Name-Ketki Khati
Nu ID-002436886

Assignment

- Create a modal.com account **using your github account.**
- Join the modal.com course workspace by clicking on the invite link
- Read through these sections of the modal.com documentation and run the examples:
    - https://modal.com/docs/examples/hello_world
    - https://modal.com/docs/guide/images
    - https://modal.com/docs/guide/gpu
    - https://modal.com/docs/guide/cuda
    - https://modal.com/docs/guide/resources
    - Please note that there are limited funds in the shared workspace. Please monitor your usage carefully and avoid submitting unnecessary runs.
- Implement matrix multiplication
    - Implement a single-threaded version in C
    - Write test cases. Check a wide range of different dimensions for the input matrices to make sure your code has no errors in corner cases.
        - for example:
            - A = 1x1, B = 1x1
            - A = 1x1, B = 1x5
            - A = 2x1, B = 1x3
            - A = 2x2, B = 2x2
            - and others.
    - Implement a multi-threaded version in C using pthreads.
    - Check that your test cases pass for the multi threaded version

- Measure the speed up for different thread counts: 1, 4, 16, 32, 64, 128.
  - Use large matrices so that the speed up is measure-able.

CODE-

```
#define _GNU_SOURCE
#include <stdio.h>
#include <stdlib.h>
#include <stdint.h>
#include <string.h>
#include <time.h>
#include <pthread.h>
#include <math.h>

typedef struct {
  const double *A;
  const double *B;
  double *C;
  int M, K, N;       // A: MxK, B: KxN, C: MxN
  int row_start;
  int row_end;       // [start, end)
} WorkerArgs;

static inline double rand_unit(unsigned *seed) {
  // simple deterministic RNG
  *seed = (*seed * 1103515245u + 12345u);
  return (double)((*seed / 65536u) % 32768u) / 32768.0;
}
```

```
static double now_seconds(void) {
   struct timespec ts;
   clock_gettime(CLOCK_MONOTONIC, &ts);
   return (double)ts.tv_sec + (double)ts.tv_nsec * 1e-9;
}

static void matmul_single(const double *A, const double *B, double *C, int M, int K, int N) {
   // Row-major layout:
   // A[i*K + k], B[k*N + j], C[i*N + j]
   for (int i = 0; i < M; i++) {
      for (int j = 0; j < N; j++) {
         double sum = 0.0;
         for (int k = 0; k < K; k++) {
            sum += A[i*K + k] * B[k*N + j];
         }
         C[i*N + j] = sum;
      }
   }
}

static void* worker_rows(void *arg) {
   WorkerArgs *w = (WorkerArgs*)arg;
   const double *A = w->A;
   const double *B = w->B;
   double *C = w->C;
```

```
  for (int i = w->row_start; i < w->row_end; i++) {
    for (int j = 0; j < w->N; j++) {
      double sum = 0.0;
      for (int k = 0; k < w->K; k++) {
        sum += A[i*w->K + k] * B[k*w->N + j];
      }
      C[i*w->N + j] = sum;
    }
  }
  return NULL;
}

static int matmul_pthreads(const double *A, const double *B, double *C, int M, int K, int N,
int num_threads) {
  if (num_threads < 1) num_threads = 1;
  if (num_threads > M) num_threads = M; // more threads than rows doesn't help

  pthread_t *threads = (pthread_t*)malloc(sizeof(pthread_t) * (size_t)num_threads);
  WorkerArgs *args = (WorkerArgs*)malloc(sizeof(WorkerArgs) * (size_t)num_threads);
  if (!threads || !args) {
    free(threads); free(args);
    return -1;
  }

  int base = M / num_threads;
```

```
    int rem  = M % num_threads;

    int row = 0;
    for (int t = 0; t < num_threads; t++) {
        int take = base + (t < rem ? 1 : 0);
        args[t].A = A; args[t].B = B; args[t].C = C;
        args[t].M = M; args[t].K = K; args[t].N = N;
        args[t].row_start = row;
        args[t].row_end   = row + take;
        row += take;

        int rc = pthread_create(&threads[t], NULL, worker_rows, &args[t]);
        if (rc != 0) {
            // join what started
            for (int j = 0; j < t; j++) pthread_join(threads[j], NULL);
            free(threads); free(args);
            return -2;
        }
    }

    for (int t = 0; t < num_threads; t++) pthread_join(threads[t], NULL);

    free(threads);
    free(args);
    return 0;
}
```

```
static void fill_random(double *X, int len, unsigned seed0) {
   unsigned seed = seed0;
   for (int i = 0; i < len; i++) X[i] = rand_unit(&seed) - 0.5;
}

static int almost_equal(double a, double b, double tol) {
   double diff = fabs(a - b);
   double scale = fmax(1.0, fmax(fabs(a), fabs(b)));
   return diff <= tol * scale;
}

static int check_equal(const double *X, const double *Y, int len, double tol) {
   for (int i = 0; i < len; i++) {
      if (!almost_equal(X[i], Y[i], tol)) return 0;
   }
   return 1;
}

static void run_tests(void) {
   struct { int M, K, N; } cases[] = {
      {1,1,1},
      {1,1,5},
      {2,1,3},
      {2,2,2},
      {3,4,2},
```

