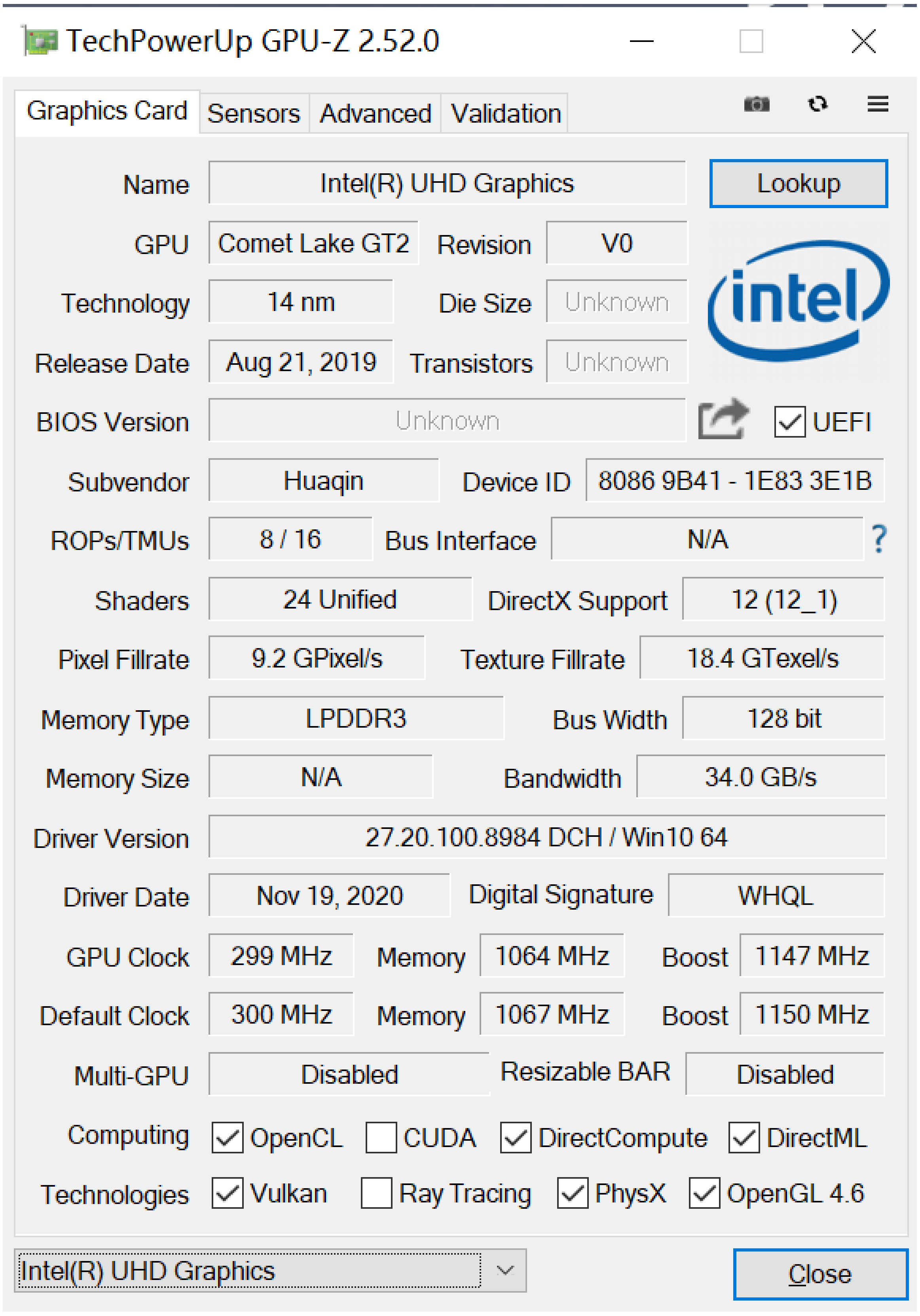
Parallel Computing B-PB20000178 李笑

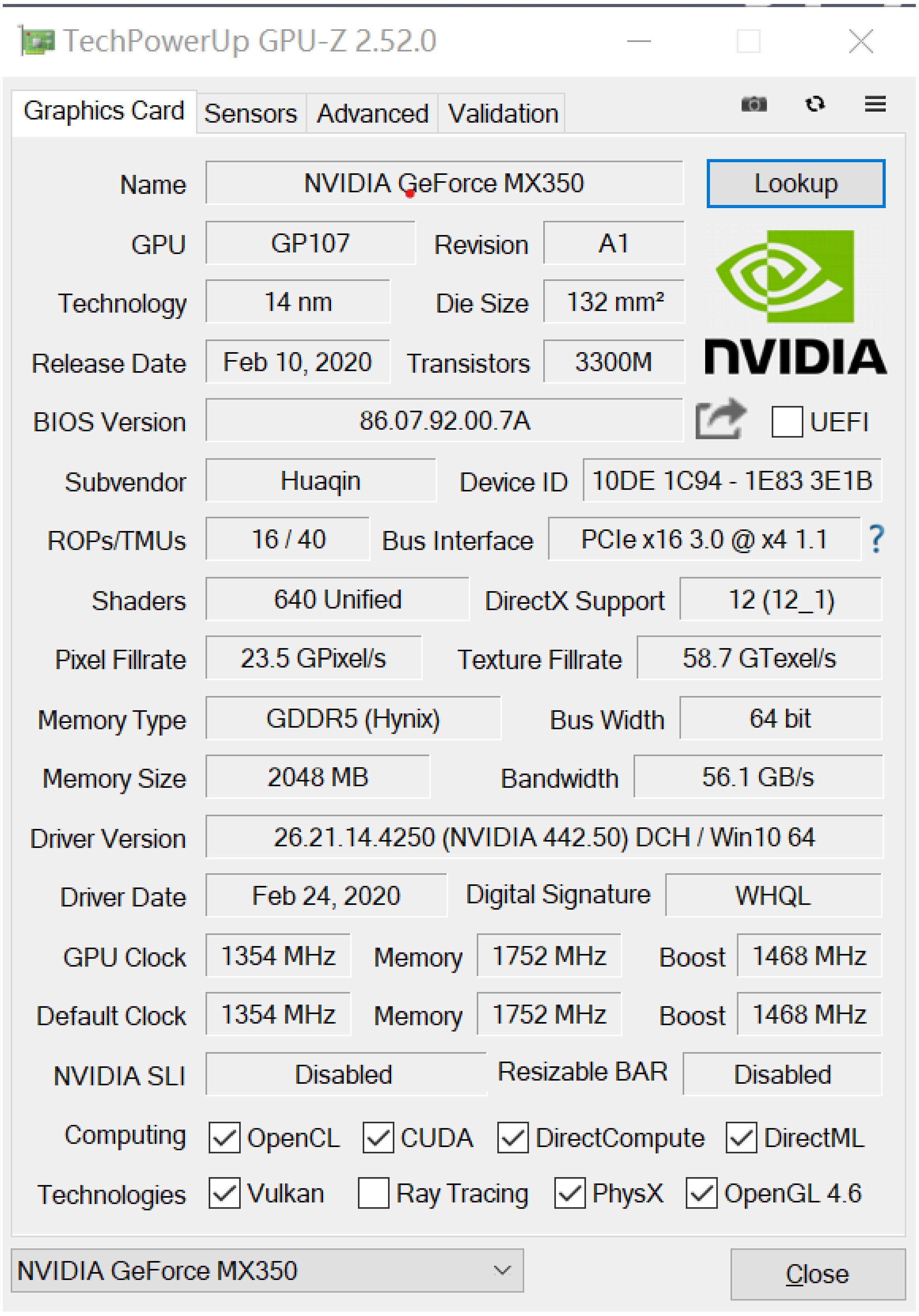
Lab 1 - OpenMP及CUDA实验环境的搭建

以下两张截图是我个人电脑的配置：


TechPowerUp GPU-Z 2.52.0

Name	Intel(R) UHD Graphics				
GPU	Comet Lake GT2	Revision	V0		
Technology	14 nm	Die Size	Unknown		
Release Date	Aug 21, 2019	Transistors	Unknown		
BIOS Version	Unknown		✓ UEFI		
Subvendor	Huaqin	Device ID	8086 9B41 - 1E83 3E1B		
ROPs/TMUs	8 / 16	Bus Interface	N/A		
Shaders	24 Unified	DirectX Support	12 (12_1)		
Pixel Fillrate	9.2 GPixel/s	Texture Fillrate	18.4 GTexel/s		
Memory Type	LPDDR3	Bus Width	128 bit		
Memory Size	N/A	Bandwidth	34.0 GB/s		
Driver Version	27.20.100.8984 DCH / Win10 64				
Driver Date	Nov 19, 2020	Digital Signature	WHQL		
GPU Clock	299 MHz	Memory	1064 MHz	Boost	1147 MHz
Default Clock	300 MHz	Memory	1067 MHz	Boost	1150 MHz
Multi-GPU	Disabled	Resizable BAR	Disabled		
Computing	✓ OpenCL	☐ CUDA	✓ DirectCompute	✓ DirectML	
