CST 8703 Lab 0 - Hello Real-Time World

Kyle Chisholm

2022-05-17

Real-Time Systems and Embedded Programming

Submission Deadline: May 19, 2022

Online version of this document: https://chishok.github.io/CST8703/CST8703-Lab0

This lab will provide a tutorial on how to install and configure a Raspberry Pi for remote development. POSIX with realtime extensions will be introduced and a Linux application written in C will showcase basic clock and pthread functions.

> ***NOTE:*** There is currently a global shortage of Raspberry Pi boards. If you do not have a Raspberry Pi, simply use WSL (follow instructions below), native Ubuntu Linux, or Virtualbox to configure your development environment, build and run software in a POSIX-compliant environment.

Background

The Portable Operating System Interface (POSIX) provides an interface for operating systems, applications, and real-time embedded development on platforms like Xenomai, VxWorks, QNX, and many more. FreeRTOS, a popular Real-Time Operating System (RTOS), also provides a wrapper for the POSIX threading API (commonly known as pthreads).

A robust development environment and tools are necessary for building and debugging applications. Proprietary Real-Time Operating Systems (RTOS) typically provide a host IDE with extensive documentation to get started. For Free and Open-Source Software (FOSS) such as the Linux operating system, development environments are as numerous are there are developers who use them. This lab provides a setup guide for the Raspberry Pi and a C development environment. Python, Bash, and CMake will also be used for scripting and managing the build and execution process.

The series of labs in this course make use of the "headless" version of the Raspberry Pi OS which does not have a desktop environment (graphical interface). A desktop environment can be installed, but embedded programming is typically done on a separate host machine with a cross-compiler and remote debugging tools. For the course labs, the embedded software is built and run on the target Raspberry Pi over a network connection. VS Code will be used as the primary Integrated Development Environment (IDE).

> ***NOTE:*** This course is focused on developing real-time embedded applications. However, there are many other aspects of creating embedded Linux systems, including cross-

compiling with toolchains, bootloaders, kernel configuration, filesystems, build systems, drivers. etc. Mastering Embedded Linux Programming is a good reference to go deeper into these areas of embedded Linux systems, if interested.

Useful Links And References For Help With C, POSIX, and Bash

The Linux `man` pages are an indispensable tool for any systems developer, and especially for POSIX real-time systems. You can access man pages online at https://man7.org/linux/man-pages or simply use the command line tool `man` on any modern Linux distribution. Type `man man` in the terminal for more information. In addition to the course textbook, the following resources are helpful when writing code for embedded Linux:

Reference	Description
https://man7.org/tlpi [1]	The ultimate reference for Linux and UNIX system programming.
Modern C	Great resource for C language coding.
Mastering Embedded Linux Programming	Build full embedded solutions and cross-compile with Yocto or buildroot.

There is an excellent online book on using CMake here but the labs won't require alterations to the build configurations.

Coding Best Practices, Standards, and Formatting

Code quality monitoring, testing, static analysis, and standards compliance are important when developing embedded code for safety-critical realtime systems in industry. Adhering to coding standards and formatting can go a long way in maintaining readable "clean" code. The Barr Embedded C Standard is recommended to follow when writing C code for systems where safety and security are important.

Several configuration files, tools, and VS Code extensions are helpful when writing and debugging code. A brief description of the tools will be provided during the installation procedures in the Methods section, but you are encouraged to learn more about them and personalize your development environment.

Using Linux With the Command Line

The series of labs in this course require basic knowledge using a Bash shell (Linux command line). There are plenty of tutorials online to gain familiarity with Bash. Stack overflow and the stack exchange network sites are also excellent resources to find answers to programming questions, including C, Unix/Linux bash scripts and tools.

Materials

1. Raspberry Pi 4 or Raspberry Pi Zero 2 W.

   A Raspberry Pi also requires a power source, MicroSD card, and case. A breakout cable for the GPIO with a breadboard is also useful for prototyping with hardware. The following list of items link to accessories required for using the Raspberry Pi. It is encouraged to search for similar products if the cost is too high or the linked items are no longer available.

   1. Raspberry Pi 4 Power Supply 5V 3A USB C Charger Adapter
   2. Raspberry Pi 4 Case
   3. GPIO Breakout kit
   4. 32GB 2-Pack Ultra microSDHC

2. Logitech C270 HD Webcam, HD 720p/30 fps
3. Desktop computer with Linux, Windows, or Mac operating system.
4. Wired or wireless local network.

Methods

The following procedures will guide you through the installation and configuration of all necessary software for developing code with this lab series in CST 8703.

Install Prerequisites (Windows 10)

1. Install OpenSSH.

   Follow instructions online to install OpenSSH.

   Follow instructions online to start and configure OpenSSH.

2. Follow instructions online to install Chocolatey. Chocolatey has extensive documentation here: https://docs.chocolatey.org/.

3. Install Git with Chocolatey. Open a powershell prompt as an administrator and run:

   ```
   choco install git.install
   ```

4. Install Python with Chocolatey. Open a powershell prompt as an administrator and run:

   ```
   choco install python3
   ```

5. Follow instructions online to install Windows Subsystem for Linux (WSL).

   Reboot the system and open Ubuntu for the first time. The installation will continue and you will be prompted to enter a username and password. Upgrade Ubuntu with the commands:

   ```
   sudo apt update
   sudo apt upgrade -y
   ```

   You can also install different distributions, such as Debian:

   ```
   Invoke-WebRequest -Uri https://aka.ms/wsl-debian-gnulinux -OutFile ~/debian.appx -UseBasicParsing
   Add-AppxPackage -Path ~/debian.appx
   ```

6. Follow instructions online to install Windows Terminal. If you want to customize a pretty terminal prompt, OhMyPosh is recommended.

7. Follow instructions online to install VS Code.

Install Prerequisites (Ubuntu 20.04)

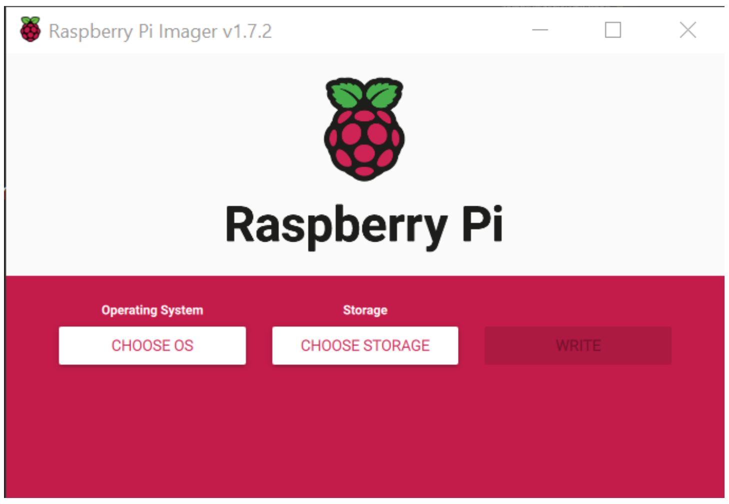
> ***NOTE:*** Ignore these instructions if you are using Windows or Mac. The following software (including VS Code) is only required if your home desktop computer is running Ubuntu.

