1. Title Page:

Assingment 2 : Raspberrypi 4 Exploration

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0. C Profiency:

Intermediate

2. Objective:

This Assignment is about exploring the capabilities of the Raspberry Pi 4 i.e the software, features, options and potential limitations. In this Assignment,we are going to characterize the target board hardware and software by using the C programming language.

3. Introduction:

Raspberry pi is a mini portable computer that needs an Operating System to work. This work is about how we characterise the board to understand it's capabilities and potential.

3.1 Equipment Required

1. Raspberry Pi board with Installed Firmware
2. Power supply compatible with the Raspberry Pi model
3. Wireless router (plus Ethernet ports) connected to the internet

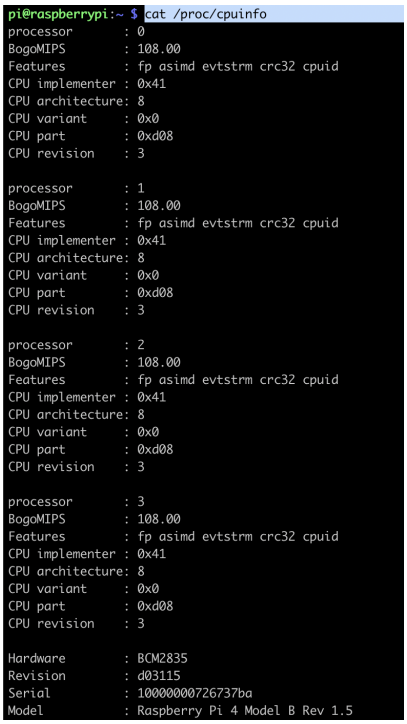
4 Characterization Questions

4.1. What SoC is on the target board? What version and manufacturer of the SoC?

To get the SOC of the target board, we need to get info like version and Revision ID.

```
cat /proc/cpuinfo
```

This returns the Revison ID ie **d03115** which when crossreferenced on the website tells us that the it **Version 1.5** manufactured by **Sony UK**



```
pi@raspberrypi:~ $ cat /proc/cpuinfo
processor       : 0
BogoMIPS        : 108.00
Features        : fp asimd evtstrm crc32 cpuid
CPU implementer : 0x41
CPU architecture: 8
CPU variant     : 0x0
CPU part        : 0xd08
CPU revision    : 3

processor       : 1
BogoMIPS        : 108.00
Features        : fp asimd evtstrm crc32 cpuid
CPU implementer : 0x41
CPU architecture: 8
CPU variant     : 0x0
CPU part        : 0xd08
CPU revision    : 3

processor       : 2
BogoMIPS        : 108.00
Features        : fp asimd evtstrm crc32 cpuid
CPU implementer : 0x41
CPU architecture: 8
CPU variant     : 0x0
CPU part        : 0xd08
CPU revision    : 3

processor       : 3
BogoMIPS        : 108.00
Features        : fp asimd evtstrm crc32 cpuid
CPU implementer : 0x41
CPU architecture: 8
CPU variant     : 0x0
CPU part        : 0xd08
CPU revision    : 3

Hardware        : BCM2835
Revision        : d03115
Serial          : 10000000726737ba
Model           : Raspberry Pi 4 Model B Rev 1.5
```

4.2. What features are present on the board/SoC?

This can be divded into the following groups:

Performance & GPU

```
SoC: Broadcom BCM2711
CPU: Quad-core Cortex-A72 (ARM v8, 64-bit, 1.5 GHz)
    Cores:4
    Clock Speed: ~1.5GHz ( max 1.8Ghz, min 0.6Ghz)
    Threads per Core : 1
    Intruction Set: AArch64
GPU: Broadcom VideoCore VI
    Clock Speed: ~500MHz
Graphics support: OpenGL ES 3.1, 4K decoding (H.265), dual-display
```

Memory(RAM)

```
Type: LPDDR4-3200 SDRAM
Memory Speed: 3200 MT/s (MegaTransfers per second)
Memory Bus Width: 32-bit
Shared Memory: CPU & GPU share RAM (adjustable via firmware)
Sizes: 2GB
```