Technologies	✓ Vulkan	☐ Ray Tracing	✓ PhysX	✓ OpenGL 4.6	

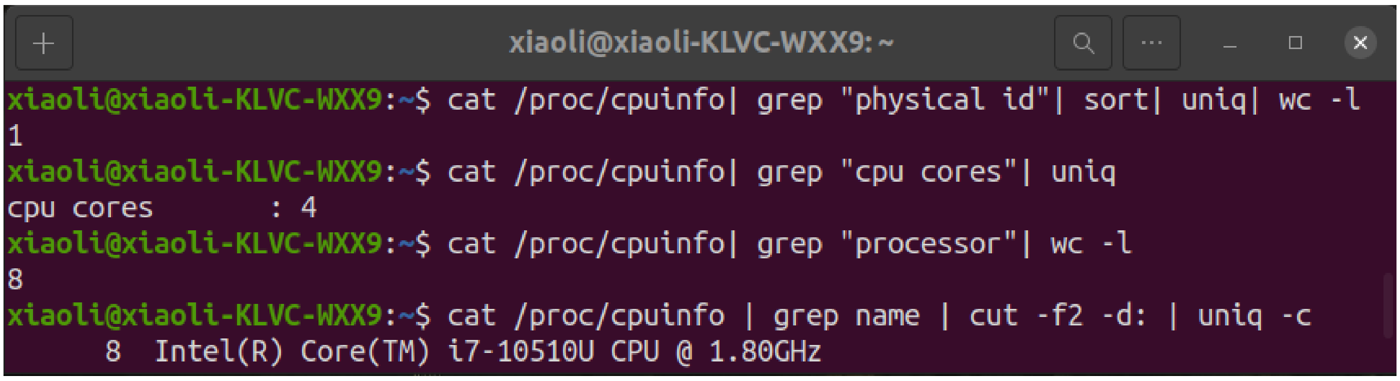
Intel(R) UHD Graphics



Name	NVIDIA GeForce MX350				
GPU	GP107	Revision	A1		
Technology	14 nm	Die Size	132 mm²		
Release Date	Feb 10, 2020	Transistors	3300M		
BIOS Version	86.07.92.00.7A		☐ UEFI		
Subvendor	Huaqin	Device ID	10DE 1C94 - 1E83 3E1B		
ROPs/TMUs	16 / 40	Bus Interface	PCIe x16 3.0 @ x4 1.1		
Shaders	640 Unified	DirectX Support	12 (12_1)		
Pixel Fillrate	23.5 GPixel/s	Texture Fillrate	58.7 GTexel/s		
Memory Type	GDDR5 (Hynix)	Bus Width	64 bit		
Memory Size	2048 MB	Bandwidth	56.1 GB/s		
Driver Version	26.21.14.4250 (NVIDIA 442.50) DCH / Win10 64				
Driver Date	Feb 24, 2020	Digital Signature	WHQL		
GPU Clock	1354 MHz	Memory	1752 MHz	Boost	1468 MHz
Default Clock	1354 MHz	Memory	1752 MHz	Boost	1468 MHz
NVIDIA SLI	Disabled	Resizable BAR	Disabled		
Computing	✓ OpenCL	✓ CUDA	✓ DirectCompute	✓ DirectML	
Technologies	✓ Vulkan	☐ Ray Tracing	✓ PhysX	✓ OpenGL 4.6	