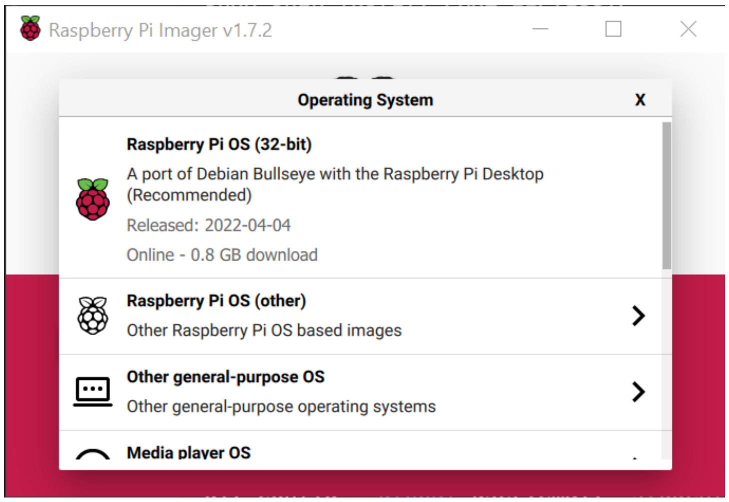
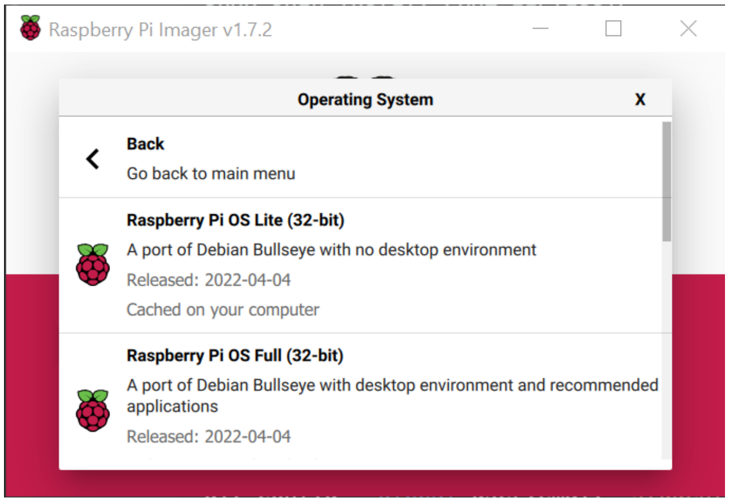
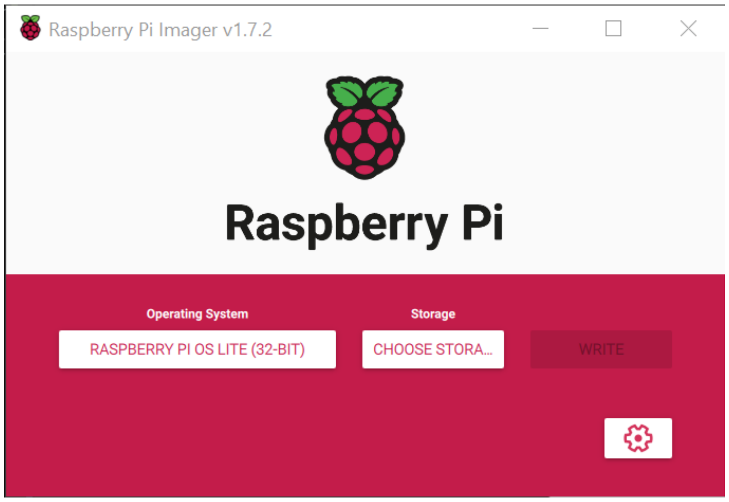
In a bash terminal, run the following:

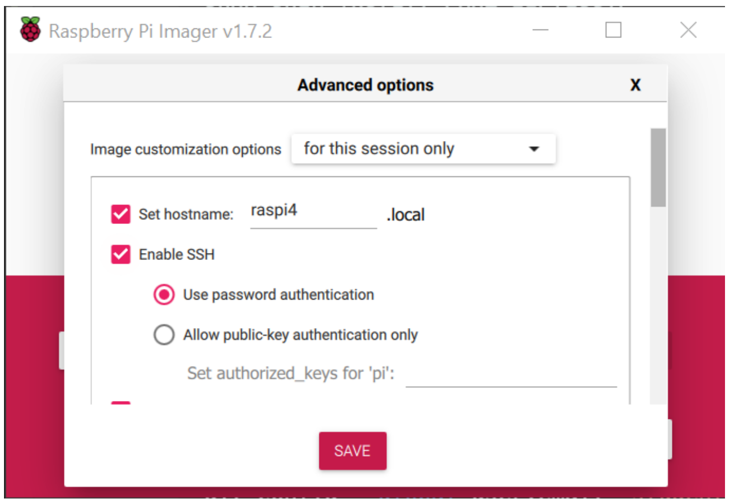
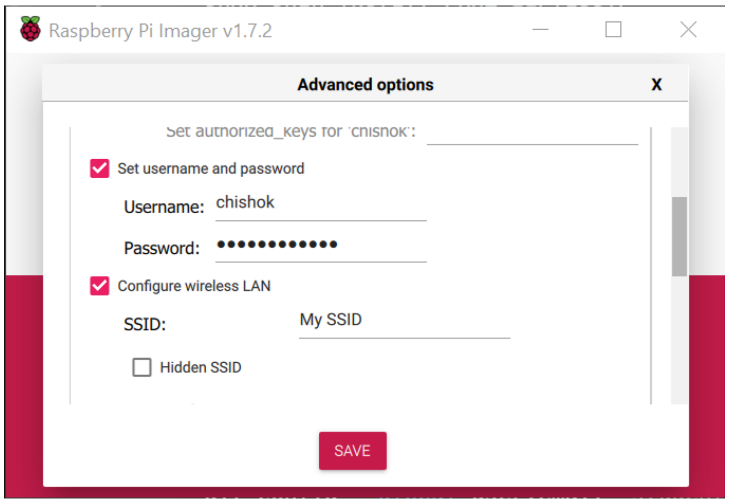
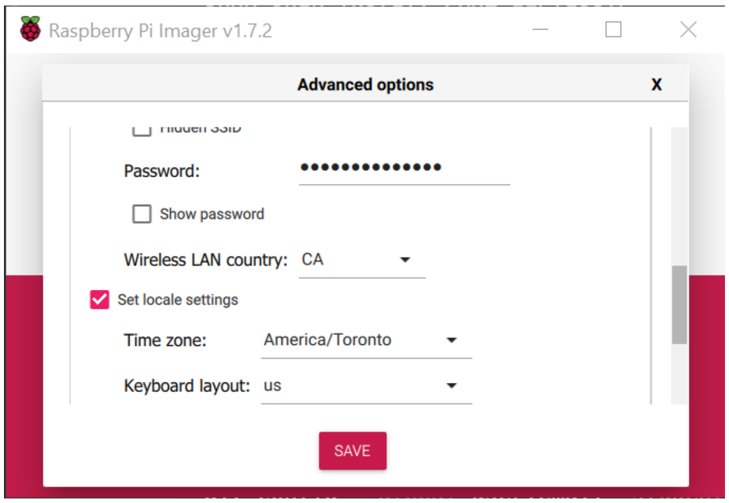
```
sudo apt install -y \
    git \
    openssh-client \
    python3
sudo snap install code --classic
```

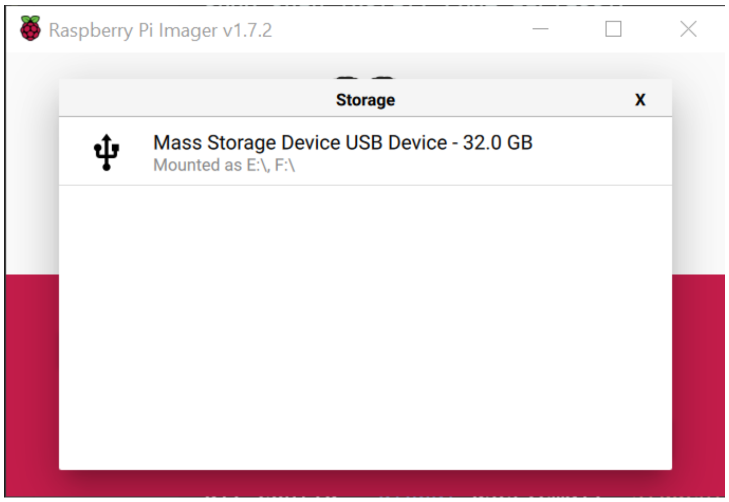
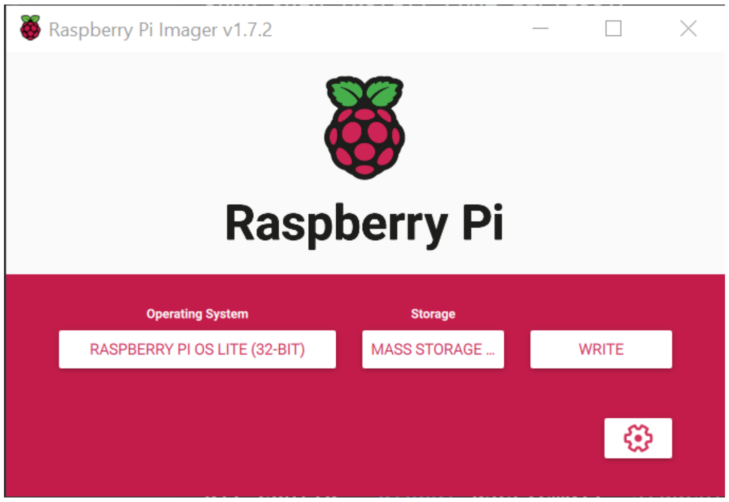
Install Raspberry Pi OS