Storage

MicroSD slot (for OS & storage) USB boot support (boot from SSD/HDD via USB 3.0)

Display & Graphics

```
Dual micro-HDMI ports (supports two 4K displays @ 60Hz)
Supports H.265 (HEVC) 4Kp60 decode, H.264 1080p60 encode/decode
OpenGL ES 3.1 support
```

Connectivity

```
Wi-Fi: 802.11ac (dual-band 2.4GHz / 5GHz)
Bluetooth: 5.0 (BLE)
Gigabit Ethernet (true 1 Gbps speed)
USB Ports:
    2 × USB 3.0
    2 × USB 2.0
GPIO: 40-pin
```

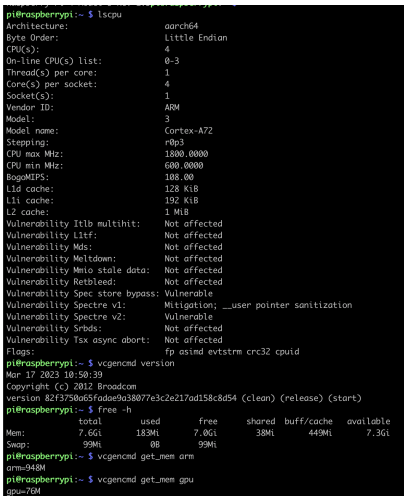
Power

Power input: USB-C (5V/3A)

4.3. What size caches are present in the Raspberry Pi?

This can be found by running the following

```
lscpu
```

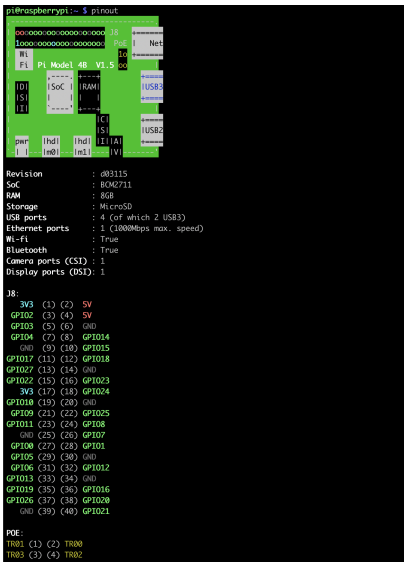



```
L1d cache:128 KiB
L1i cache:192 KiB
L2 cache:1 MiB
```

4.4. What is the pin layout on this specific version of the target board?

Pinout found by running the following

```
pinout
```



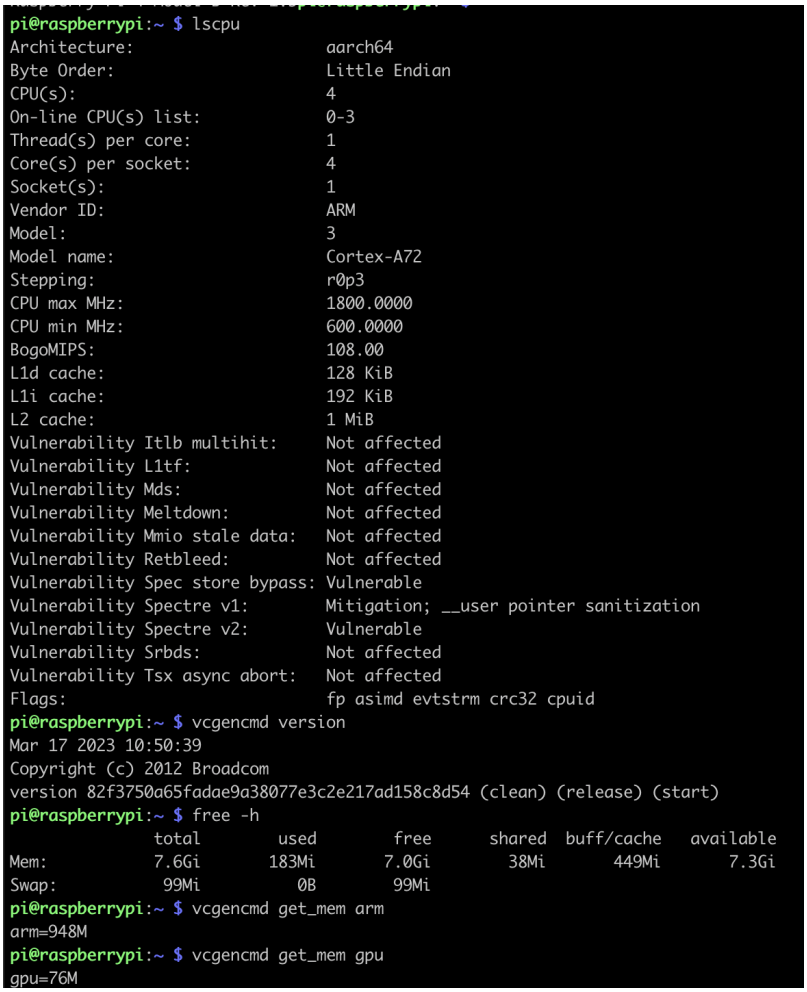
4.5. How does the board boot? What is the process?

```
Power On: The Pi powers up, and the Boot ROM in the GPU begins executing.

Stage 1 (bootcode.bin): Loads the initial bootloader, sets up memory.

Stage 2 (start.elf & config.txt): Initializes the ARM processor and loads
the kernel.

Linux Kernel: Initializes the operating system and mounts the root
filesystem.

Init Process: Starts system services and presents a user interface
```