NVIDIA GeForce MX350

切换到`Ubuntu20.04`进行后续实验，通过命令行查看配置：

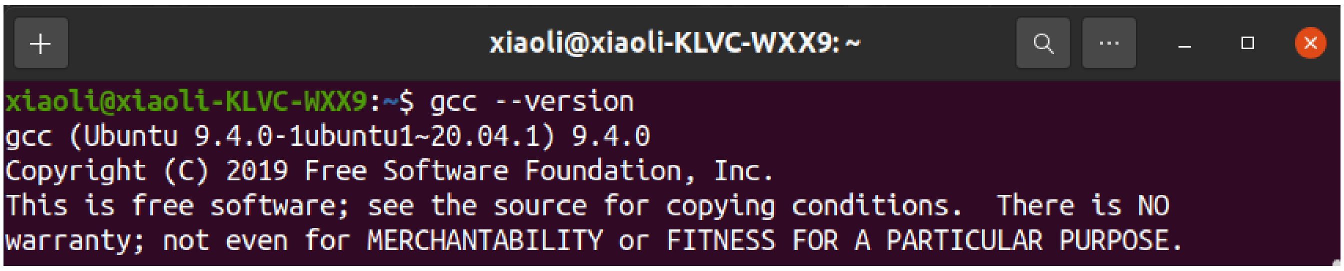


```
xiaoli@xiaoli-KLVC-WXX9:~$ cat /proc/cpuinfo| grep "physical id"| sort| uniq| wc -l
1
xiaoli@xiaoli-KLVC-WXX9:~$ cat /proc/cpuinfo| grep "cpu cores"| uniq
cpu cores       : 4
xiaoli@xiaoli-KLVC-WXX9:~$ cat /proc/cpuinfo| grep "processor"| wc -l
8
xiaoli@xiaoli-KLVC-WXX9:~$ cat /proc/cpuinfo | grep name | cut -f2 -d: | uniq -c
      8  Intel(R) Core(TM) i7-10510U CPU @ 1.80GHz
```

安装OpenMP

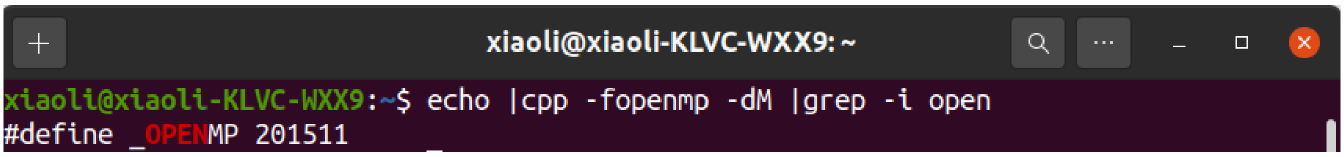
步骤：

1. 快捷键`Ctrl+Atl+T`打开终端
2. 在终端输入`sudo apt-get install libomp-dev`安装OpenMP
3. 在终端输入`sudo apt-get install gcc`安装GCC
4. 在终端输入`gcc --version`检查安装是否成功



```
xiaoli@xiaoli-KLVC-WXX9:~$ gcc --version
gcc (Ubuntu 9.4.0-1ubuntu1~20.04.1) 9.4.0
Copyright (C) 2019 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.
```

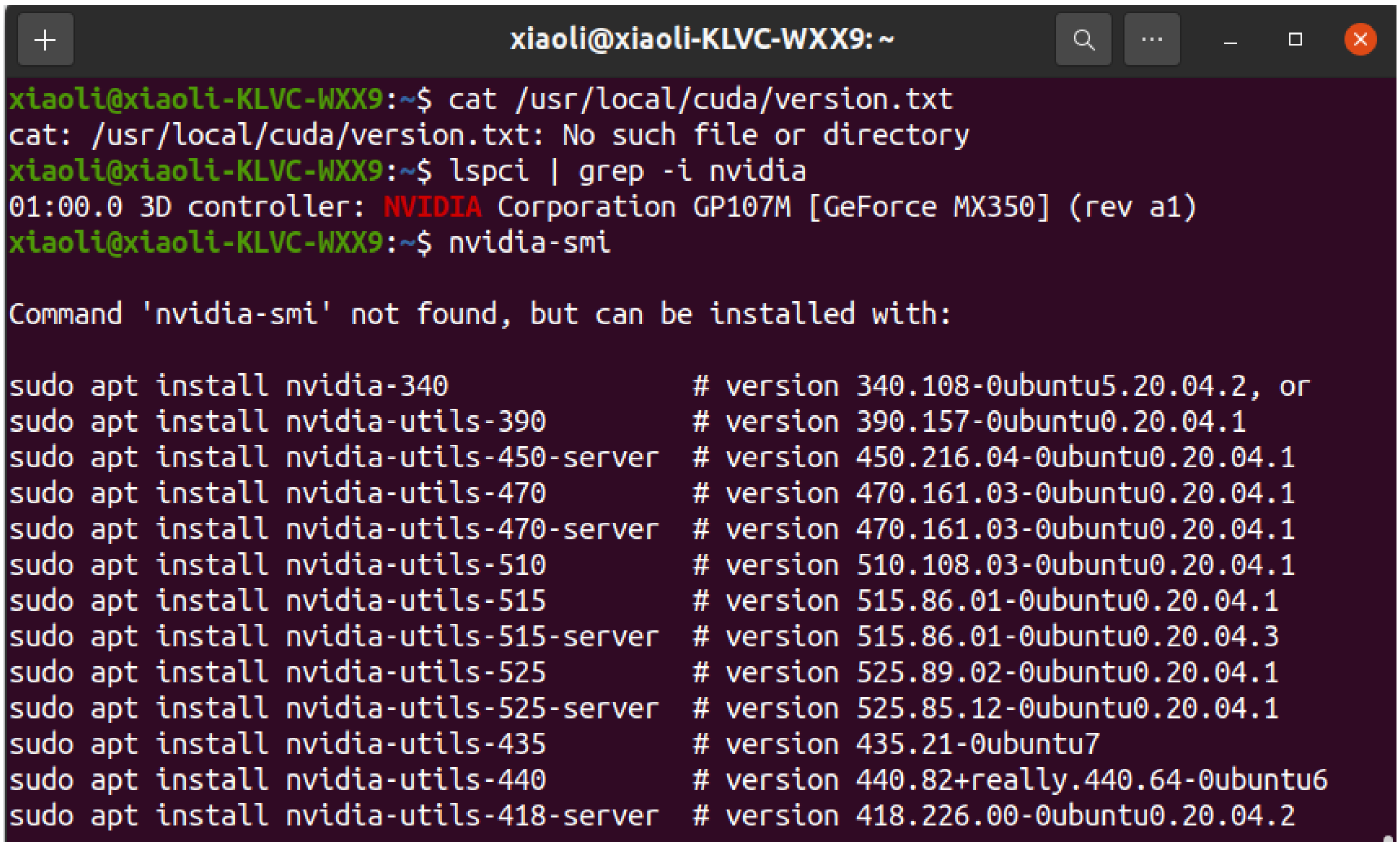
5. 在终端输入`echo |cpp -fopenmp -dM |grep -i open`检查OpenMP安装是否成功



```
xiaoli@xiaoli-KLVC-WXX9:~$ echo |cpp -fopenmp -dM |grep -i open
#define _OPENMP 201511
```