1. Download and install the Raspberry Pi OS Imager application.
2. Insert a blank MicroSD card into a reader attached to the host computer.
3. Run the program "Raspberry Pi Imager"
4. Follow these steps to configure the Raspberry Pi OS:

Step	Screenshot
1. Select 'CHOOSE OS'	 Raspberry Pi Imager v1.7.2 Raspberry Pi Operating System CHOOSE OS Storage CHOOSE STORAGE WRITE

Step	Screenshot
2. Select ‘Raspberry Pi OS (other)’	 Raspberry Pi Imager v1.7.2 Operating System X **Raspberry Pi OS (32-bit)** A port of Debian Bullseye with the Raspberry Pi Desktop (Recommended) Released: 2022-04-04 Online - 0.8 GB download **Raspberry Pi OS (other)** Other Raspberry Pi OS based images **Other general-purpose OS** Other general-purpose operating systems **Media player OS**
3. Select ‘Raspberry Pi OS Lite (32-bit)’	 Raspberry Pi Imager v1.7.2 Operating System X **Back** Go back to main menu **Raspberry Pi OS Lite (32-bit)** A port of Debian Bullseye with no desktop environment Released: 2022-04-04 Cached on your computer **Raspberry Pi OS Full (32-bit)** A port of Debian Bullseye with desktop environment and recommended applications Released: 2022-04-04
4. Click on the button with the gear symbol to set advanced options	 Raspberry Pi Imager v1.7.2 Raspberry Pi Operating System: RASPBERRY PI OS LITE (32-BIT) Storage: CHOOSE STORA... WRITE

Step	Screenshot
5. Set custom hostname and enable SSH	 Raspberry Pi Imager v1.7.2 **Advanced options** Image customization options: for this session only ☑ Set hostname: raspi4 .local ☑ Enable SSH ● Use password authentication ○ Allow public-key authentication only Set authorized_keys for 'pi': SAVE
6. Set username and password and configure wireless LAN with your router SSID and password.	 Raspberry Pi Imager v1.7.2 **Advanced options** Set authorized_keys for 'chishok': ☑ Set username and password Username: chishok Password: •••••••••••• ☑ Configure wireless LAN SSID: My SSID ☐ Hidden SSID SAVE
7. Set your locale and click 'SAVE'	 Raspberry Pi Imager v1.7.2 **Advanced options** ☐ Hidden SSID Password: •••••••••••••• ☐ Show password Wireless LAN country: CA ☑ Set locale settings Time zone: America/Toronto Keyboard layout: us SAVE

Step	Screenshot
8. Select 'CHOOSE STORAGE' and choose the MicroSD card.	 Raspberry Pi Imager v1.7.2 Storage Mass Storage Device USB Device - 32.0 GB Mounted as E:\, F:\
9. Select 'WRITE' and wait for process to complete.	 Raspberry Pi Imager v1.7.2 Raspberry Pi Operating System Storage RASPBERRY PI OS LITE (32-BIT) MASS STORAGE ... WRITE

5. Insert the microSD into your Raspberry Pi and connect it to a power source.

Set Up Raspberry Pi With Development Tools

When your Raspberry Pi is connected to power, it will turn on and connect to the local network with SSID and password provided in the previous section. You can also connect to the local network with an Ethernet cable instead of relying on WiFi. The first step in setting up for remote development is to connect to the Raspberry Pi with ssh by entering the following command:

```
ssh <username>@<hostname>
```

Enter `<username>` and `<hostname>` as configured when creating the OS image in the previous section. For example:

```
ssh chishok@raspi4
```

If provided a warning "The authenticity of host '...' can't be established.", simply respond "yes".

If the hostname cannot be resolved, look at your router's DHCP settings to find the assigned IP address corresponding to the Raspberry Pi and use that instead. You may also configure a reserved IP address just for your Pi by changing the appropriate settings in your router. For example if the IP address is `192.168.1.120`, login with the command:

```
ssh chishok@192.168.1.120
```

Once connected to your Pi, the following steps will guide you through the initial setup for remote C/C++ and Python development:

1. Install C/C++ development tools with the following commands:

   ```
   sudo apt update
   sudo apt upgrade -y
   sudo apt install -y \
       git \
       build-essential \
       cmake \
       clang-format \
       shellcheck
   ```

2. Install Python with the following command:

   ```
   sudo apt install -y \
       python3 \
       python3-pip \
       python3-venv \
       python3-setuptools \
       python3-flake8 \
       python3-flake8-docstrings \
       python3-autopep8
   ```

3. Configure Git with your name and email:

   ```
   git config --global user.name "First Last"
   git config --global user.email "student@algonquincollege.com"
   ```

4. Create ssh key pair with the command:

   ```
   ssh-keygen -t rsa
   ```

   Do not enter a passphrase and accept all default options.

5. Source profile script from `~/.bash_profile`:

   ```
   echo "source ${HOME}/.bashrc" >> ${HOME}/.bash_profile
   ```

6. Create local directory `~/.local` and add it to `PATH` environment variable with the following commands:

   ```
   mkdir -p "${HOME}/.local/bin"
   echo "export PATH=\${PATH}:${HOME}/.local/bin" >> ${HOME}/.bash_profile
   ```

7. For lab submissions, environment variables `AC_USERNAME` and `AC_EMAIL` must be set with your student id name and email. These variables can be set when logging in in by adding them to the bash profile script as follows:

```
echo "export AC_USERNAME=chishok" >> "${HOME}/.bash_profile"
echo "export AC_EMAIL=chishok@algonquincollege.com" >> "${HOME}/.bash_profile"
```

Replace `chishok` and `chishok@algonquincollege.com` with your own student name and email.

(Recommended) Use SSH key pair to Connect To Raspberry Pi

Exit the ssh connection with the command `exit` to return to your desktop computer command line. Follow these steps from your home desktop computer to conveniently connect to the Raspberry Pi without having to enter a username and password:

1. Generate key pair

   ```
   ssh-keygen -t rsa
   ```

   Do not enter a passphrase and accept all default options.

2. Copy your public key to the Raspberry Pi's authorized keys file:

   From Windows:

   ```
   ssh-keygen -t rsa
   cat $env:USERPROFILE\.ssh\id_rsa.pub | ssh chishok@raspi4 "cat >> .ssh/authorized_keys"
   ```

   From Linux:

   ```
   ssh-copy-id chishok@raspi4
   ```

You should now be able to `ssh` into your Raspberry Pi from your computer without having to enter a password.

(Optional) Local Network Static IP Connection

If you do not have a router available with DHCP, you can also create a direct connection over ethernet with a cable connecting your personal computer to the Raspberry Pi. The following diagram shows the local network setup options:

> **NOTE**: If you have access to a common local network provided by a router, there is no need to connect over a static IP address.