4.6. How much memory is available on the board?

Memory Info can be found by running

```
lscpu
```



4.7. How many different types of memory are on the board?

```
RAM (LPDDR4-3200) – Main system memory (2GB, 4GB, or 8GB depending on the model).

microSD Card – Boot device and persistent storage for the OS and files.

GPU Shared Memory (VideoCore IV) – Graphics processing memory (shared with RAM).

EEPROM – Bootloader storage, non-volatile memory for boot configuration.
```

4.8. What is the name and release version of the Operating System used on the target board?

OS info can be found by

```
cat /etc/os-release
```

```
pi@raspberrypi:~ $ cat /etc/os-release
PRETTY_NAME="Raspbian GNU/Linux 11 (bullseye)"
NAME="Raspbian GNU/Linux"
VERSION_ID="11"
VERSION="11 (bullseye)"
VERSION_CODENAME=bullseye
ID=raspbian
ID_LIKE=debian
HOME_URL="http://www.raspbian.org/"
SUPPORT_URL="http://www.raspbian.org/RaspbianForums"
BUG_REPORT_URL="http://www.raspbian.org/RaspbianBugs"
pi@raspberrypi:~ $
```

4.9. What is the compiler name and version?

Compiler info can be found by

```
gcc --version
```

```
pi@raspberrypi:~ $ gcc --version
gcc (Raspbian 10.2.1-6+rpi1) 10.2.1 20210110
Copyright (C) 2020 Free Software Foundation, Inc.
This is free software; see the source for copying conditions.  There is NO
warranty; not even for MERCHANTABILITY or FITNESS FOR A PARTICULAR PURPOSE.

pi@raspberrypi:~ $
```

4.10. How long does it take for a context switch?

To test this, a context switch script was written here

```
gcc ctx_measure.c -o ctx
sudo ./ctx
```

```
pi@raspberrypi:~/Work/raspi/experiment/ee_course $ gcc ctx_measure.c -o ctx
pi@raspberrypi:~/Work/raspi/experiment/ee_course $ sudo ./ctx
Total time for 100000 context switches: 2703975 microseconds
Average time per context switch: 13.52 microseconds
pi@raspberrypi:~/Work/raspi/experiment/ee_course $
```

4.11. What is the interrupt latency for the board? E.g., from an interrupt to the first instruction executed in the service routine?

The Interrupt was latched on GPIO 17, where the interrupt Rising Trigger was manually generated with a jumper connected to 3V3.