安装CUDA

配置前：



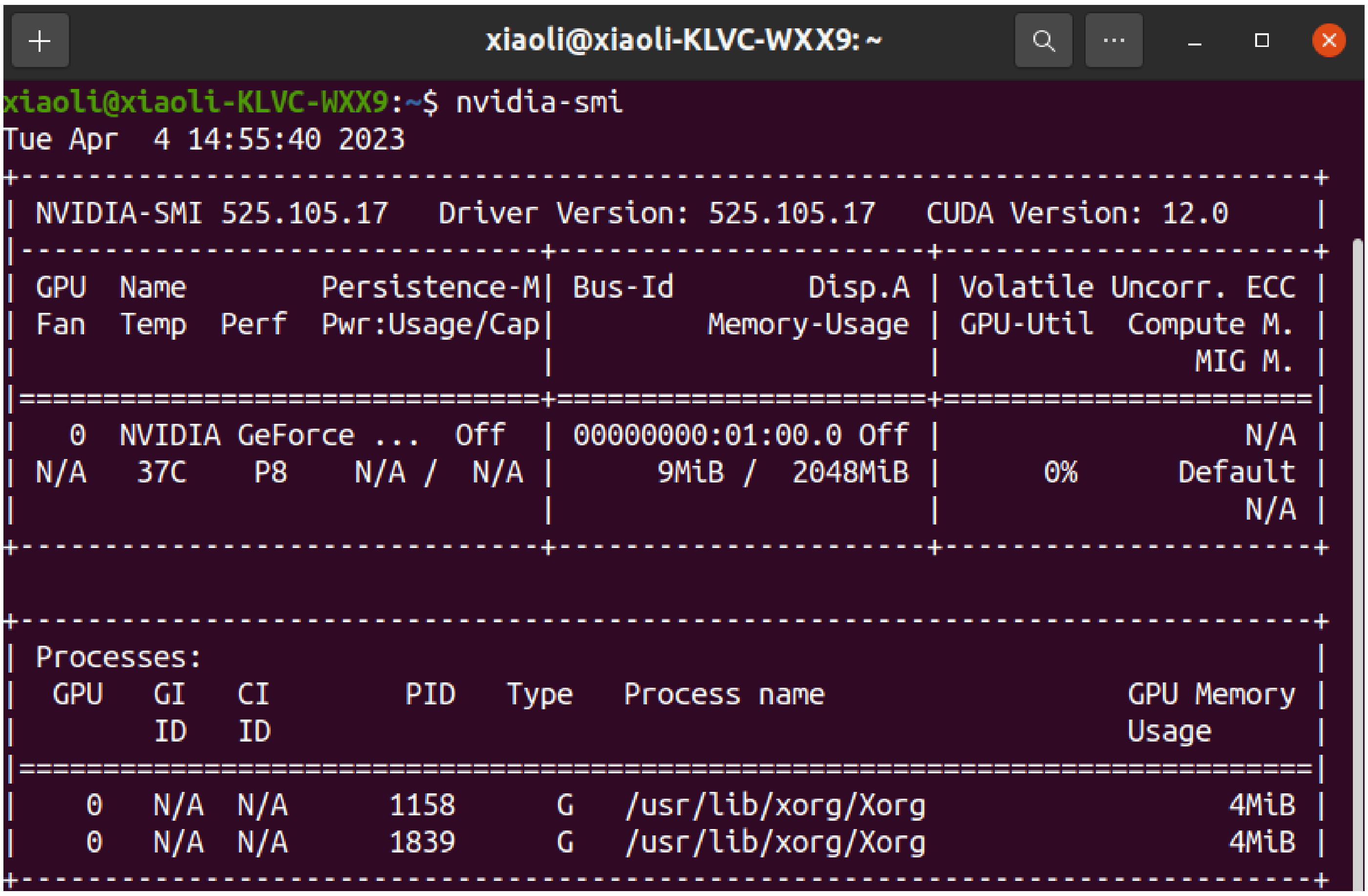
```
xiaoli@xiaoli-KLVC-WXX9:~$ cat /usr/local/cuda/version.txt
cat: /usr/local/cuda/version.txt: No such file or directory
xiaoli@xiaoli-KLVC-WXX9:~$ lspci | grep -i nvidia
01:00.0 3D controller: NVIDIA Corporation GP107M [GeForce MX350] (rev a1)
xiaoli@xiaoli-KLVC-WXX9:~$ nvidia-smi

Command 'nvidia-smi' not found, but can be installed with:

sudo apt install nvidia-340               # version 340.108-0ubuntu5.20.04.2, or
sudo apt install nvidia-utils-390         # version 390.157-0ubuntu0.20.04.1
sudo apt install nvidia-utils-450-server  # version 450.216.04-0ubuntu0.20.04.1
sudo apt install nvidia-utils-470         # version 470.161.03-0ubuntu0.20.04.1
sudo apt install nvidia-utils-470-server  # version 470.161.03-0ubuntu0.20.04.1
sudo apt install nvidia-utils-510         # version 510.108.03-0ubuntu0.20.04.1
sudo apt install nvidia-utils-515         # version 515.86.01-0ubuntu0.20.04.1
sudo apt install nvidia-utils-515-server  # version 515.86.01-0ubuntu0.20.04.3
sudo apt install nvidia-utils-525         # version 525.89.02-0ubuntu0.20.04.1
sudo apt install nvidia-utils-525-server  # version 525.85.12-0ubuntu0.20.04.1
sudo apt install nvidia-utils-435         # version 435.21-0ubuntu7
sudo apt install nvidia-utils-440         # version 440.82+really.440.64-0ubuntu6
sudo apt install nvidia-utils-418-server  # version 418.226.00-0ubuntu0.20.04.2
```

