card
3. We will be using a second SD card in Lab 4. The second SD card will be used to build the PreemptRT kernel. The idea is to have two functional SD cards:
  - a. Lab3 SD card with latest raspbian kernel
  - b. Lab4 SD card with Preempt-SD kernel
4. There are a number of links in this weeks' reading in Canvas. These readings contain a lot of information relative to Lab 4. Please take some time to read these selections as this will save you a lot of time on lab procedures.
5. The following Lab instructions have been developed from a variety of links included in Canvas and a number of experiments in compiling the RT kernel. When you review the links you will notice the various items included in these instructions.

## Part 1: Verify current system performance

The following will be used to verify system performance:

- Perf using sort programs and square wave programs introduced in Lab 4
- The Cyclictest utility we have been discussing in class
- Measurement of signals using the oscilloscope

## Performance measurement using cyclictest

Download, install, and run Cyclictest on the current system

Cyclictest is loaded from github. Canvas includes a link to the cyclictest page; please reference this page for complete instructions. The short form is included below:

```
pi@RPi3-jfs9$ git clone
git://git.kernel.org/pub/scm/linux/kernel/git/clrkwlms/rt-tests.git
pi@RPi3-jfs9$ cd rt-tests
pi@RPi3-jfs9$ make all
pi@RPi3-jfs9$ sudo make install
pi@RPi3-jfs9$ sudo cyclictest --help
```

Once cyclic test is installed, test it by running *cyclictest --help*

Check the latency of the system by running:

```
time sudo cyclictest -p 90 -n -m -t4 -l 10000
```

This command runs threads at priority = 90, uses the nanosleep timer, locks memory, runs four threads, for 10000 loops. After you record these results, re-run the command with the following options:

```
time sudo cyclictest -p 90 -n -m -h 500 -t4 -l 300000
```

This command runs threads at priority = 90, uses the nanosleep timer, locks memory, records 500 histogram bins, runs four threads, for 300000 loops. This should run in about 5 minutes.

Record the details of the histogram and convert the histogram into a chart in Excel to capture the behavior of the tracking of the maximum latencies. What do these results show about latency of the system?

You should also test the behavior of `cyclictest` while running cpu-intensive tasks on the RPi cores. Note that `sort_v1.c` (in the next section) is a good cpu loading test.

Run 20 – 30 copies of `sort_v1` in the background and repeat the command:

```
time sudo cyclictest -p 90 -n -m -h 500 -t4 -l 300000
```

Use `htop` to make sure the cores remain busy for the duration of the `cyclictest` run. You might need to restart `sort_v1` programs during the run. You might also consider modifying `sort_v1` to run a bit longer.

Later in the Lab, you will compare these histograms of `cyclictest` on the loaded and unloaded RPi against the same tests under the RP-PREEMPT kernel.

## Performance measurement of `sort.c`

From the `ece5725-f19` server, download:

```
/home/jfs9/lab4_files_f19/c_tests/sort_v1.c
```

have a look at the code with your editor of choice to understand the code

Use the following command (the C compiler, `gcc`) to compile the source:

```
gcc -std=c99 -o sort_v1 sort_v1.c
```

Note: the `-std=c99` is used for `sort_v1` to support older C calls. Once the file has been compiled, run the executable `sort_v1` using `perf`:

```
sudo perf_4.9 stat ./sort_v1
```

Record all the results

Modify `sort_v1.c` to include a sort on the large array prior to entering the loop to sum results. Compile and run the altered file. Run the executable using `perf`. Record all the results. In your lab report, please describe the difference in the performance measurements relative to system architecture.

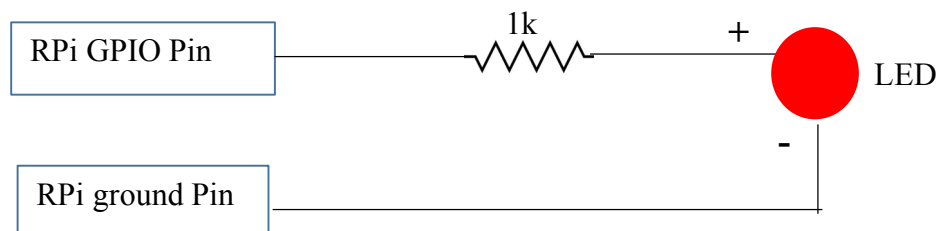
## Performance measurement of square wave in python and C

Quick summary:

- Use `blink.py` to generate a stable square wave in python..
- Use `blink_v6.c` to generate a stable square wave in c.
- Run `blink_v6.c` again with system loading and check the stable square wave

Design a python program, `blink.py`, to output a high/low pulse on a free GPIO pin. The pin you select will be used for the duration of Lab4 so insure that it is a free GPIO pin that may be safely configured as an output.