To test this, a script was written here

The script uses **RPi.GPIO** package to get the pin status. To install

```
sudo apt-get update
sudo apt-get upgrade
sudo apt-get install python-pip python-dev
sudo pip install RPi.GPIO
```

```
gcc interrupt_latency.c -o interr
sudo ./interr
```

```
pi@raspberrypi:~/Work/raspi/experiment/ee_course $ sudo ./interr
Waiting for interrupt on GPIO 17...
StartTime: 1739134844.544552 seconds
EndTime: 1739134844.544772 seconds
Interrupt latency: 0.000220 seconds
pi@raspberrypi:~/Work/raspi/experiment/ee_course $
```

4.12. How much time does it take to copy 1 KB, 1 MB, and 1GB in bytes, half words, and words in RAM?

To test this, a script was written here

```
gcc mem_ram_cp.c -o memram
./memram
```

```
pi@raspberrypi:~/Work/raspi/experiment/ee_course $ gcc mem_ram_cp.c -o memram
pi@raspberrypi:~/Work/raspi/experiment/ee_course $ ./memram
Benchmark for 1 KB:
Byte copy (8-bit) - Size: 1024 bytes, Element size: 1 bytes, Time: 270 microseconds
Half-word copy (16-bit) - Size: 1024 bytes, Element size: 2 bytes, Time: 111 microseconds
Word copy (32-bit) - Size: 1024 bytes, Element size: 4 bytes, Time: 102 microseconds

Benchmark for 1 MB:
Byte copy (8-bit) - Size: 1048576 bytes, Element size: 1 bytes, Time: 22175 microseconds
Half-word copy (16-bit) - Size: 1048576 bytes, Element size: 2 bytes, Time: 14529 microseconds
Word copy (32-bit) - Size: 1048576 bytes, Element size: 4 bytes, Time: 7984 microseconds

Benchmark for 1 GB:
Byte copy (8-bit) - Size: 1073741824 bytes, Element size: 1 bytes, Time: 22577094 microseconds
Half-word copy (16-bit) - Size: 1073741824 bytes, Element size: 2 bytes, Time: 14186387 microseconds
Word copy (32-bit) - Size: 1073741824 bytes, Element size: 4 bytes, Time: 7567376 microseconds
```

4.13. How much time does it take to copy 1 KB, 1 MB, and 1GB in bytes, half words, and words on the filing system?

To test this, a script was written here

To generate files of 1 KB, 1 MB, and 1GB in bytes you can run the following

```
dd if=/dev/urandom of=test_1KB.bin bs=1K count=1
dd if=/dev/urandom of=test_1MB.bin bs=1M count=1
dd if=/dev/urandom of=test_1GB.bin bs=1G count=1
```

Next, you can execute the script by running

```
gcc mem_sd_cpy.c -o memsd
sudo ./memsd
```

```
pi@raspberrypi:~/Work/raspi/experiment/ee_course $ sudo ./memsd
Benchmarking file copy times:
File copy with buffer size 1 bytes took 745 microseconds
File copy with buffer size 2 bytes took 140953 microseconds
File copy with buffer size 4 bytes took 84254723 microseconds
pi@raspberrypi:~/Work/raspi/experiment/ee_course $
```

4.14. How long does it take between reboot and an active board? Is it deterministic?

This was done by executing a C script on the host PC which connects to RPi over SSH server, sends the reboot command, keeps pinging to check if the board is alive or not.

The C script was written here . It takes an arguement to either reboot or halt

```
gcc reboot_time.c -o reboottime
./reboottime reboot
```

```
➜  ~/Work/GitClones/raspi/experiment/ee_course git:(dev/ass_2) ✗ ./reboottime reboot
Measuring reboot time for 192.168.4.49...
Issuing reboot command...
Waiting for 192.168.4.49 to go offline...
Waiting for 192.168.4.49 to come back online...
Time Taken: 31.46 seconds
➜  ~/Work/GitClones/raspi/experiment/ee_course git:(dev/ass_2) ✗ ./reboottime halt
Measuring reboot time for 192.168.4.49...
Issuing halt command...
Waiting for 192.168.4.49 to go offline...
Time Taken: 1.76 seconds
➜  ~/Work/GitClones/raspi/experiment/ee_course git:(dev/ass_2) ✗
```

No, the reboot time is not deterministic by default while running the Raspberry Pi OS. It is because of filesystem checks, some OS service initialisations etc. It can be made deterministics by optimising some of the boot up services, moving to a read-only filesystem, or by using OS Lite which avoids GUI boot up.