A static IP and direct connection can be configured as follows:

1. Attach a keyboard an monitor to the Raspberry Pi and login.
2. Attach an ethernet cable to the Raspberry Pi 4 or to a USB-Ethernet adapter on the Zero 2 W. Attach the other end to your desktop or laptop computer.
3. From the terminal, check the device name of the ethernet port by running `ip addr`. On Debian (Raspberry Pi OS) ethernet devices start with `eth` followed by a number. You'll likely only that the one physical ethernet device `eth0` listed.
4. Choose a static ip address for the Raspberry Pi. By convention, a local private network should choose ip addresses in the ranges:
   - `10.0.0.0` to `10.255.255.255`

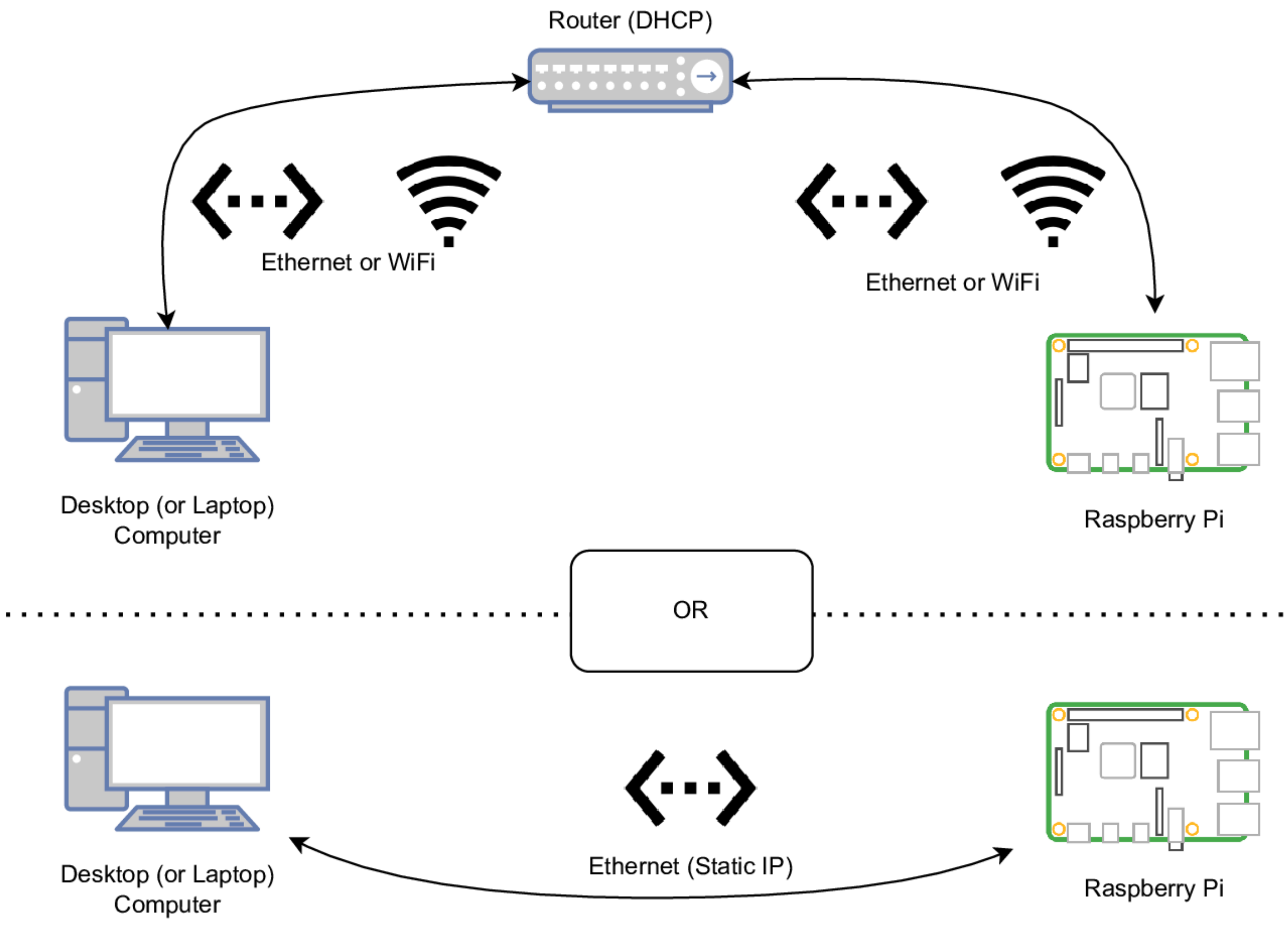


Figure 1: Diagram of local network to connect to raspberry pi

- `172.16.0.0` to `172.31.255.255`
- `192.168.0.0` to `192.168.255.255`

For this example, we choose `172.16.1.110`.

5. Configure the static ip address. Use a heredoc in bash to write the multi-line file in one command:

```
sudo tee "/etc/network/interfaces.d/static_network" > /dev/null <<EOF
# Static IP ethernet interface
allow-hotplug eth0
iface eth0 inet static
        address 172.16.1.110
        netmask 255.255.255.0
        gateway 172.16.1.110
        metric 30
        post-up ip route del default dev eth0
EOF
```

This creates a static IP address `172.16.1.110` on `eth0` with a netmask of `255.255.255.0` meaning it will only be able to connect to any other ip address starting with `172.16.1.`. The `allow-hotplug` bring up the interface when an ethernet cable is attached. The last line ensures it is not the default route when attempting to access the internet.

6. Choose an IP address for the desktop computer. For this example, we choose `172.16.1.120`.

7. Configure a static IP address on your desktop computer. On Windows, go to "Settings > Ethernet" and click on the ethernet device connected to the Raspberry Pi. Edit the IP address, setting it to "Manual" with the following settings:

   Use the same Gateway as selected in the Raspberry Pi configuration (`172.16.1.110` in this case), `24` subnet prefix which is equivalent to a mask of `255.255.255.0`, and the Windows IP static address (`172.16.1.120` in this example).

8. Reboot the Raspberry Pi and test the ssh connection from Windows:

```
ssh chishok@172.16.1.110
```

Set Up VS Code for SSH Remote Development With The Raspberry Pi

1. Open VS Code and install the Remote Development Extension Pack.

2. Follow the instructions online to connect to a remote host by SSH.

3. You can now use VS Code as though it was running on the Raspberry Pi. Using the integrated terminal is also very convenient.

4. While connected remotely, install the extensions in the table below. Refer to online help for more information about managing extensions on remote hosts.

Extension	Description
C/C++ Extension Pack	C/C++ build and debug, CMake integration, code-completion suggestions, etc.
Clang-Format	C/C++ code formatting.

Extension	Description
Python	Python integration, debugging, linting, formatting, etc.

Optional extensions for themes and syntax highlighting (install on desktop computer):

Extension	Link
Better C++ Syntax	Improves syntax highlighting.
C/C++ Themes	Color syntax themes for C/C++ code.
Material Icon Theme	Improved file icons.
Shellcheck	Bash script linting.

Retrieve Lab Source

On the Raspberry Pi (or local Linux system, if desired), checkout the code sample for this lab:

```
git clone https://github.com/chishok/CST8703-Lab0
```

Run VS Code on your desktop computer and connect remotely with SSH (or WSL if on Windows without a Raspberry Pi). Open the folder `CST8703-Lab0` checked out with Git. The following screenshot shows how the folder should eventually appear:

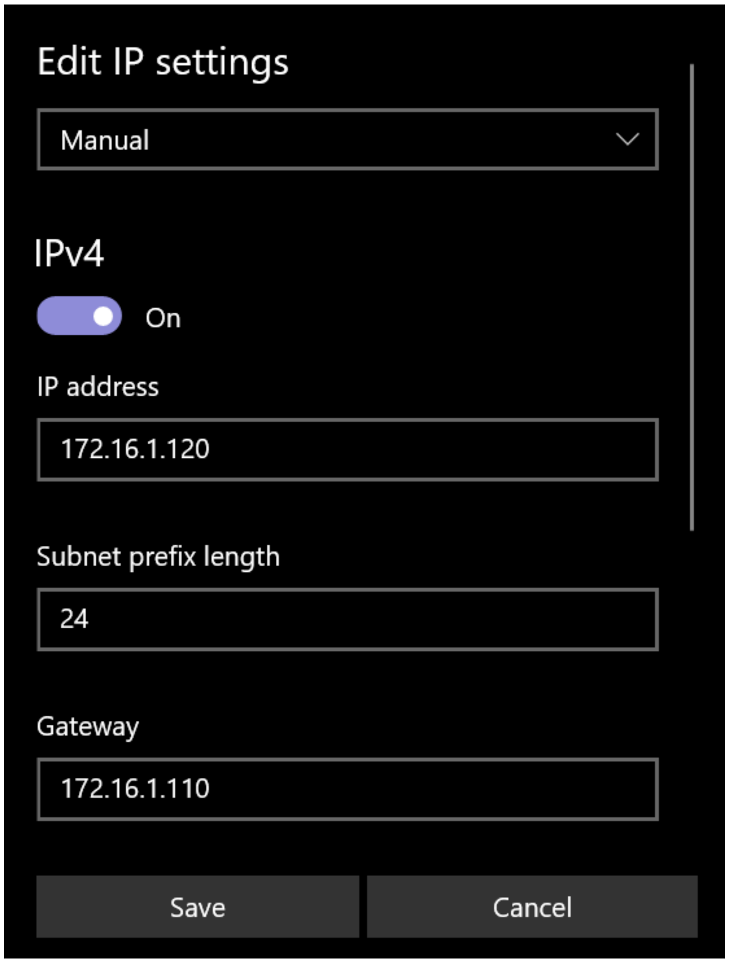
Build and Debug

> ***NOTE***: For more information on how to use CMake Tools on VS Code, refer to the help available online.