上图信息表明，我的电脑装有NVIDIA显卡，但是没有安装显卡驱动

步骤：

1. 手动安装显卡驱动。依次在终端输入，选择系统推荐版本驱动`nvidia-driver-525`

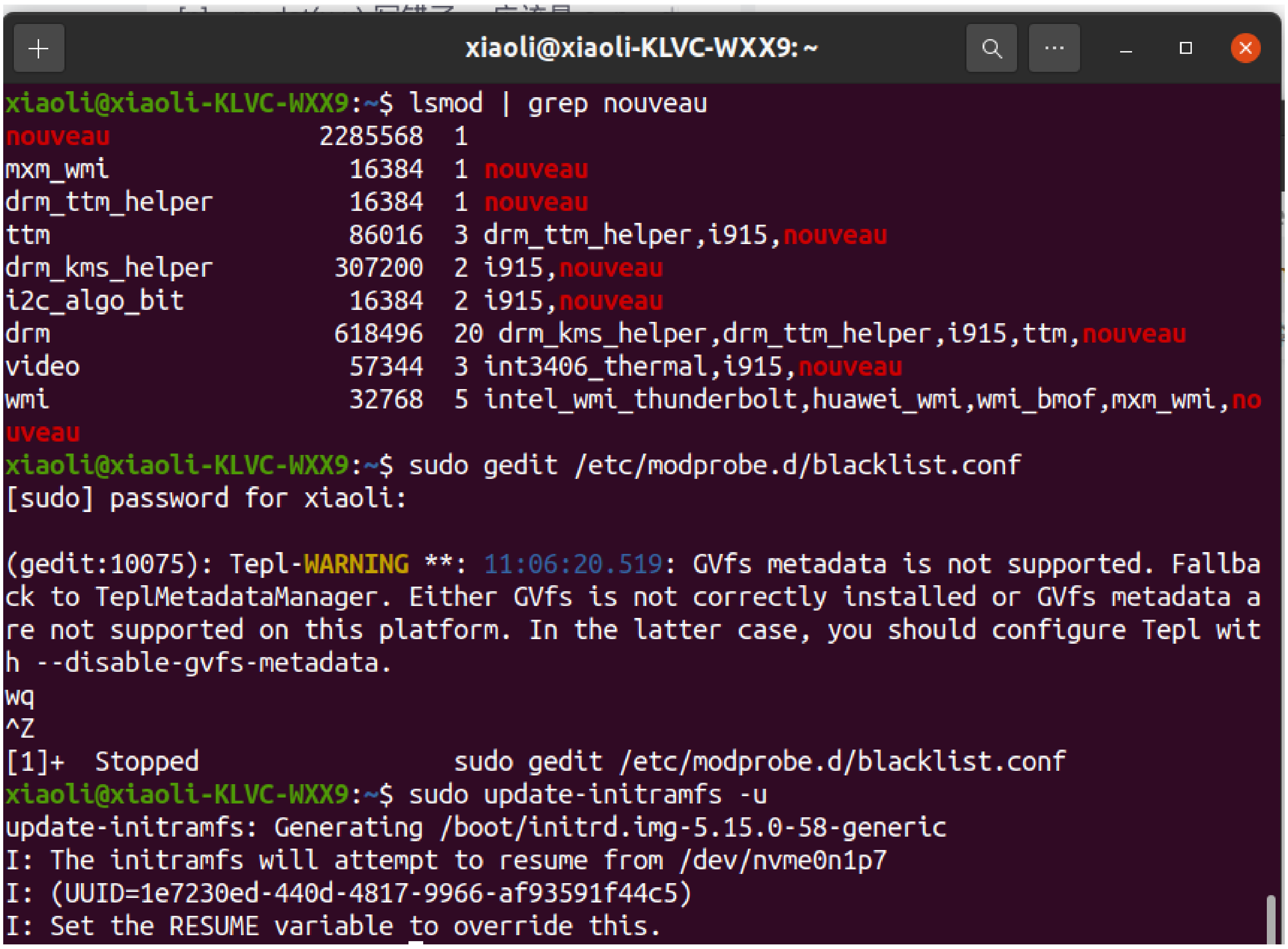
```
$ sudo add-apt-repository ppa:graphics-drivers/ppa
$ sudo apt update
$ ubuntu-drivers devices
$ sudo apt install nvidia-driver-525
```



```
xiaoli@xiaoli-KLVC-WXX9:~$ nvidia-smi
Tue Apr  4 14:55:40 2023
+-----------------------------------------------------------------------------+
| NVIDIA-SMI 525.105.17   Driver Version: 525.105.17   CUDA Version: 12.0     |
|-------------------------------+----------------------+----------------------+
| GPU  Name        Persistence-M| Bus-Id        Disp.A | Volatile Uncorr. ECC |
| Fan  Temp  Perf  Pwr:Usage/Cap|         Memory-Usage | GPU-Util  Compute M. |
|                               |                      |               MIG M. |
|===============================+======================+======================|
|   0  NVIDIA GeForce ...  Off  | 00000000:01:00.0 Off |                  N/A |
| N/A   37C    P8    N/A /  N/A |      9MiB /  2048MiB |      0%      Default |
|                               |                      |                  N/A |
+-------------------------------+----------------------+----------------------+

+-----------------------------------------------------------------------------+
| Processes:                                                                  |
|  GPU   GI   CI        PID   Type   Process name                  GPU Memory |
|        ID   ID                                                   Usage      |
|=============================================================================|
|    0   N/A  N/A      1158      G   /usr/lib/xorg/Xorg                  4MiB |
|    0   N/A  N/A      1839      G   /usr/lib/xorg/Xorg                  4MiB |
+-----------------------------------------------------------------------------+
```

2. 关闭系统自带驱动`nouveau`。通过在终端输入指令`lsmod | grep nouveau`查看驱动启用情况。我输入后发现有输出，表明`nouveau`驱动正在工作。所以,接下来在终端输入`sudo gedit /etc/modprobe.d/blacklist.conf`，弹出了`blacklist.conf`文件，在文件末尾加上`blacklist`