As in Lab 3, one useful method for testing is to attach an LED (with appropriate 1k resistor) to this pin. For low frequency signals, the LED will blink when the software is running correctly. As functions in the lab will vary from Python to a few flavors of C, on two different kernels, the low speed LED check is a good way to quickly verify program correctness. From Lab 3, recall the example LED circuit:



Once you have `blink.py` running, connect the oscilloscope to the output pin and, decreasing the period of the generated wave, determine (roughly) where a stable square wave may be maintained. Use the scope frequency display (using the 'measure' setting) to determine the upper limit for the frequency that can be obtained with the `blink.py` program. If the frequency set in the `blink.py` program matches (**within 10% of the expected frequency**) what the scope reports, the generated wave is stable. You should expect to reach an upper bound for the frequency reported by the scope (this will be somewhat subjective). Plan to plot a number of points for this experiment (for example, expected frequency versus frequency reported by scope)

Once you have determined a stable value for blink.py, generate a similar square wave program in C. Before doing this, it is necessary to load a C library that acts like rpi.GPIO in Python. This will provide simple access to the GPIO pins in C. The library we will be using is wiringPi. There is a link to the Installation instructions for WiringPi on Canvas. In short:

First, check if wiringPi is already installed:

```
gpio -v  # if this command returns anything ,then wiringPi is already
          # installed
```

Example run indicating that wiringPi is installed:

```
pi@RPi-jfs9:~/rt-tests $ gpio -v
gpio version: 2.46
Copyright (c) 2012-2018 Gordon Henderson
This is free software with ABSOLUTELY NO WARRANTY.
For details type: gpio -warranty
```

Raspberry Pi Details:

```
Type: Pi 3, Revision: 02, Memory: 1024MB, Maker: Embest
* Device tree is enabled.
*--> Raspberry Pi 3 Model B Rev 1.2
* This Raspberry Pi supports user-level GPIO access.
```

If wiringPi is **not** installed, you can get wiringPi from git:

```
git clone git://git.drogon.net/wiringPi
```

Make sure wiringPi is at the latest version:

```
cd wiringPi
```

```
git pull origin
```

Build the libraries:

```
cd wiringPi
```

```
./build
```

## IMPORTANT:

As if Board and BCM pin numbering didn't lead to enough confusion, wiringPi introduces YET another pin numbering scheme for the RaspberryPi!! There is a link on Canvas detailing the pin numbers which are NEITHER board nor BCM numbers, but something unique. Make sure you pay attention to the numbering scheme in your C code.

With wiringPi installed, you can now work on the square wave application. Plan to use the same output pin as you used for the Python code. When using the wiringPi libraries, you will have to make sure to indicate this to the C compiler. There is a link on Canvas to sample 'blink' code. Here is a snip:

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

#define LED      0    // BCM.GPIO pin 17 = wiringPi pin 0

int main (void)
{
    wiringPiSetup () ;

    pinMode (LED, OUTPUT) ;

    for (;;)
    {
        digitalWrite (LED, 1) ;    // On
        delay (500) ;              // mS
        digitalWrite (LED, 0) ;    // Off
        delay (500) ;
    }
    return 0 ;
}
```

### Notes:

- The designation of wiringPi pin 0 = BCM\_GPIO pin 17!! By the way, wiringPi pin 0 would be a poor choice for these Lab experiments...why? Please select a free GPIO pin (the same one you used for the Python test) and MAKE SURE to use the correct numbering for wiringPi.
- The 'delay' call in wiringPi accepts integers only
- To move towards higher frequencies, try using 'delayMicroseconds' from wiring pi...which also takes integer arguments. Remember, there may be some issues with delayMicroseconds (check the description at the wiringPi site)

- Please check the lab4\_files\_f19 files on the server. blink\_v6 shows a version of blink which uses a nanosleep function – this should give better results for all frequencies.

To compile a C program using the wiringPi library, use the command:

```
gcc -o blink_v6 blink_v6.c -lwiringPi
```

Once you have the code running and the LED blinking, use the scope test to (roughly) determine a minimum setting for the period in the C code to generate a stable square wave. Note that if the frequency reported by the scope is within 10% of the expected frequency, consider this a stable result. Use the scope frequency display to determine the upper limit for the frequency that can be obtained with the blink program. Plan to plot a number of points for this experiment (for example, expected frequency versus frequency reported by scope)

Next, create a python or C code designed to use 100% of a single cpu (floating point computations are good candidates for using a lot of cpu time). Once you have this running, launch it at least 4 times and verify (using htop) that all cpus are 100% used.

Once the system is loaded, run the blink test. Are you able to generate a square wave as in the first performance experiment? Adjust the period as needed to generate a stable square wave, generating a second graph of these results.



## Part 2: Build the PreemptRT kernel

There are a number of steps in this section. If you follow the installation plan all will be well; skip a step or wander from the instructions at your own peril! As noted above, the basic steps to creating a new Linux kernel include:

- Download the Linux source files
- Download the PreemptRT patch
- Merge the patch with the Linux source
- Configure the Linux code
- Compile the Linux kernel
- Copy the kernel to the SD card and boot the R-Pi

There is a link on Canvas to instructions for installing kernel changes. This is a reference for the detailed instructions that follow. A few notes about the process:

- There are two main elements to forming the kernel: The Linux source files and the PreemptRT patch files. The idea is to combine these two source repositories in order to compile a new kernel.
- There are a number of versions of each of these packages. We have found specific versions that work. We will be using a version of the most recent Raspbian kernel that we know is stable with the PreemptRT patch. The versions we will be using are:
  - Kernel files: 4.14.91-rt
  - PreemptRT patch: 4.14.87-rt49
- There are a number of methods for creating the PreemptRT kernel:
  1. Begin with a clean install of Raspbian and compile on the Rpi
  2. Begin with an SD card loaded with a copy of the current ('Lab 3') version of Raspbian and compile the modified kernel (4.14.91 with PreemptRT patch) on the Rpi
  3. Cross compile the PreemptRT kernel on a Linux server (Ubuntu, for example). Once complete, move the compiled kernel elements to the RPi SD card
- We have been most successful with (2), compiling using the 'Lab 3' version of Raspbian and compiling on the Rpi. The advantages for this method:
  - All work is done on the Rpi platform
  - We save a number of steps, including transferring files from a server to the RPi
  - This method preserves all of the work done so far in Labs 1-3

- However, there are some disadvantages
  - The biggest disadvantage is the kernel compile time on the RPi (90 – 120 minutes!). This is the big motivation to go to a cross-compile platform; more memory and a faster process lead to faster compile times.
  - Because of the limited space on the SD card, we need to manage free space to allow the compilation to complete.

There are techniques to overcome these disadvantages. The alternative compile methods are available if you would like to try them as well. As long as we can achieve the goal of a compiled PreemptRT kernel, alternative paths are acceptable.

Next are the step by step instructions for compiling the Kernel patched with Preempt-RT.

### *Step 1: Initial Setup and Download Linux Source Files*

We are now ready to begin creation of the patched kernel. Refer to the Canvas links for several methods used for the installation of a new kernel. The steps below detail the path used to build the kernel on the Rpi. Please execute the steps below in exact order.

First, copy your saved image of the Lab 3 SD card to your second SD card. This second SD card will form the base for installation of the Linux source and PreemptRT kernel patch.

Boot the Rpi with this second SD card. Verify that this version is identical to the Lab3 version by running past code applications and testing remote login using ssh from a laptop using the wireless connection or an Ethernet connection.

Note: as you will be downloading some large source libraries, you may want to use the wired Ethernet connection for increased download speed (compared to wireless).

### **Free Space on SD Card**

You may want to free as much space as possible on the SD card for the upcoming downloads and compilation. This is less critical than in the past since we have switched from 8 GByte to a 16 GByte SD card. However, it is good practice to keep the SD card trim because we will be loading A LOT of C code for the compile process.

- Remove large mp4 videos, games, and experimental applications. (1.7G free)
- Make sure wolfram-engine is removed:
  - `sudo apt-get remove --purge wolfram-engine`

- Remove supercollider (music processing software) (1.9G free)
  - `sudo apt-get remove --purge supercollider*`
- Turn off swapping on in the current kernel (see Canvas links in Guides / SD Card Management) (2.5 G free)
- Complete with the final set of commands: (2.9G free)
  - `sudo apt-get autoclean`
  - `sudo apt-get clean`
  - `sudo apt-get autoremove`

A few commands for checking storage:

`df -h`

Checks the free space in the filesystem

`dpkg --get-selections`

Shows all installed applications

`du -sh *`

Details the storage used in a particular directory. For example, you can use ‘`cd /var`’ followed by ‘`du -sh *`’ which will detail storage in the /var directory

Using these methods, you should be able to free enough space to enable subsequent downloads and compilations as detailed below. Continue to check, and record, SD space as you move forward with Lab 4. This is especially important before you begin the long compilation run (more on this a bit later).

Next load the appropriate source code for the base Linux kernel:

```
user@RPi ~$ cd /home/pi # Make sure you are in the home directory for the pi user
```

**DO NOT** cut and paste the following command. Additional control characters may be introduced during cut-and-paste and, although the command may appear correct, it will not execute correctly!