1. Click on kits button at the bottom of VS Code window taskbar. Select the GCC compiler kit.
2. Select the CMake button and choose the Build type "Debug."

   CMake will configure and a `build` folder is created where target programs are created. The following screenshot shows the output on successful build:
3. Select a target program by clicking on `[all]` button on bottom taskbar and choosing `CST8703Lab0-HelloWorld` as shown here:
4. Click the "Build" button on the bottom taskbar to build the target. The build process output is shown here:
5. Click the "Play" button beside the target name to run the program. The terminal appears with output from running the program as shown here:
6. Open `HelloWorld/main.c` and create a breakpoint on line 112.Debug the program by clicking on the "Bug" button on the bottom taskbar. VS Code enters debug mode as shown here:

   More information on debugging in VS Code can be found online.


Edit IP settings

Manual

IPv4

On

IP address: 172.16.1.120

Subnet prefix length: 24

Gateway: 172.16.1.110

Figure 2: Windows Static IP Settings Screenshot

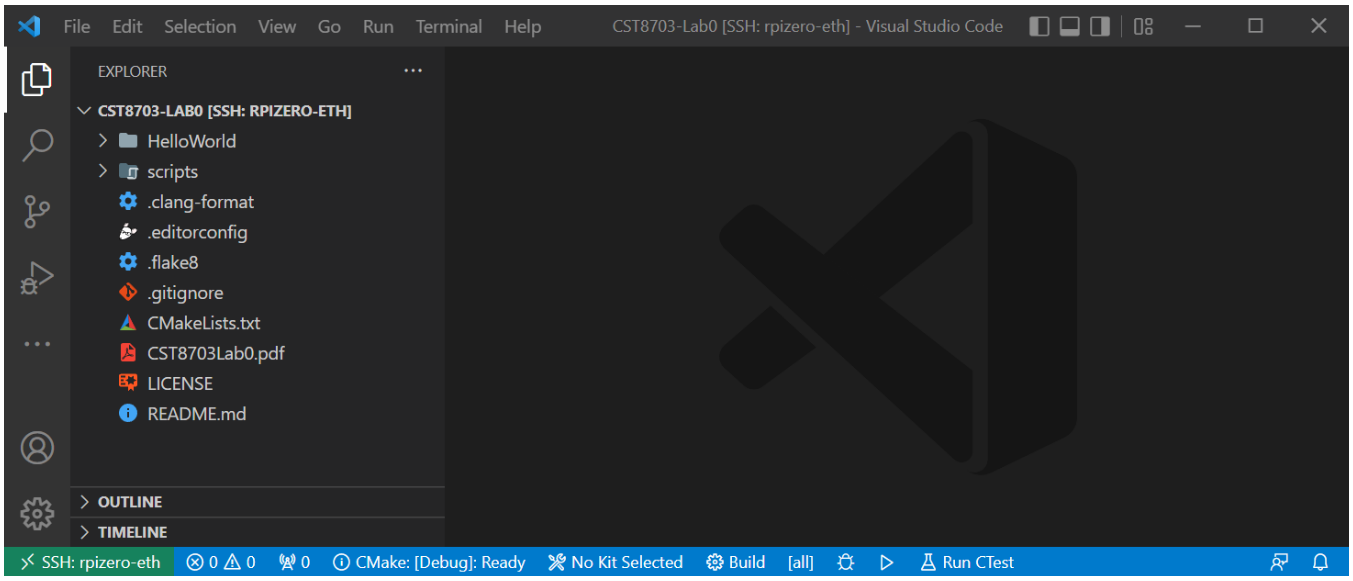
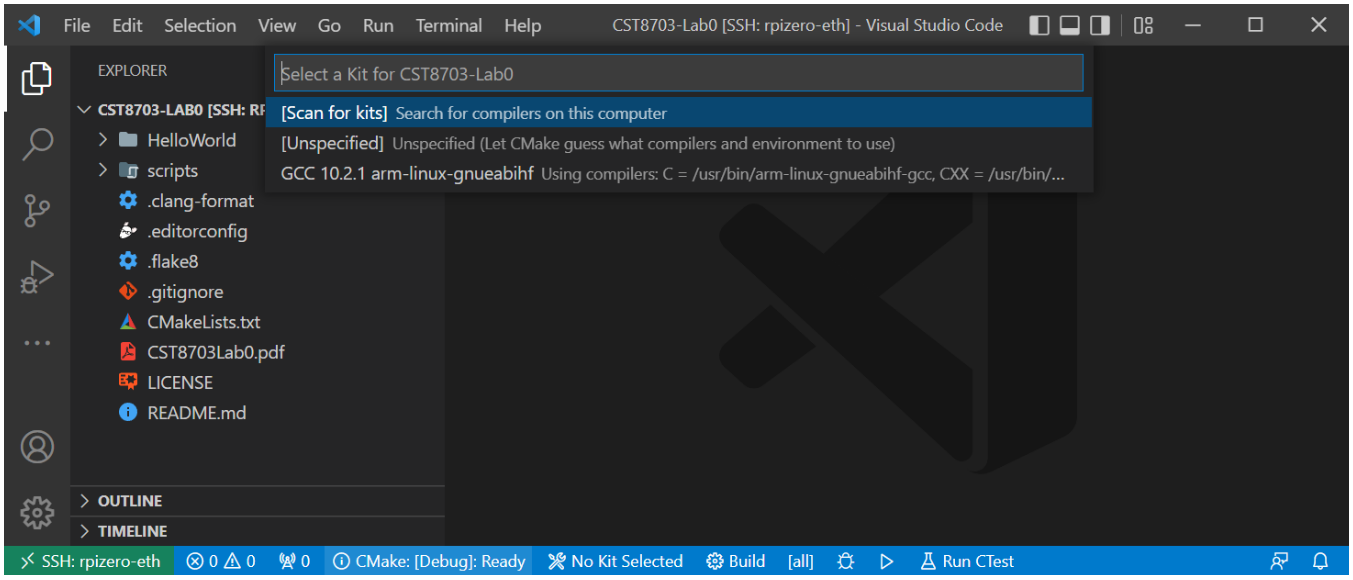


Figure 3: Screenshot of VS Code



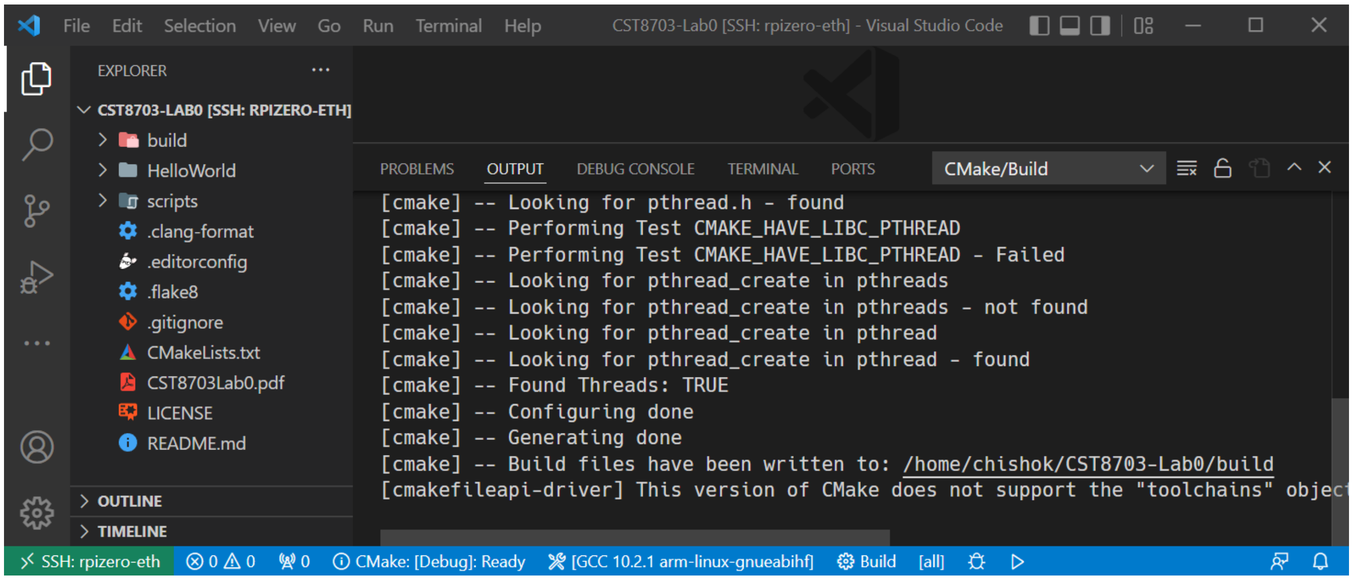
Select a Kit for CST8703-Lab0

[Scan for kits] Search for compilers on this computer

[Unspecified] Unspecified (Let CMake guess what compilers and environment to use)