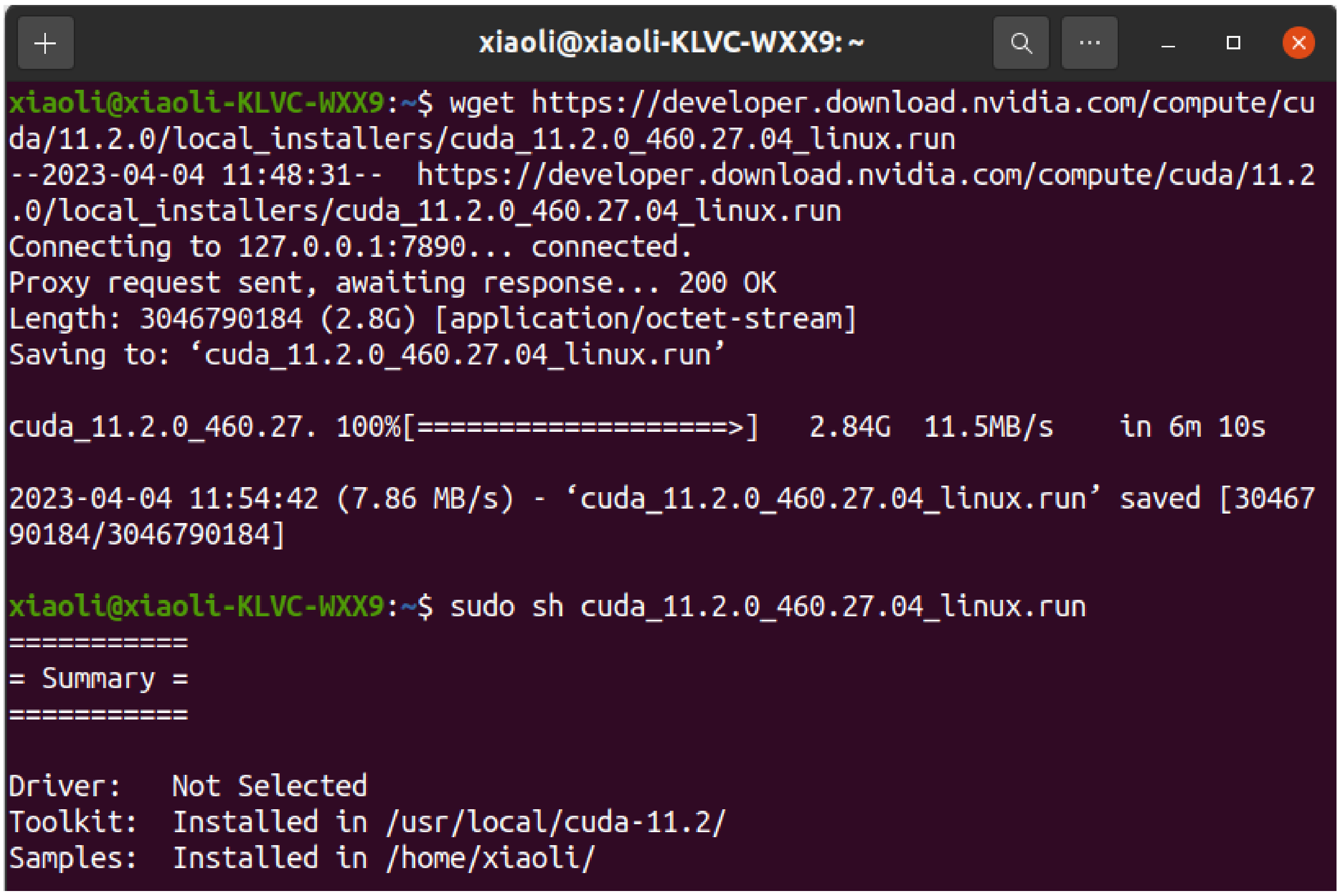
`nouveau`和`options nouveau modeset=0`两行并保存。



```
xiaoli@xiaoli-KLVC-WXX9:~$ lsmod | grep nouveau
nouveau              2285568  1
mxm_wmi                16384  1 nouveau
drm_ttm_helper         16384  1 nouveau
ttm                    86016  3 drm_ttm_helper,i915,nouveau
drm_kms_helper        307200  2 i915,nouveau
i2c_algo_bit           16384  2 i915,nouveau
drm                   618496  20 drm_kms_helper,drm_ttm_helper,i915,ttm,nouveau
video                  57344  3 int3406_thermal,i915,nouveau
wmi                    32768  5 intel_wmi_thunderbolt,huawei_wmi,wmi_bmof,mxm_wmi,no
uveau
xiaoli@xiaoli-KLVC-WXX9:~$ sudo gedit /etc/modprobe.d/blacklist.conf
[sudo] password for xiaoli:

(gedit:10075): Tepl-WARNING **: 11:06:20.519: GVfs metadata is not supported. Fallba
ck to TeplMetadataManager. Either GVfs is not correctly installed or GVfs metadata a
re not supported on this platform. In the latter case, you should configure Tepl wit
h --disable-gvfs-metadata.
wq
^Z
[1]+  Stopped                 sudo gedit /etc/modprobe.d/blacklist.conf
xiaoli@xiaoli-KLVC-WXX9:~$ sudo update-initramfs -u
update-initramfs: Generating /boot/initrd.img-5.15.0-58-generic
I: The initramfs will attempt to resume from /dev/nvme0n1p7
I: (UUID=1e7230ed-440d-4817-9966-af93591f44c5)
I: Set the RESUME variable to override this.
```

1. 重启
2. 进入NVIDIA官网CUDA下载页面`https://developer.nvidia.com/cuda-toolkit-archive`选择`CUDA Toolkit 11.2.0(December 2020)`，依次选择`Linux`→`x86_64`→`Ubuntu`→`20.04`→`runfile(local)`
3. 在终端输入`sudo apt-get install freeglut3-dev build-essential libx11-dev libxmu-dev libxi-dev libgl1-mesa-glx libglu1-mesa libglu1-mesa-dev`安装依赖库文件
4. 在终端输入`wget https://developer.download.nvidia.com/compute/cuda/11.2.0/local_installers/cuda_11.2.0_460.27.04_linux.run`和`sudo sh cuda_11.2.0_460.27.04_linux.run`安装CUDA。接下来会弹出两个页面，在第一个页面输入`accept`、回车，在第二个页面按空格取消`Driver`勾选，然后点击