```
user@RPi ~$ time git clone --single-branch --branch 'rpi-4.14.y-rt'
https://github.com/raspberrypi/linux.git
# The above git command clones the branch 'rpi-4.14.y-rt'
# to a local directory named 'linux' under the /home/pi directory.
# 'clone' commands copy code from git repository to a location on a
# local machine (Rpi, in this case)
```

Sample command output plus an indication of remaining space once Linux 4.4.y C source code is loaded on to the SD card:

```
pi@jfs9-RPi3:~ $ time git clone --branch 'rpi-4.14.y-rt'
https://github.com/raspberrypi/linux.git
Cloning into 'linux'...
remote: Counting objects: 4507768, done.
remote: Compressing objects: 100% (52/52), done.
remote: Total 4507768 (delta 41), reused 32 (delta 32), pack-reused 4507684
Receiving objects: 100% (4507768/4507768), 1.23 GiB | 4.54 MiB/s, done.
Resolving deltas: 100% (3746209/3746209), done.
Checking out files: 100% (52749/52749), done.

real    16m50.406s
user    18m24.260s
sys     2m31.110s
```

```
pi@RPi3-jfs9:~ $ df -h
Filesystem      Size  Used Avail Use% Mounted on
/dev/root        15G   6.4G   7.5G   47% /
devtmpfs         460M    0   460M    0% /dev
tmpfs            464M    0   464M    0% /dev/shm
tmpfs            464M   6.3M   458M    2% /run
tmpfs            5.0M   4.0K   5.0M    1% /run/lock
tmpfs            464M    0   464M    0% /sys/fs/cgroup
/dev/mmcblk0p1   43M    22M   21M   52% /boot
tmpfs            93M    0    93M    0% /run/user/1000
```

I downloaded the above code while the RPi was connected to wired Ethernet. Time to download was between 15 and 20 minutes.

To check the version of the code you have downloaded, run:

```
$ cd /home/pi/linux  
$ head Makefile
```

The top of the Makefile should indicate the level you just downloaded. The release should be 4.14.91

Make sure any missing dependencies are installed by running:

```
$ sudo apt-get install bc
```

### *Step 2: Download the PreemptRT Patch and merge with kernel source*

Get a copy of the PreemptRT-patch, directly into the ‘linux’ source directory, by running:

```
user@host $ cd /home/pi/linux  
  
user@host ~/linux$ wget  
https://www.kernel.org/pub/linux/kernel/projects/rt/4.14/patch-  
4.14.87-rt49.patch.gz
```

**Important:** Once you have confirmed that you have the correct version of the linux source, and have downloaded the patch file,

## **Backup the SD card**

This will preserve a ‘clean’ copy of linux source in case there are issues with later install steps.

After you backup the SD card, apply the patches to the linux source:

```
user@host$ cd /home/pi/linux
```

```
user@host ~/linux$ zcat patch-4.14.87-rt49.patch.gz | patch -p1 >
/home/pi/patch.log 2>&1
```

Notes: The `-p1` option is 'patch p-one'....not 'patch p-ell'

Output from this command will be placed in '/home/pi/patch.log'

A sample 'patch.log' is saved in Lab4 links

After this command runs error-free (a few seconds) patches have been applied to the original kernel source. Check /home/pi/patch.log to make sure there are no errors.

### *Step 3: Configure the kernel*

Begin by making sure the install will begin with a clean make environment. Note that all commands are run in /home/pi/linux unless indicated otherwise:

```
$ make clean
$ make mrproper
```

The above two commands remove any previously compiled files from the /linux directory

Install the ncurses development headers (required by the upcoming menuconfig command):

```
$ sudo apt-get install libncurses5-dev
```

Give the kernel image the correct name (kernel7). The second command insures that the default configuration for the R-Pi is created.