4.15. How long does it take to halt the board? Is it deterministic?

This was done by executing a C script on the host PC which connects to RPi over SSH server, sends the reboot command, keeps pinging to check if the board is alive or not.

The C script was written here . It takes an arguement to either reboot or halt

```
gcc reboot_time.c -o reboottime
./reboottime halt
```

```
➜  ~/Work/GitClones/raspi/experiment/ee_course git:(dev/ass_2) ✗ ./reboottime reboot
Measuring reboot time for 192.168.4.49...
Issuing reboot command...
Waiting for 192.168.4.49 to go offline...
Waiting for 192.168.4.49 to come back online...
Time Taken: 31.46 seconds
➜  ~/Work/GitClones/raspi/experiment/ee_course git:(dev/ass_2) ✗ ./reboottime halt
Measuring reboot time for 192.168.4.49...
Issuing halt command...
Waiting for 192.168.4.49 to go offline...
Time Taken: 1.76 seconds
➜  ~/Work/GitClones/raspi/experiment/ee_course git:(dev/ass_2) ✗
```

4.16. Determine the speed of integer arithmetic with a benchmark.

This was done by executing a C script that performs 4 math operations ie addition, substraction, multiplication and division for 1 billion times. It even takes an arguement for either interger or float point calculations.

The C script can be found here

```
gcc arithmetic_benchmark.c -o arithmeticbenchmark
./arithmeticbenchmark integer
```

```
pi@raspberrypi:~/Work/raspi/experiment/ee_course $ gcc arithmetic_benchmark.c -o arithmenticbenchmark
pi@raspberrypi:~/Work/raspi/experiment/ee_course $ ./arithmenticbenchmark integer
Benchmarking integer arithmetic...
Addition: 281.60 million operations per second
Subtraction: 283.05 million operations per second
Multiplication: 286.07 million operations per second
Division: 157.51 million operations per second
Benchmark completed!
pi@raspberrypi:~/Work/raspi/experiment/ee_course $ ./arithmenticbenchmark float
Benchmarking float arithmetic...
Addition: 288.49 million operations per second
Subtraction: 288.60 million operations per second
Multiplication: 285.72 million operations per second
Division: 157.46 million operations per second
Benchmark completed!
pi@raspberrypi:~/Work/raspi/experiment/ee_course $
```

4.17. Determine the rate of floating-point arithmetic with a benchmark.

```
gcc arithmetic_benchmark.c -o arithmeticbenchmark
./arithmeticbenchmark float
```

```
pi@raspberrypi:~/Work/raspi/experiment/ee_course $ gcc arithmetic_benchmark.c -o arithmenticbenchmark
pi@raspberrypi:~/Work/raspi/experiment/ee_course $ ./arithmenticbenchmark integer
Benchmarking integer arithmetic...
Addition: 281.60 million operations per second
Subtraction: 283.05 million operations per second
Multiplication: 286.07 million operations per second
Division: 157.51 million operations per second
Benchmark completed!
pi@raspberrypi:~/Work/raspi/experiment/ee_course $ ./arithmenticbenchmark float
Benchmarking float arithmetic...
Addition: 288.49 million operations per second
Subtraction: 288.60 million operations per second
Multiplication: 285.72 million operations per second
Division: 157.46 million operations per second
Benchmark completed!
pi@raspberrypi:~/Work/raspi/experiment/ee_course $
```

4.18 Write a multithreaded example application that illustrates the producer-consumer algorithm with protected data running on multiple processors.