`Install`、等待。

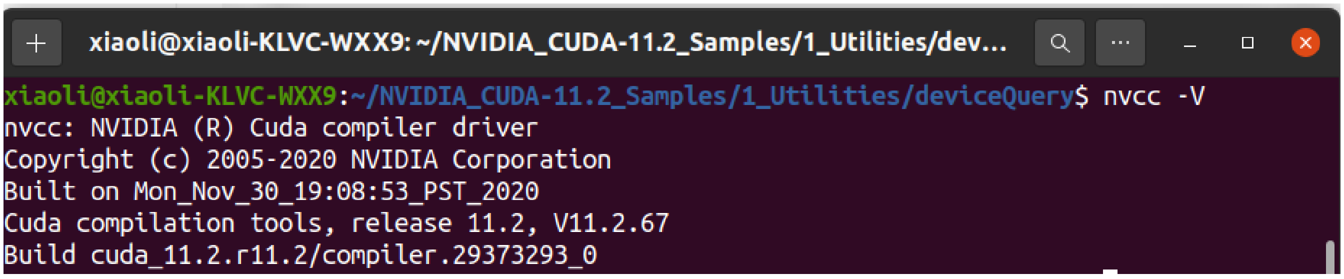


```
xiaoli@xiaoli-KLVC-WXX9: ~
xiaoli@xiaoli-KLVC-WXX9:~$ wget https://developer.download.nvidia.com/compute/cu
da/11.2.0/local_installers/cuda_11.2.0_460.27.04_linux.run
--2023-04-04 11:48:31--  https://developer.download.nvidia.com/compute/cuda/11.2
.0/local_installers/cuda_11.2.0_460.27.04_linux.run
Connecting to 127.0.0.1:7890... connected.
Proxy request sent, awaiting response... 200 OK
Length: 3046790184 (2.8G) [application/octet-stream]
Saving to: ‘cuda_11.2.0_460.27.04_linux.run’

cuda_11.2.0_460.27. 100%[===================>]   2.84G  11.5MB/s    in 6m 10s

2023-04-04 11:54:42 (7.86 MB/s) - ‘cuda_11.2.0_460.27.04_linux.run’ saved [30467
90184/3046790184]

xiaoli@xiaoli-KLVC-WXX9:~$ sudo sh cuda_11.2.0_460.27.04_linux.run
===========
= Summary =
===========

Driver:   Not Selected
Toolkit:  Installed in /usr/local/cuda-11.2/
Samples:  Installed in /home/xiaoli/
```

5. 配置环境变量

```
$ export PATH=/usr/local/cuda-10.1/bin${PATH:+:${PATH}}
$ export LD_LIBRARY_PATH=/usr/local/cuda-10.1/lib64\
                         ${LD_LIBRARY_PATH:+:${LD_LIBRARY_PATH}}
```

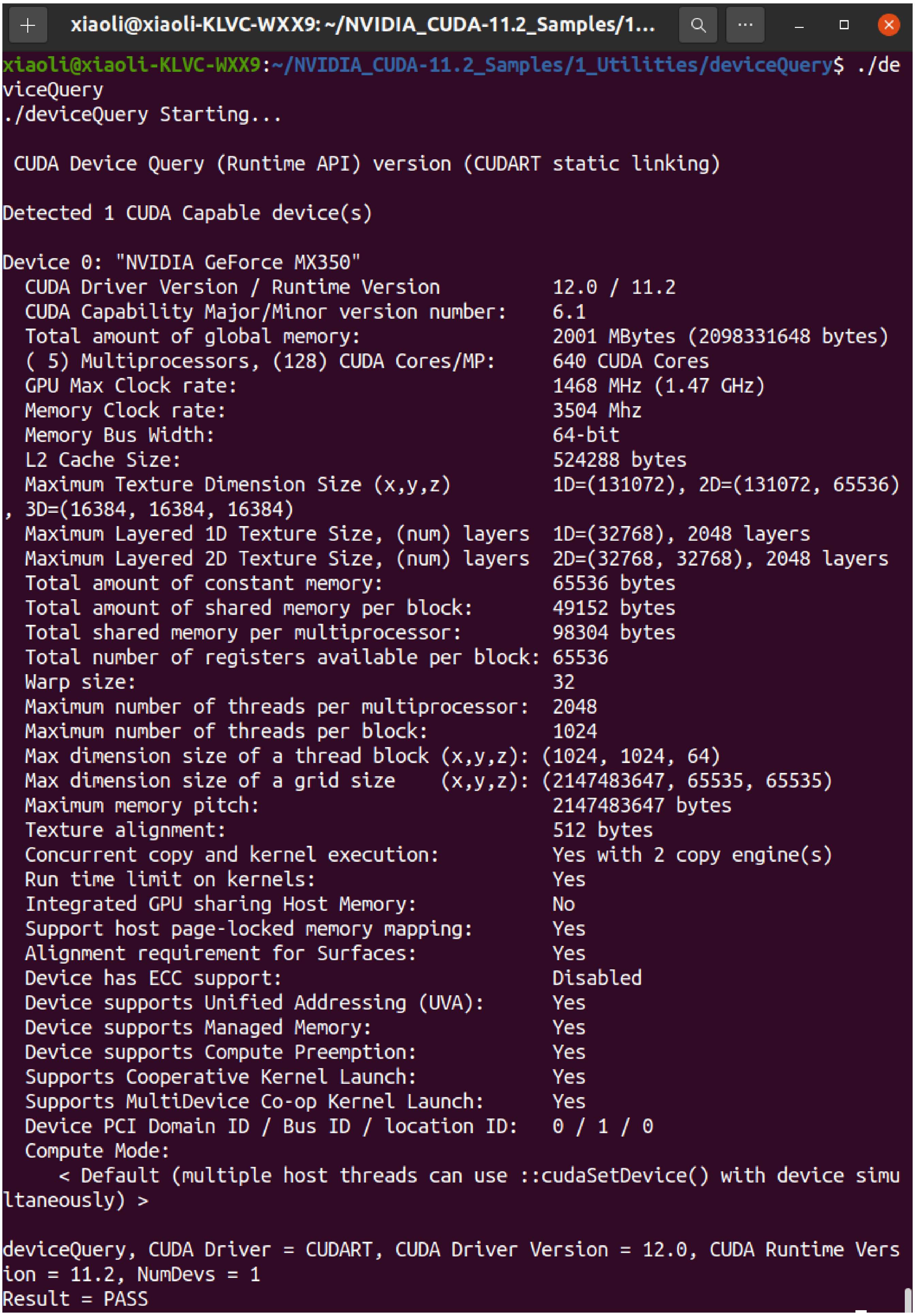
6. 在终端输入`source ~/.bashrc`使环境变量生效。
7. 查看CUDA安装信息



```
xiaoli@xiaoli-KLVC-WXX9: ~/NVIDIA_CUDA-11.2_Samples/1_Utilities/dev...
xiaoli@xiaoli-KLVC-WXX9:~/NVIDIA_CUDA-11.2_Samples/1_Utilities/deviceQuery$ nvcc -V
nvcc: NVIDIA (R) Cuda compiler driver
Copyright (c) 2005-2020 NVIDIA Corporation
Built on Mon_Nov_30_19:08:53_PST_2020
Cuda compilation tools, release 11.2, V11.2.67
Build cuda_11.2.r11.2/compiler.29373293_0
```

8. CUDA测试。进入NVIDIA CUDA示例包，其位于`/home/xiaoli/NVIDIA_CUDA-11.2_Samples`，在该文件夹下打开终端，并输入`make`。然后进入`1_Utilities/deviceQuery`文件夹，并在终端执