```
$ KERNEL=kernel7
$ echo $KERNEL      # to check environment variable setting
$ kernel7           # kernel7 will be returned if setting is correct
$ make bcm2709_defconfig
```

Notes: `KERNEL=kernel7` # the KERNEL environment variable is set to  
kernel7 (kernelSeven) NOT kernel17 (kernelSeventeen)

The 'make bcm2709\_defconfig' command creates a skeleton .config file to be used by the menuconfig command.

Run make menuconfig to check/change settings for the upcoming compilation

```
$ make menuconfig
```

menuconfig allows you to select a LARGE number of options for the kernel configuration. Look through the menu that pops up; note the navigation tips at the top...you can use help at any point to get more information on any selection in the menu. Please look through the menu and make the following selections (if they are not already set):

- In 'General Setup', 'preemption model', select 'RT Fully Preemptable kernel'  
Note, that 'preemption model' could also appear in the 'Kernel Features' section
- In 'General Setup', 'Timers subsystem', select 'High Resolution Timer Support'

As the instructions indicate, please save your changes, in the default location (which is the .config file), to complete menuconfig.

#### *Step 4: Compile the patched, configured kernel*

A few notes before you begin compilation:

- At this point, a lot of new source code has been loaded onto the SD card. Check the available free storage on the card using 'df -h'. In my experiment, I began with about 7.5 Gbytes free at this point.
- Once you run the initial make command, below, it will run for about 90 - 120 minutes on the Rpi. During this time, the Rpi should remain powered up (!) and should be undisturbed until the compilation is complete. The best solution would be to run this between week1 and week2 lab sessions. If you decide to start the compilation in a Lab session, please make sure there is enough time remaining in the lab session to complete the compilation.
- Note that the results of the make command are saved in /home/pi/make.log. A sample make.log is saved in the Lab 4 link for comparison.
- The make command will use all of the cores on the RPi. Do not run anything else on the RPi (like web browsers, full screen editors, etc) when running the make command

The first command is the long compilation of the Linux kernel. The 'tail' command will indicate progress as the compilation is underway.

## **Week1 Checklist**

Show the TAs a copy of the following

- blink.py at the highest recorded frequency
- blink at the highest recorded frequency when the Rpi is unloaded
- blink at the highest recorded frequency when the Rpi is loaded
- saved data from cyclicttest on the original kernel
- perf results for the two sort programs
- the linux source directory at the correct version with the correct patch file
- a copy of patch.log
- display the results of 'df -h' to show free space on the SD card



**Stop HERE for Week 1 Lab session. The following commands should be run between Week1 and Week2**

This is the break between Lab4, week1 and Lab 4, week 2. The second week of Lab 4 will begin with testing the function of the PreemptRT kernel. If you end week 1 at this point, you will be taking the Rpi home and performing the compile step between week 1 and week 2 lab sessions. Please plan accordingly.....

If you are compiling outside of the lab, don't forget the following important steps:

- Check the value of the \$KERNEL environment variable before you begin.
- Make sure you run commands in the /home/pi/linux directory.
- The following commands should help:

```
$ cd /home/pi/linux
$ KERNEL=kernel7
$ echo $KERNEL      # to check environment variable setting
$ kernel7           # kernel7 will be returned if setting is correct
```

The first compile step (below) will run for about 90-120 minutes on the RPi. Please plan to run this step between the Week 1 and Week 2 Lab 4 sessions.

For the compilation, run the following commands **(DO NOT start this command at the end of Week 1 LAB section)**

```
$ time make -j4 zImage modules dtbs > /home/pi/make.log 2>&1
```

In a second window:

```
$ tail -f make.log    // to watch progress
```

Note: This command will take about 90-120 minutes to run. Once it has completed, plan to check the make.log to see if there were any errors during compilation (check the sample 'make.log' saved in /home/lab4\_files\_f19 on the class server.

Before you run the next command:

- Check the file `make.log` for any warnings or errors
- Make sure the `$KERNEL` environment variable is still set

```
$ time sudo make -j4 modules_install > /home/pi/modules_install.log 2>&1
```

The `-j4` argument informs the `make` command to start 4 tasks which should use all four processors on the R-Pi. The first '`make -j4 zImage modules dtbs`' command performs the bulk of the compilation and will take about 90 minutes on a R-Pi 2.

After completing both commands, note the remaining free space on the SD card:

```
pi@RPi3-jfs9:~/linux $ df -h
Filesystem      Size  Used Avail Use% Mounted on
/dev/root        15G   7.1G   6.9G  51% /
devtmpfs         460M    0   460M   0% /dev
tmpfs            464M    0   464M   0% /dev/shm
tmpfs            464M   13M   452M   3% /run
tmpfs            5.0M   4.0K   5.0M   1% /run/lock
tmpfs            464M    0   464M   0% /sys/fs/cgroup
/dev/mmcblk0p1   43M    22M   21M  52% /boot
tmpfs            93M    0    93M   0% /run/user/1000
```

The second `make` command will run in a few minutes. Results will be saved in the `modules_install.log` (see the sample in the Lab 4 link for comparison)

**IMPORTANT: Backup the SD card at this point.**

If the log files show that the above operations occurred without errors, the system will still be configured with the original, Lab 3 kernel. In addition, the newly compiled PREEMPT RT kernel is saved to the card but HAS NOT yet been completely installed.

## Lab 4, Week 2

**IMPORTANT:** If you completed the compilation, make sure to **Backup the SD card at this point**. If the log files show that the above operations occurred without errors, the system will still be configured with the original, Lab 3 kernel. In addition, the newly compiled PREEMPT RT kernel is saved to the card but HAS NOT yet been completely installed.

After backup, reboot the SD card and continue with the remaining installation instructions.

Run: `uname -a`

Record results for the current kernel. At this point, the kernel should show the Lab 3 version (4.19.58, on my lab system). After kernel installation, you will use `uname -a` to confirm the updated kernel version.

The following commands are used to place elements of the new kernel in the correct locations:

```
$ cd /home/pi/linux # make sure you are in the linux source directory
$ KERNEL=kernel7    # Make sure the $KERNEL environment variable is set
$ echo $KERNEL       # to check environment variable setting
$ kernel7            # kernel7 will be returned if setting is correct
$
$ sudo cp arch/arm/boot/dts/*.dtb /boot/
$ sudo cp arch/arm/boot/dts/overlays/*.dtb* /boot/overlays/
$ sudo cp arch/arm/boot/dts/overlays/README /boot/overlays/
$ sudo scripts/mkknimg arch/arm/boot/zImage /boot/$KERNEL.img
```

Note that the copy commands move compiled results from a variety of locations in the /linux directory to the /boot location of the current Linux kernel. The final command replaces the original kernel image with the newly compiled Preempt-RT kernel.

Once these commands are run, a reboot should bring up the new PreemptRT kernel.

### *Step 5: System Setup*

At this point, the new kernel has been compiled and written to the SD card. On reboot, the newly compiled kernel will be launched

Note that you **might** have to perform the initial raspi\_config steps from Lab1. This step depends on your initial starting point. If you discover that you need to run raspi-config, please refer to the Lab1 writeup on Canvas if you need some hints on how to perform the initial setup. The section from Lab 1 describing raspi-config is included in an appendix.

### Part 3: Check performance of the PreemptRT system

OK, at this point, you have a shiny new PreemptRT kernel running on the R-Pi. Now what? First, check to make sure that the PreemptRT kernel is indeed running:

```
pi@raspberrypi ~ $ uname -a
Linux raspberrypi 4.14.91-rt49-v7+ #1 SMP PREEMPT RT Thu Oct 11:17:25
UTC 2019 armv7l GNU/Linux
```

Note that the kernel indicated is 4.14.91 and shows that the Preempt RT kernel is running

If you started with the ‘Lab3’ base, you code from past labs should still be in place. Try some examples to make sure everything continues to run. If you have a ‘Test Plan’ in place including some of your favorite codes, this would be a great time to run the test plan

Since we have a new kernel, we need to install a few things in order to check performance:

- For Python. Rpi.GPIO should be pre-installed so we are OK here.
- Perf, Cyclicttest, and WiringPi should still be installed.
- If you began with a basic Linux system (instead of ‘Lab3’):
  - Have a look at Part 1 of this lab to install cyclicttest and wiringPi.
  - From Lab2 instructions, install perf from the ece5725-f19 server, also included in an Appendix for reference.
  - If you have saved your code to a cloud/usb location, load all of your code back onto the system.

One last configuration step:

Because of an issue with a USB driver, some of the testing on the PreemptRT kernel may cause the Rpi to freeze. Please apply the following changes to eliminate the impacts to testing. Add the following to the end of the file /boot/cmdline.txt

```
dwc_otg.fiq_enable=0 dwc_otg.fiq_fsm_enable=0 dwc_otg.nak_holdoff=0
```

Note DO NOT use an ‘enter’ on this line anywhere...just let characters on the line wrap.

An example of cmdline.txt with the changes:

```
pi@jfs9-RPi3:~ $ cat /boot/cmdline.txt
dwc_otg.lpm_enable=0 console=serial0,115200 console=tty1 root=/dev/mmcblk0p7
rootfstype=ext4 elevator=deadline fsck.repair=yes rootwait fbcon=map:10
fbcon=font:VGA8x8 splash plymouth.ignore-serial-consoles dwc_otg.fig_enable=0
dwc_otg.fig_fsm_enable=0 dwc_otg.nak_holdoff=0
```

Once these changes are in place, reboot the RPi

**Important: Backup the SD card. At this point, the Preempt RT patched kernel is installed.**

After the backup is completed, you can reboot the Raspberry Pi with the new Preempt-RT kernel. Just to review what was accomplished:

1. The 4.14.91 Linux source code was loaded to /home/pi/linux
2. The 4.14.87 Preempt-RT patch was downloaded and applied to the source code
3. The modified kernel code was compiled to generate a new Linux kernel image
4. The new Linux kernel image was installed, along with necessary support code and system modifications.

These operations used much of the free space on the SD card. At this point, the new Linux Kernel is up and running and backups were made at each development step.

Since compilation is completed, the /home/pi/linux directory will not be used beyond this point (in step 4, above, the result of all this work, the new Linux kernel was installed). As an optional step, you may remove the /home/pi/linux directory which will free up considerable space on the SD card. Note that you can recover this directory by loading a previously backed-up version of your Lab4 work.

## Performance of the new System

Once all of these tools and codes are loaded. Let's move on to performance of the system.

### First, try cyclic test:

Note: since a new kernel was installed, /usr/bin has been updated. Check the cyclicttest instructions from Lab4, week1 in order to reinstall cyclicttest in the new system.

```
sudo cyclicttest -p 90 -m -n -t4 -l 10000
```

Add 'dash h' to display the histogram of the run

```
sudo cyclicttest -p 90 -h 500 -m -n -t4 -l 300000
```

Again, note the results and save the output of the histogram to create a chart in excel. If all is well, the maximum latency should be lower than in the cyclic test run run under the Raspbian kernel.

You should also test the behavior of cyclicttest while loading the RPi cores during the test. Note that sort\_v1.c makes a pretty good cpu loading test. Compare a histogram of a loaded and unloaded RPi, with the RT Kernel.

For example, un 20 – 30 copies of sort\_v1 in the background and repeat the command:

```
time sudo cyclicttest -p 90 -n -m -h 500 -t4 -l 300000
```

Use htop to make sure the cores remain busy for the duration of the cyclicttest run. You might need to restart sort\_v1 programs during the run. You might also consider modifying sort\_v1 to run a bit longer.

### Perf tests

Re-run the perf tests on the two sort\_v1 C codes and note the results. Compare these tests against the sort\_v1 tests run under the Raspbian kernel. Are there any changes of note?

## Square Wave Tests

The C code square wave generator will be quite a bit different. As noted in class, to get the most out of the PreemptRT kernel, we have to place some controls on memory and stack space. Sample code on the ECE5725 server shows a skeleton of a routine to be used for the PreemptRT C code square wave generator (test\_rt\_skel\_v7.c) Some notes about this code:

```
#define MY_PRIORITY (49)
```

We pick a priority for the process that is not zero. As we saw in class, this will allow this application to preempt most other processes (including Linux processes).

```
#define MAX_SAFE_STACK (8*1024)
```

This definition sets the size of the stack that the application is allowed to use.

```
param.sched_priority = MY_PRIORITY;  
if(sched_setscheduler(0, SCHED_FIFO, &param) == -1) {
```

These statements set the scheduling policy for the test to ‘Sched\_FIFO’ with a priority of 49.