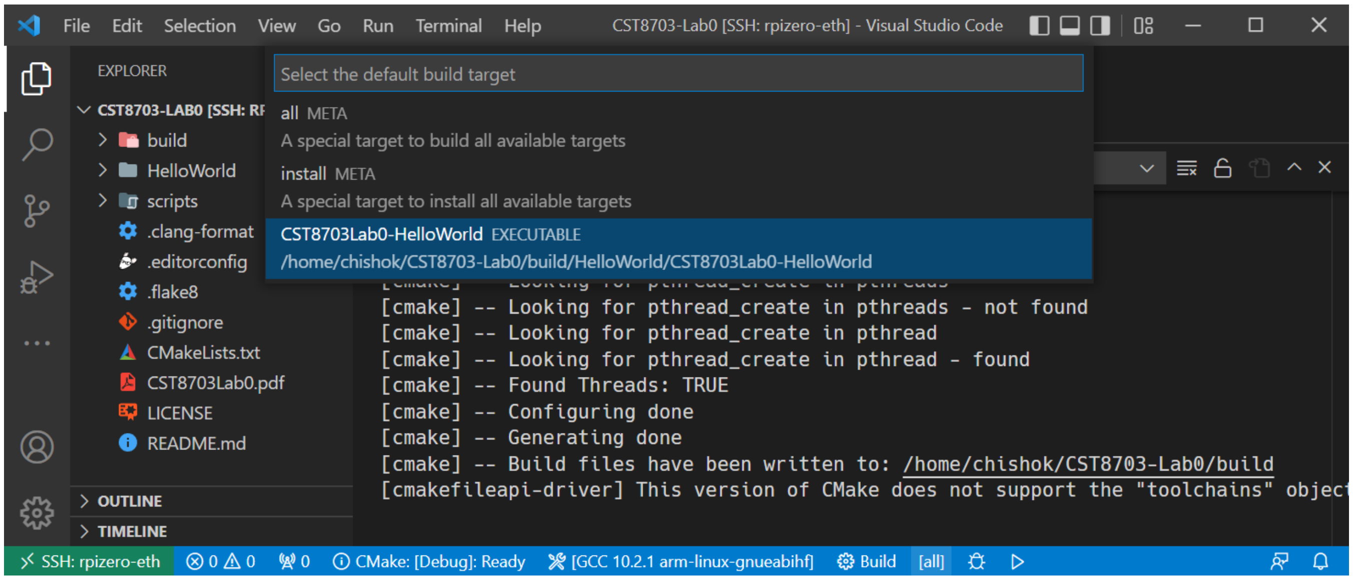
GCC 10.2.1 arm-linux-gnueabihf Using compilers: C = /usr/bin/arm-linux-gnueabihf-gcc, CXX = /usr/bin/...

Figure 4: Screenshot of VS Code with CMake kits selection



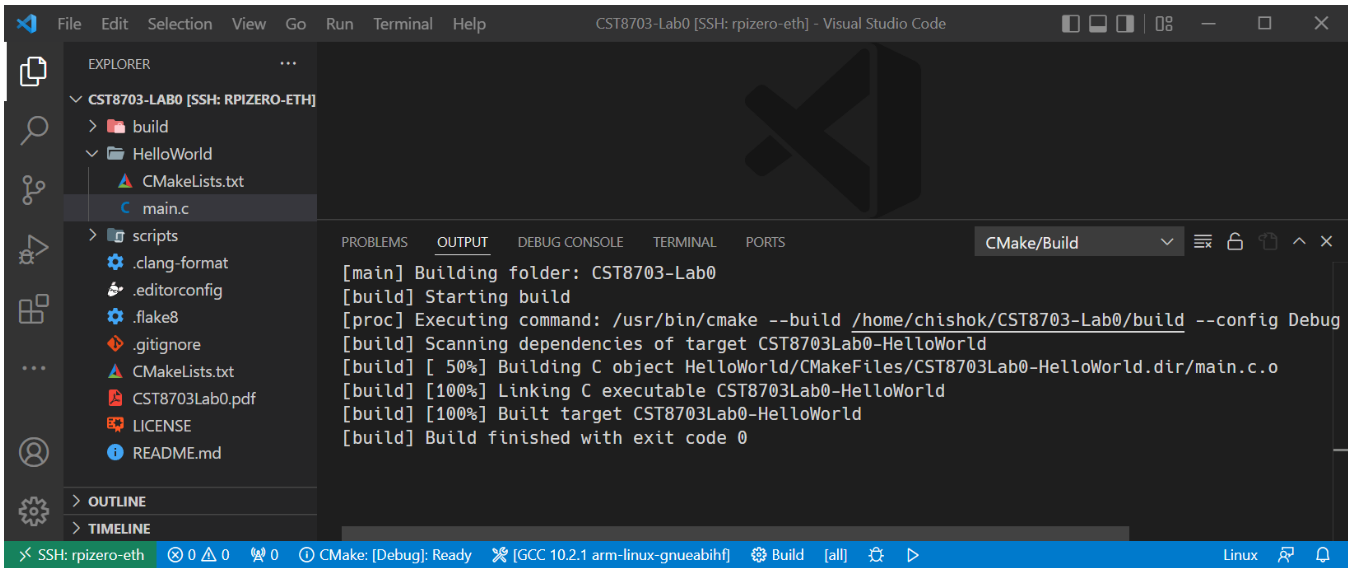
```
[cmake] -- Looking for pthread.h - found
[cmake] -- Performing Test CMAKE_HAVE_LIBC_PTHREAD
[cmake] -- Performing Test CMAKE_HAVE_LIBC_PTHREAD - Failed
[cmake] -- Looking for pthread_create in pthreads
[cmake] -- Looking for pthread_create in pthreads - not found
[cmake] -- Looking for pthread_create in pthread
[cmake] -- Looking for pthread_create in pthread - found
[cmake] -- Found Threads: TRUE
[cmake] -- Configuring done
[cmake] -- Generating done
[cmake] -- Build files have been written to: /home/chishok/CST8703-Lab0/build
[cmakefileapi-driver] This version of CMake does not support the "toolchains" objec
```

Figure 5: Screenshot of VS Code with CMake configuration output


File Edit Selection View Go Run Terminal Help
CST8703-Lab0 [SSH: rpizero-eth] - Visual Studio Code
EXPLORER
CST8703-LAB0 [SSH: RP
build
HelloWorld
scripts
.clang-format
.editorconfig
.flake8
.gitignore
CMakeLists.txt
CST8703Lab0.pdf
LICENSE
README.md
OUTLINE
TIMELINE
Select the default build target
all META
A special target to build all available targets
install META
A special target to install all available targets
CST8703Lab0-HelloWorld EXECUTABLE
/home/chishok/CST8703-Lab0/build/HelloWorld/CST8703Lab0-HelloWorld
SSH: rpizero-eth
CMake: [Debug]: Ready
[GCC 10.2.1 arm-linux-gnueabihf]
Build
[all]