行`./deviceQuery`命令，输出结果`result=PASS`表示安装成功。



```
xiaoli@xiaoli-KLVC-WXX9:~/NVIDIA_CUDA-11.2_Samples/1_Utilities/deviceQuery$ ./de
viceQuery
./deviceQuery Starting...

 CUDA Device Query (Runtime API) version (CUDART static linking)

Detected 1 CUDA Capable device(s)

Device 0: "NVIDIA GeForce MX350"
  CUDA Driver Version / Runtime Version          12.0 / 11.2
  CUDA Capability Major/Minor version number:    6.1
  Total amount of global memory:                 2001 MBytes (2098331648 bytes)
  ( 5) Multiprocessors, (128) CUDA Cores/MP:     640 CUDA Cores
  GPU Max Clock rate:                            1468 MHz (1.47 GHz)
  Memory Clock rate:                             3504 Mhz
  Memory Bus Width:                              64-bit
  L2 Cache Size:                                 524288 bytes
  Maximum Texture Dimension Size (x,y,z)         1D=(131072), 2D=(131072, 65536)
, 3D=(16384, 16384, 16384)
  Maximum Layered 1D Texture Size, (num) layers  1D=(32768), 2048 layers
  Maximum Layered 2D Texture Size, (num) layers  2D=(32768, 32768), 2048 layers
  Total amount of constant memory:               65536 bytes
  Total amount of shared memory per block:       49152 bytes
  Total shared memory per multiprocessor:        98304 bytes
  Total number of registers available per block: 65536
  Warp size:                                     32
  Maximum number of threads per multiprocessor:  2048
  Maximum number of threads per block:           1024
  Max dimension size of a thread block (x,y,z): (1024, 1024, 64)
  Max dimension size of a grid size    (x,y,z): (2147483647, 65535, 65535)
  Maximum memory pitch:                          2147483647 bytes
  Texture alignment:                             512 bytes
  Concurrent copy and kernel execution:          Yes with 2 copy engine(s)
  Run time limit on kernels:                     Yes
  Integrated GPU sharing Host Memory:            No
  Support host page-locked memory mapping:       Yes
  Alignment requirement for Surfaces:            Yes
  Device has ECC support:                        Disabled
  Device supports Unified Addressing (UVA):      Yes
  Device supports Managed Memory:                Yes
  Device supports Compute Preemption:            Yes
  Supports Cooperative Kernel Launch:            Yes
  Supports MultiDevice Co-op Kernel Launch:      Yes
  Device PCI Domain ID / Bus ID / location ID:   0 / 1 / 0
  Compute Mode:
     < Default (multiple host threads can use ::cudaSetDevice() with device simu
ltaneously) >

deviceQuery, CUDA Driver = CUDART, CUDA Driver Version = 12.0, CUDA Runtime Vers
ion = 11.2, NumDevs = 1
Result = PASS
```

Lab 2 - 排序算法的并行及优化（验证）

Lab 3 - 矩阵乘法的并行及优化（验证）

Lab 4 - 快速傅里叶变换的并行实现（验证）

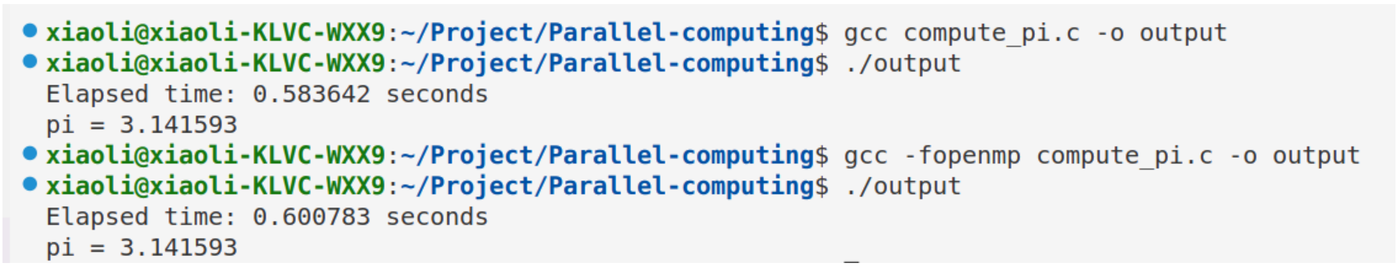
Lab 5 - 常用图像处理算法的并行及优化（设计）

Appendix

仅以此记录一下自己被困扰了一天的问题。以下是我写的第一个测试OpenMP的C语言代码，其过程是近似计算PI的值

```
#include <stdio.h>
#include <time.h>
#include <omp.h>

void sum(){
    int sum = 0;
    for(int i = 0; i < 100000000; i++){
        sum++;
    }
}

void parallel(){
    clock_t start, end;
    start = clock();
    # pragma omp parallel for
    for(int i = 0; i < 100; i++){
        sum();
    }
    end = clock();
    printf("Parallel time: %ld \n", end - start);
}

void no_parallel(){
    clock_t start, end;
    start = clock();
    for(int i = 0; i < 100; i++){
        sum();
    }
    end = clock();
    printf("Serial time: %ld \n", end - start);
}
```

```
int main() {
    parallel();
    no_parallel();
    return 0;
}
```



```
● xiaoli@xiaoli-KLVC-WXX9:~/Project/Parallel-computing$ gcc compute_pi.c -o output
● xiaoli@xiaoli-KLVC-WXX9:~/Project/Parallel-computing$ ./output
  Elapsed time: 0.583642 seconds
  pi = 3.141593
● xiaoli@xiaoli-KLVC-WXX9:~/Project/Parallel-computing$ gcc -fopenmp compute_pi.c -o output
● xiaoli@xiaoli-KLVC-WXX9:~/Project/Parallel-computing$ ./output
  Elapsed time: 0.600783 seconds
  pi = 3.141593
```

但是输出结果却令我大为震惊，因为开了并行竟然比不开更浪费时间，虽然我一开始以为可能是老师上课说的那种情况——并行的开销比并行的收益更大，但是当我把参数量调大之后发现这个现象仍然存在，于是我上网进行了搜索，终于发现原来是时间的测量方法使用错误。`clock()`记录的是CPU的滴答数，当并行多个进程同时计算，CPU滴答数成倍增加，所以我们得到的差值并不是真实的时间数，OpenMP提供的`omp_get_wtime()`才记录的是真实的运行时间，当我把时间测量函数修改后发现代码运行正常，结果为