This was written such the 4 parallel threads (2 consumers and 2 producers) are created and a random generate data is shared between the producer and the consumer

The C script can be found here

```
gcc multithread.c -o multithread -pthread
```

4.19 What are the operating temperature ranges?

For Raspberry Pi 4 Model B can operate between 0-85 degrees Celcius

4.20 What is the power consumption without load and with load?

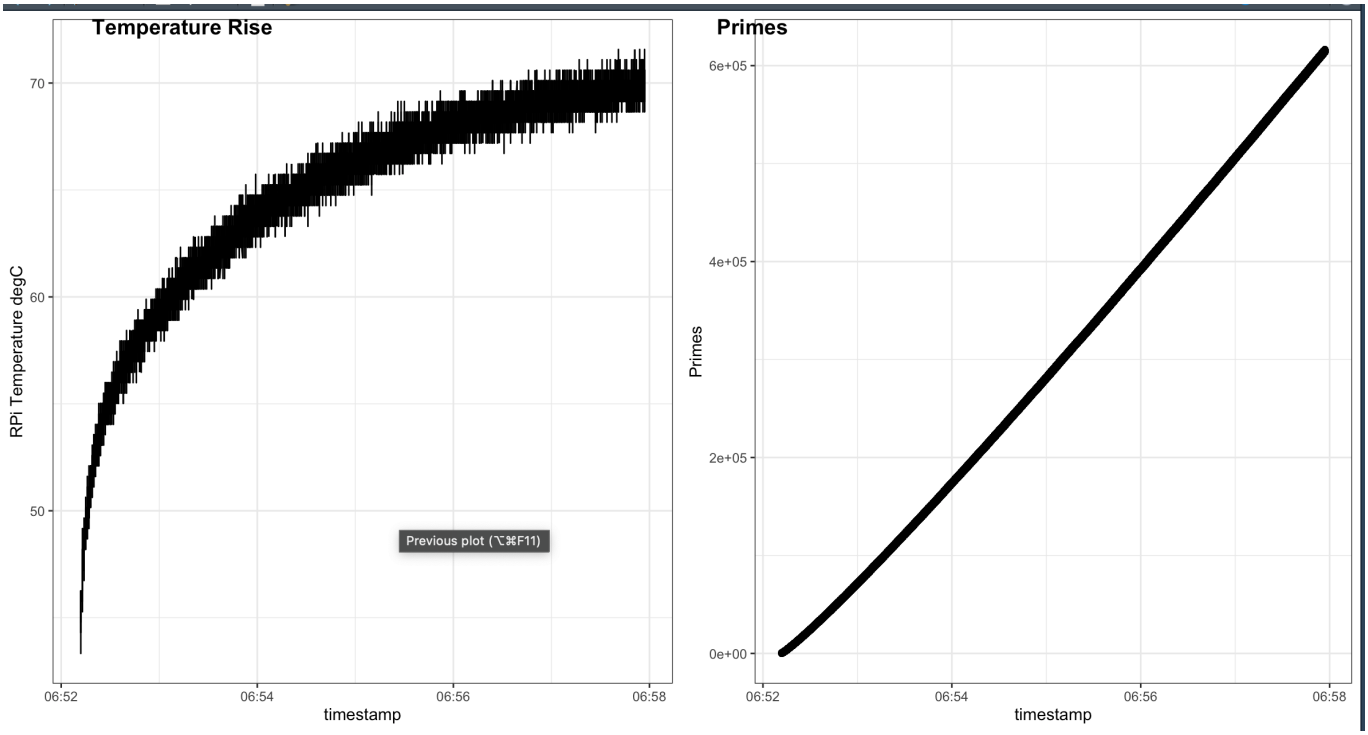
For Raspberry Pi 4B(2GB) the no load power consumption is 3.4 watts where as Full Load is 7.6 watts. Unfortunately I did not have a smart meter to measure. I could measure the temperature, power and frequency with a script but that is not direct indicator of the power consumption.

4.21 What would be a useful stress test to determine reliability?

Putting the system under maximum CPU, GPU, memory and I/O would definitely test the realiability of the Raspberry Pi.