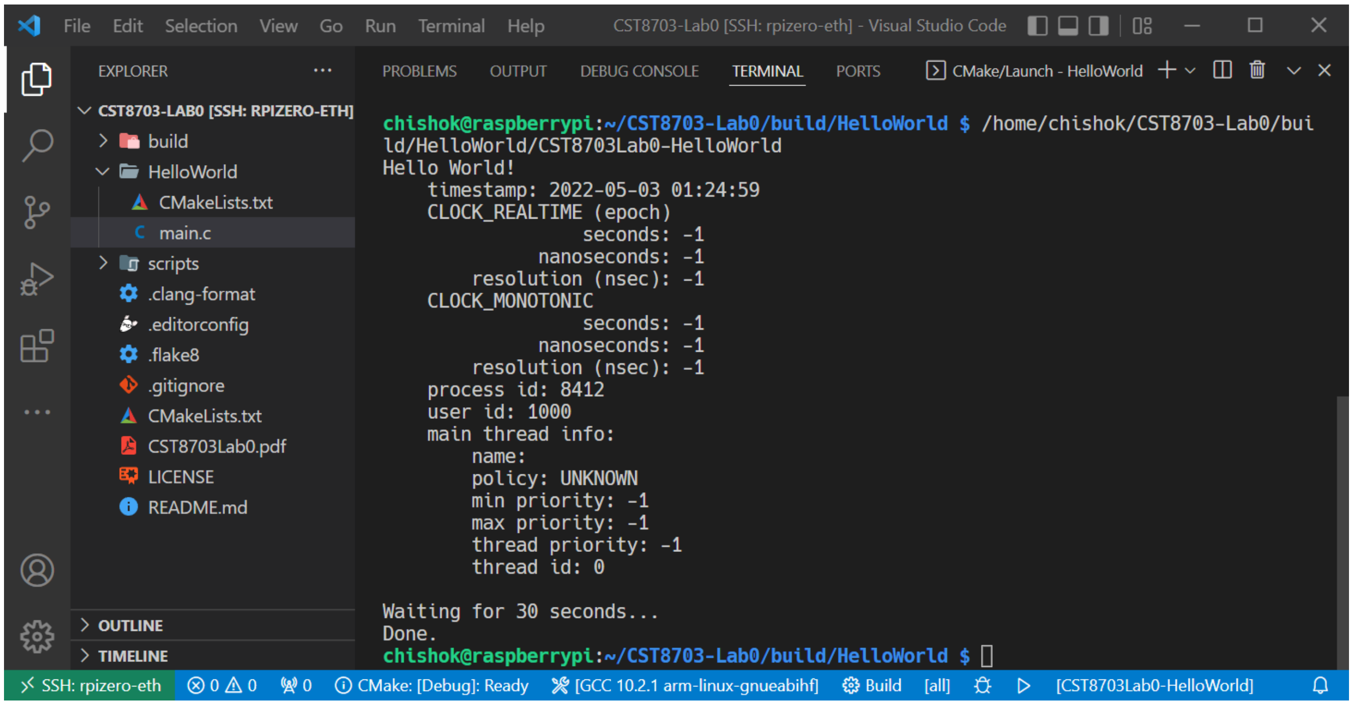
```
[cmake] -- Looking for pthread_create in pthreads - not found
[cmake] -- Looking for pthread_create in pthread
[cmake] -- Looking for pthread_create in pthread - found
[cmake] -- Found Threads: TRUE
[cmake] -- Configuring done
[cmake] -- Generating done
[cmake] -- Build files have been written to: /home/chishok/CST8703-Lab0/build
[cmakefileapi-driver] This version of CMake does not support the "toolchains" objec
```

Figure 6: Screenshot of VS Code to select target



```
[main] Building folder: CST8703-Lab0
[build] Starting build
[proc] Executing command: /usr/bin/cmake --build /home/chishok/CST8703-Lab0/build --config Debug
[build] Scanning dependencies of target CST8703Lab0-HelloWorld
[build] [ 50%] Building C object HelloWorld/CMakeFiles/CST8703Lab0-HelloWorld.dir/main.c.o
[build] [100%] Linking C executable CST8703Lab0-HelloWorld
[build] [100%] Built target CST8703Lab0-HelloWorld
[build] Build finished with exit code 0
```

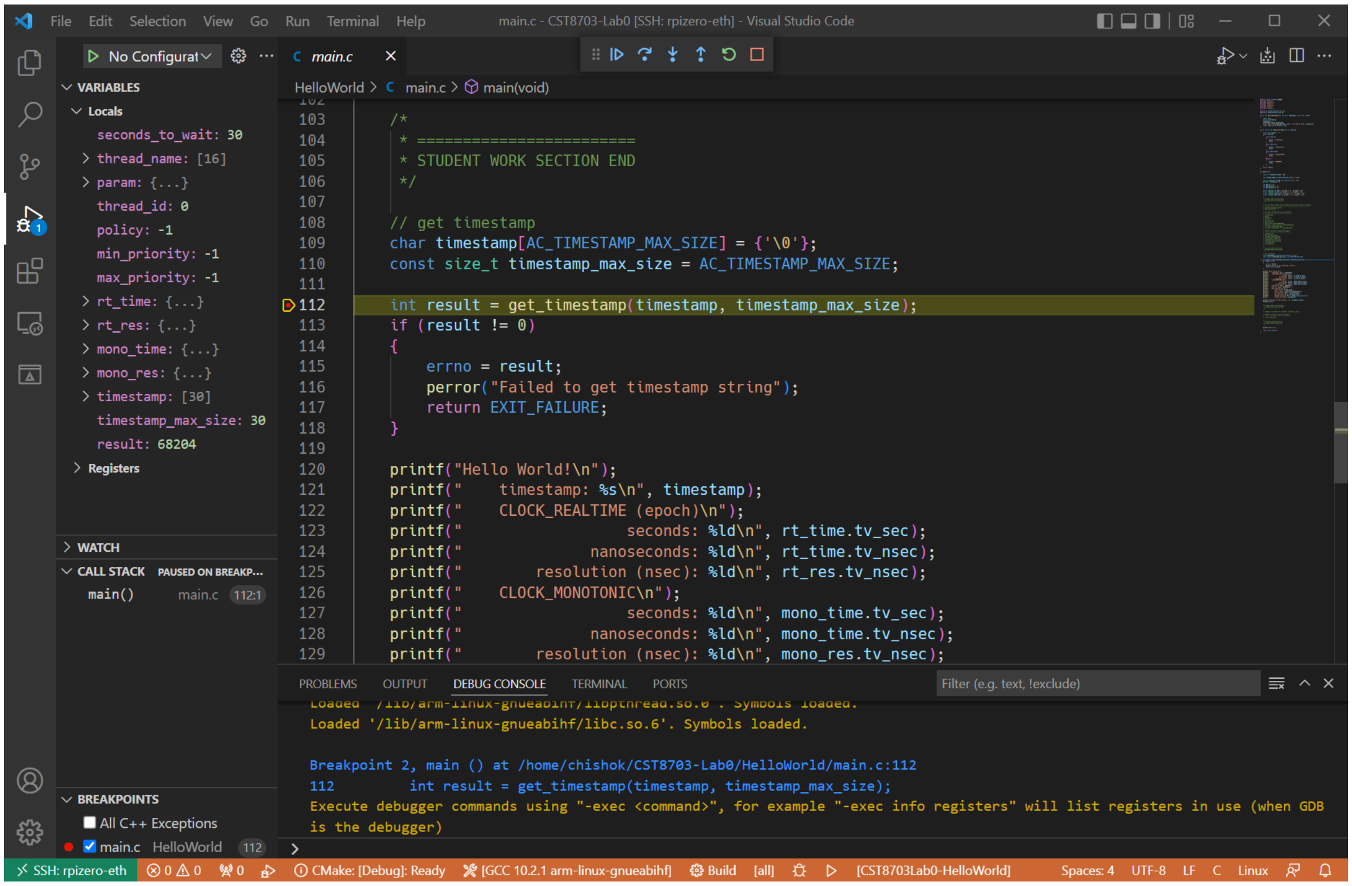
Figure 7: Screenshot of VS Code with build output



```
chishok@raspberrypi:~/CST8703-Lab0/build/HelloWorld $ /home/chishok/CST8703-Lab0/bui
ld/HelloWorld/CST8703Lab0-HelloWorld
Hello World!
    timestamp: 2022-05-03 01:24:59
    CLOCK_REALTIME (epoch)
                  seconds: -1
              nanoseconds: -1
        resolution (nsec): -1
    CLOCK_MONOTONIC
                  seconds: -1
              nanoseconds: -1
        resolution (nsec): -1
    process id: 8412
    user id: 1000
    main thread info:
        name:
        policy: UNKNOWN
        min priority: -1
        max priority: -1
        thread priority: -1
        thread id: 0

Waiting for 30 seconds...
Done.
chishok@raspberrypi:~/CST8703-Lab0/build/HelloWorld $ 
```