```
mlockall(MCL_CURRENT|MCL_FUTURE)  
stack_preload();
```

These statements lock memory (to avoid VM page faults) and ‘prefault’ the stack, which sets the entire stack for this process to zero, so that a future random-access of a stack variable will not cause a stack fault to add additional delay.

The while loop in the code uses a high precision timer to sleep for the prescribed amount of time (50 microseconds, initially). After the sleep, the code will ‘do something’.

Using this skeleton, modify the code so that:

- wiringPi is used to access the GPIO pins.
- add code to toggle a GPIO pin (use the same pin as in part 1 of this lab).
- Check code operation with the LED.
- Remember to add -lwiringPi to the compilation of the test code.



Once this is working, name the code `test_rt_v7.c`. Generate a stable square wave, checking it with the oscilloscope. When running this code:

- This code uses a for loop as a delay mechanism rather than `nanosleep` (have a look at `test_rt_skel_v1.c` to see the `nanosleep` version). The for loop keeps the code 'resident' when running using `sched_FIFO` in the RT kernel.
- You can select the interval with a command line argument therefore, change the interval of the for loop without a recompile.
- Try reducing the interval to smaller values; what frequencies do you see on the scope?
- Recall that for `blink.py` (python code) and `blink_v6.c` (C code) you discovered a performance 'knee' at the upper frequency bound. Do you observe a similar performance knee using `test_rt_skel_v7`?
- To test a stable, higher frequency, run `test_rt_v7 730`
  - This will run the test with an interval of 730 for the for loop
  - It should give you a stable frequency around 100 kHz
- Load the cores (with `sort_v1`, for example). Measure the performance difference of the square wave with a fully loaded system.

## Final square wave tests:

For these tests, you will be exploring the features of the Preempt-RT kernel. For each of the steps, record the scheduling algorithm and priority for each of the tests. Summarizing these in a table, with associated notes about each test, would be a good way to record results.

1. Run `test_rt_v7` without any system loading (as above) to generate a stable square wave.
  - a. Run `'ps -alef | grep test_rt_v7'` and note the pid of the running `test_rt_v7`
  - b. Run `'chrt -p pid'` where `pid` = pid of `test_rt_v7` from the command above. Record results.
2. Run `test_rt_v7 730` with system loading (I used `sort_v1` for system loading, running it 20 times in the background). Comment on any impacts to the square wave generated from `test_rt_v7`.
  - a. Run `'ps -alef | grep sort_v1'` and note the pid of the running loading test (`sort_v1` for my experiment)
  - b. Run `'chrt -p pid'` where `pid` = pid of the loading test from the command above. Record results.
3. Run the c code `'blink_v6'` from the first week of lab to generate a stable square wave
  - a. Run `'ps -alef | grep blink'` and note the pid of the running blink test
  - b. Run `'chrt -p pid'` where `pid` = pid of the blink test from the command above. Record results.
4. Run `'blink_v6'` to generate a stable square wave and add system loading. Comment on any impacts on the output of blink under loading.

## Week 2 Checklist

Show the TAs a copy of the following

- `uname -a` results for the PREEMPT-RT kernel
- saved data from `cyclictst` on the PREEMPT-RT kernel
- `perf` results for the two sort programs
- `test_rt` code running with system loading

## Appendix A: raspi-config instructions from Lab 1

After having a brief look at the system, continue with the following install steps:

- issue the command ‘sudo raspi-config’
- In the ‘boot options’ select ‘Desktop/CLI’ then ‘B1 Console’

This change will boot directly to the console window on the next RPi reboot. Since you are already in raspi-config, continue with the notes below for more configuration.

Working your way through the config screens, please make sure to apply the following settings:

- Change the pi user password to something you will remember!
- In ‘Network Options’, select ‘Hostname’: set a unique hostname to ‘netid\_netid’ where ‘netid\_netid’ are the Cornell netids of the two team members in your group.
- For Localization options:
  - Change locale:
    - Use the Spacebar and tab to navigate
    - De-select ‘en\_GB.UTF-8 UTF-8’. Set the Locale ‘en-us.UTF8 UTF8’. When prompted, select ‘None’ for the Default Locale
  - Change Timezone
    - Set the local time to America
    - Set the location to ‘New York’
  - Change Keyboard Layout
    - ‘Generic 101 key PC’ keyboard
    - select ‘Other’, then ‘English US’
    - ‘configuring keyboard-configuration’
      - select ‘English (US)’
      - next, select ‘The default for the keyboard layout’
      - next, select ‘no compose key’
      - finally, select “Ctrl-Alt-backspace to exit the X server”

Why these settings? These are the best settings for the time, keyboard and mouse you will be using

- Interfacing Options: enable ssh
- In the ‘Advanced’ settings
  - A1, expand the file system

- A4 Audio: Force 3.5 mm jack
- Update: update this tool to the latest version

Once you hit 'Finish', raspi-config will save your changes and ask if you want to reboot now. Answer 'yes'.

## Appendix B: Perf Installation from Lab 2

**Step1:** Install Perf with the following commands:

```
sudo apt-get install linux-tools
```

Try the command:

```
perf -help
```

And it should fail. The message will tell you that your system is missing the correct version of perf. Example:

```
pi@RPi-jfs9:~ $ perf --help
/usr/bin/perf: line 13: exec: perf_4.14: not found
E: linux-perf-4.14 is not installed.
```

You can remedy this by running:

```
sudo apt-get install linux-perf-4.9
```

**Step2:**

Test that perf is operating as designed by running:

```
perf_4.9 --help
perf_4.9 list
perf_4.9 --version
```

Notes:

1. Perf is able to track a number of different hardware and software events. Take a look at the output of 'list', above, to get an idea of these events perf is able to track.
2. Keep in mind that not all of these measurements are available on all platforms.
3. With perf, there is a bash shell installed in /usr/bin/perf. Run this by issuing the command 'perf'. What error do you see? Take a look at the bash script and see if you can form a theory for why this fails and how you might overcome the problem.