One such tests is to continuously calculate prime numbers. An exmaple code was written with monitoring enabled to see how the CPU behaves under this stress load.

```
gcc stress.c -o stresstest -lm -pthread
```



4.22 Does temperature affect performance?

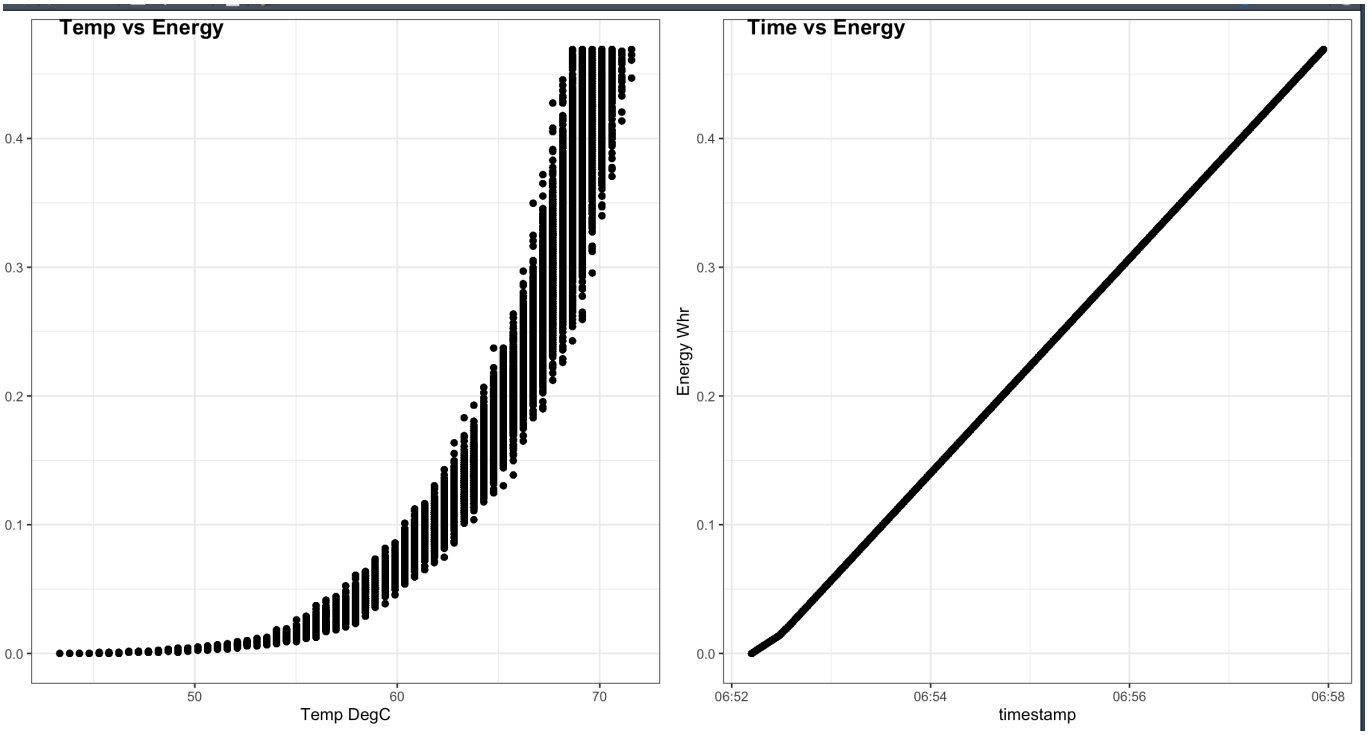
The SoC (System on Chip) may throttle performance when it reaches around 80°C to prevent overheating.

4.23 Determine how much energy is required to run a benchmark. E.g., use temperature as a rough guide.

The relation between power and temperature is complex as an increase in dynamic power increases the total power, which increases the temperature, which increases the leakage power, which increases the total power, which increases the temperature. For a rough guide, Rpi Consumes

```
45–55degC : 2–3watts
55–70degC : 4–5watts
```

With that said, in the stress test performed, the total energy would look like this :