Figure 8: Screenshot of VS Code with run output


main.c - CST8703-Lab0 [SSH: rpizero-eth] - Visual Studio Code
No Configurat
main.c
HelloWorld > main.c > main(void)
PROBLEMS
OUTPUT
DEBUG CONSOLE
TERMINAL
PORTS
Filter (e.g. text, !exclude)
SSH: rpizero-eth
CMake: [Debug]: Ready
[GCC 10.2.1 arm-linux-gnueabihf]
Build
[all]
[CST8703Lab0-HelloWorld]
Spaces: 4
UTF-8
LF
C
Linux

```
VARIABLES
  Locals
    seconds_to_wait: 30
  > thread_name: [16]
  > param: {...}
    thread_id: 0
    policy: -1
    min_priority: -1
    max_priority: -1
  > rt_time: {...}
  > rt_res: {...}
  > mono_time: {...}
  > mono_res: {...}
  > timestamp: [30]
    timestamp_max_size: 30
    result: 68204
  > Registers

WATCH
CALL STACK    PAUSED ON BREAKP...
  main()    main.c  112:1

BREAKPOINTS
  All C++ Exceptions
  main.c  HelloWorld  112
```

```
    /*
     * ========================
     * STUDENT WORK SECTION END
     */

    // get timestamp
    char timestamp[AC_TIMESTAMP_MAX_SIZE] = {'\0'};
    const size_t timestamp_max_size = AC_TIMESTAMP_MAX_SIZE;

    int result = get_timestamp(timestamp, timestamp_max_size);
    if (result != 0)
    {
        errno = result;
        perror("Failed to get timestamp string");
        return EXIT_FAILURE;
    }

    printf("Hello World!\n");
    printf("    timestamp: %s\n", timestamp);
    printf("    CLOCK_REALTIME (epoch)\n");
    printf("                  seconds: %ld\n", rt_time.tv_sec);
    printf("              nanoseconds: %ld\n", rt_time.tv_nsec);
    printf("        resolution (nsec): %ld\n", rt_res.tv_nsec);
    printf("    CLOCK_MONOTONIC\n");
    printf("                  seconds: %ld\n", mono_time.tv_sec);
    printf("              nanoseconds: %ld\n", mono_time.tv_nsec);
    printf("        resolution (nsec): %ld\n", mono_res.tv_nsec);
```

```
Loaded '/lib/arm-linux-gnueabihf/libpthread.so.0'. Symbols loaded.
Loaded '/lib/arm-linux-gnueabihf/libc.so.6'. Symbols loaded.

Breakpoint 2, main () at /home/chishok/CST8703-Lab0/HelloWorld/main.c:112
112         int result = get_timestamp(timestamp, timestamp_max_size);
Execute debugger commands using "-exec <command>", for example "-exec info registers" will list registers in use (when GDB
is the debugger)
```

Figure 9: Screenshot of VS Code while debugging

Coding Task: Provide thread and timing information

Alter the target program to set scheduling parameters of the main thread, retrieve time, and cause the main program to sleep for 30 seconds. Make your modifications between the comments

```
    /*
     * STUDENT WORK SECTION BEGIN
     * ==========================
     */
```

and

```
    /*
     * ========================
     * STUDENT WORK SECTION END
     */
```

Hints and instruction may be provided as comments in the code. Write code to do the following:

1. Set the following for the main thread:
    1. Scheduling priority: 90
    2. Scheduling policy: `SCHED_RR`
2. Retrieve the following information from the main thread:
    1. Scheduling priority
    2. Scheduling policy
    3. Thread name
    4. Thread ID
    5. Minimum priority for current scheduling policy
    6. Maximum priority for current scheduling policy
3. Get the current time from the following real-time clocks:
    1. `CLOCK_REALTIME`
    2. `CLOCK_MONOTONIC`
4. Get the resolution of the following real-time clocks:
    1. `CLOCK_REALTIME`
    2. `CLOCK_MONOTONIC`
5. Sleep until 30 seconds after current time was retrieved on `CLOCK_MONOTONIC`. Use the absolute time flag (see `man clock_nanosleep` for more information).

Run the Program From Terminal

1. Build and run the code using the CMake-Tools in VS Code by using the taskbar buttons at the bottom of the window or commands with `Ctrl+Shift+P` (refer to instructions above for details).

2. Locate the built program `CST8703Lab0-HelloWorld` in the folder `./build/HelloWorld/CST8703Lab0-HelloWorld` and run it in the terminal:

    ```
    ./build/HelloWorld/CST8703Lab0-HelloWorld
    ```

    The output should show information about the process. If you see the priority and policy as

    ```
        policy: SCHED_OTHER
        thread priority: 0
    ```

then it likely did not have permission to change the scheduling and priority.

3. Re-run with `sudo`

   ```
   sudo ./build/HelloWorld/CST8703Lab0-HelloWorld
   ```

   and it should output the desired policy and priority:

   ```
   policy: SCHED_RR
   thread priority: 90
   ```

4. Open a second terminal. It's recommended to use VS Code's integrated terminal and split it so you have two side-by-side.
5. Run the program on the left terminal without using `sudo`.

   ```
   ./build/HelloWorld/CST8703Lab0-HelloWorld
   ```

6. While running the program during the 30 second pause in execution, access and terminate process using the following Linux tools and commands in the second terminal to the right:

   ```
   HELLO_PID=$(pgrep -f HelloWorld)
   ps -F -p ${HELLO_PID}
   kill -s TERM ${HELLO_PID}
   ```

Analysis

1. What does the command `pgrep -f HelloWorld` do?
2. Is the process id printed out when you run the program consistent with the result of `pgrep -f HelloWorld` while it's running?
3. What does the command `ps -F -p ${HELLO_PID}` do?
4. What does the command `kill -s TERM ${HELLO_PID}` do? What is the meaning of the word `TERM` in this command?
5. Why are `root` user privileges required (using "super-user do" command `sudo`) for the program to be able to modify real-time scheduling and priority?

Submission

Provide a short report with responses to the analysis questions.

If you forked the repo on your personal GitHub, commit and push your changes, then download your repo as a zip file. If you do not use GitHub, compress the source code in a zip file or tar file. Have a look at `man tar` or `man zip` for more information. Once the code is submitted, it will be run using the command:

```
./scripts/run_submission.sh
```

The expected contents of output_user.txt should be similar to:

```
pthread_setschedparam: Operation not permitted
Hello World!
    timestamp: 2022-05-17 23:50:55
    CLOCK_REALTIME (epoch)
                  seconds: 1652845596
```

```
             nanoseconds: 125681800
        resolution (nsec): 1
    CLOCK_MONOTONIC
                 seconds: 24198
             nanoseconds: 538200
        resolution (nsec): 1
    process id: 16222
    user id: 1000
    Main thread info:
        policy: SCHED_OTHER
        min priority: 0
        max priority: 0
        thread priority: 0
        thread id: 140187543078720

Waiting for 30 seconds...
UID        PID  PPID  C    SZ   RSS PSR STIME TTY          TIME CMD
chishok  16607 16462  0   613   604   4 23:50 pts/8    00:00:00 ./build/HelloWorld/CST8703Lab0-
HelloWorld
```

The expected contents of output_root.txt:

```
Hello World!
    timestamp: 2022-05-17 23:50:59
    CLOCK_REALTIME (epoch)
                 seconds: 1652845601
             nanoseconds: 880888700
        resolution (nsec): 1
    CLOCK_MONOTONIC
                 seconds: 24203
             nanoseconds: 755745100
        resolution (nsec): 1
    process id: 16251
    user id: 0
    Main thread info:
        policy: SCHED_RR
        min priority: 1
        max priority: 99
        thread priority: 90
        thread id: 140532105078592

Waiting for 30 seconds...
Done.
```

References

[1] M. Kerrisk, *The linux programming interface : A linux and unix system programming handbook.* No Starch Press, 2010.