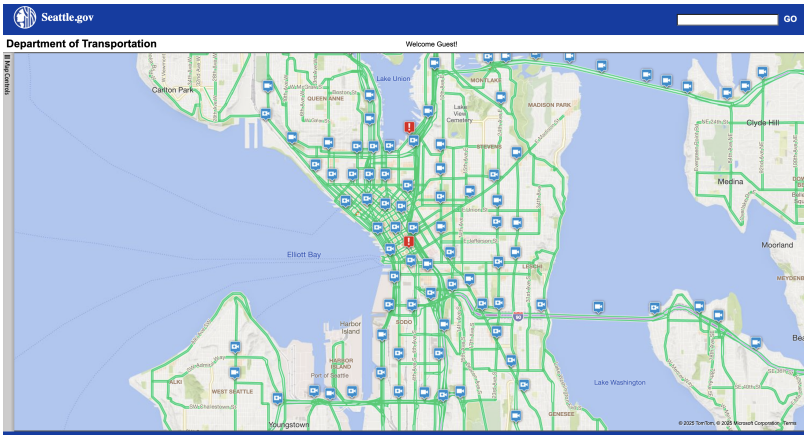


5 Project Stuff

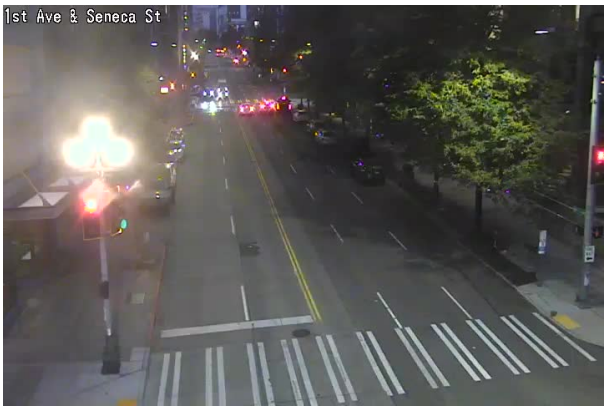
5.1 Introduction

Finding a parking spot in downtown of any city is a major issue and especially with Return to Office policies, this can even intensified. Moreover, if you live in downtown and prefer to walk, unruly weather is quite an annoyance. Here is an attempt to use Traffic Cams to find parking spots and stress wise weather updates in near real time.

Seattle Gov has an extensive array of Traffic Cameras spread across the city that update the image and sometimes videos every minute.



The cameras are located on all major jucntions and crossings and have a decent picture as you can see



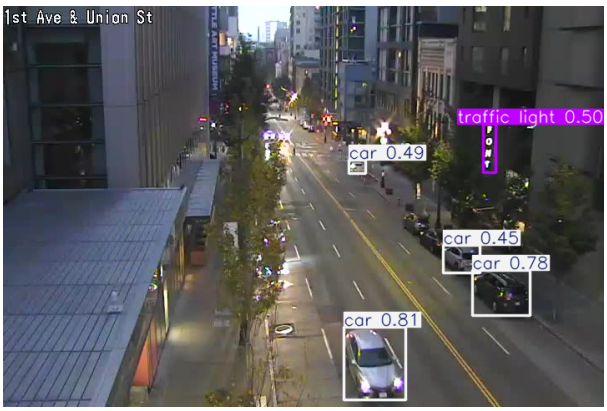
- This project aims at querying this data, make a cache, and then run some object detection model on these images to find cars parked by the curbs.
- A stretch goal is to detect the weather conditions by these images and get a near real time update if it is convinient to walk down a few blocks.
- Finally, this could all be overlaid as a custom layer on Open Street Maps.

5.2 How to fetch images from a server?

- Python Package **requests** seems like an option to download images from a url

5.3 How to run YOLO on Rpi?

- Ultralytics has some info here. A quick check with this on PC looked promising.



5.4 OpenCV on Rpi?

- This maybe used for some segmentation

5.5 Package Manager to deploy cross architectures and PCs.

- Poetry seems to be promisiong for package creation and deployment.

5.6 System Service

- This is to keep running the pipeline on the rpi when it is powered on. Crontab seems to be a way to get this done.

7. Conclusion:

The temperature monitoring will definitely come handy when machine learning models like Yolo has to be deployed on Pi.

The project may need some lightweight machine learning to segment images. The idea here is write the package such that it could be deployed on multiple architectures and OS.

Some of the new tools like Renode which lets you simulate actual hardware will definitely reduce the hardware development iterations. Moreover the embedded development work can begin much before the physical hardware comes in hand.

8. References:

- Wikipedia
- RaspberryPi
- StackOverFlow
- ChatGPT