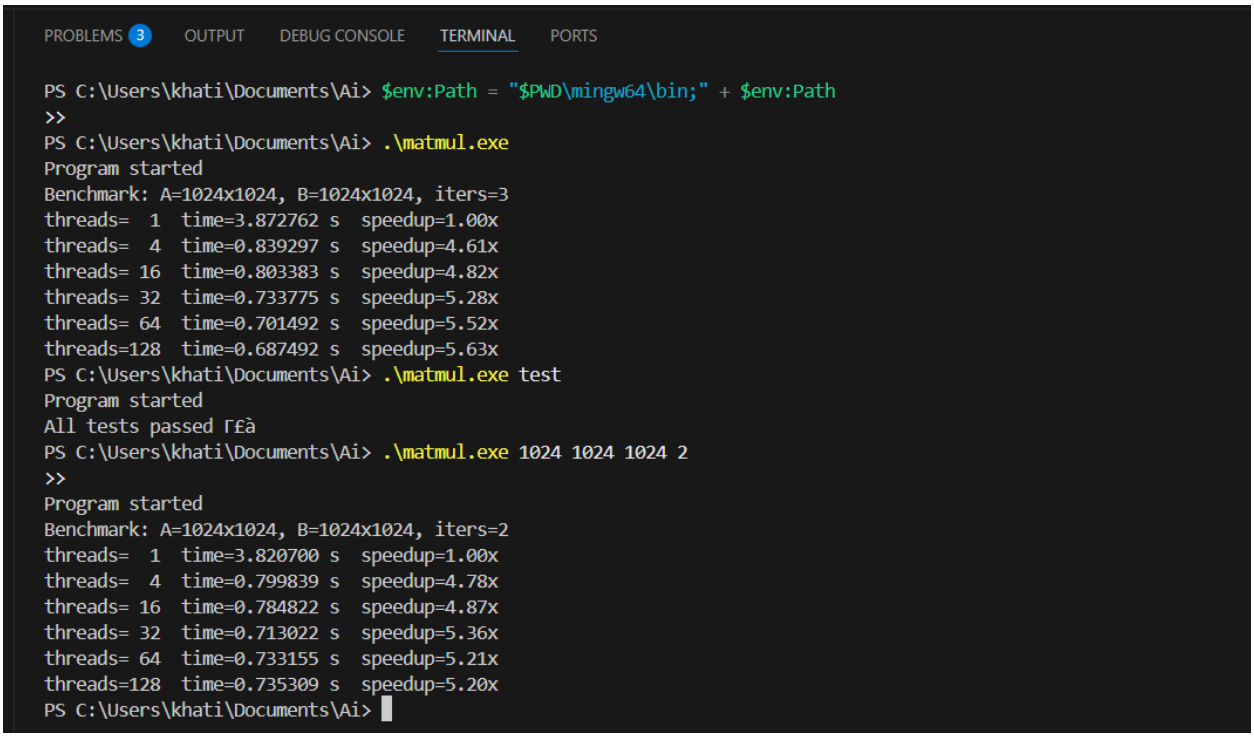
```
    {4,3,5},
    {7,8,9},
    {16,16,16},
    {31,17,29},
};

for (size_t idx = 0; idx < sizeof(cases)/sizeof(cases[0]); idx++) {
    int M = cases[idx].M, K = cases[idx].K, N = cases[idx].N;

    double *A  = (double*)malloc(sizeof(double)*(size_t)(M*K));
    double *B  = (double*)malloc(sizeof(double)*(size_t)(K*N));
    double *C1 = (double*)malloc(sizeof(double)*(size_t)(M*N));
    double *C2 = (double*)malloc(sizeof(double)*(size_t)(M*N));
    if (!A || !B || !C1 || !C2) { fprintf(stderr, "malloc failed\n"); exit(1); }

    fill_random(A, M*K, 1234u + (unsigned)idx);
    fill_random(B, K*N, 5678u + (unsigned)idx);

    matmul_single(A, B, C1, M, K, N);

    // test multiple thread counts
    int thread_counts[] = {1,2,4,8,16,32,64,128};
    for (size_t t = 0; t < sizeof(thread_counts)/sizeof(thread_counts[0]); t++) {
        memset(C2, 0, sizeof(double)*(size_t)(M*N));
        matmul_pthreads(A, B, C2, M, K, N, thread_counts[t]);
        if (!check_equal(C1, C2, M*N, 1e-9)) {
```

```
            fprintf(stderr, "TEST FAIL: M=%d K=%d N=%d threads=%d\n", M, K, N,
thread_counts[t]);
            exit(2);
        }
      }

    free(A); free(B); free(C1); free(C2);
  }

  printf("All tests passed ✅ \n");
}

static double bench_matmul(int M, int K, int N, int threads, int iters) {
  double *A  = (double*)malloc(sizeof(double) * (size_t)(M*K));
  double *B  = (double*)malloc(sizeof(double) * (size_t)(K*N));
  double *C  = (double*)malloc(sizeof(double) * (size_t)(M*N));

  if (!A || !B || !C) { fprintf(stderr, "alloc failed\n"); exit(1); }

  fill_random(A, M*K, 111u);
  fill_random(B, K*N, 222u);

  // warmup
  if (threads == 1) matmul_single(A, B, C, M, K, N);
  else matmul_pthreads(A, B, C, M, K, N, threads);
```

```
    double t0 = now_seconds();
    for (int i = 0; i < iters; i++) {
        if (threads == 1) matmul_single(A, B, C, M, K, N);
        else matmul_pthreads(A, B, C, M, K, N, threads);
    }
    double t1 = now_seconds();

    // prevent optimizing away
    volatile double sink = C[0];
    (void)sink;

    free(A); free(B); free(C);
    return (t1 - t0) / (double)iters;
}

int main(int argc, char **argv) {
    printf("Program started\n");

    if (argc >= 2 && strcmp(argv[1], "test") == 0) {
        run_tests();
        return 0;
    }

    // Default benchmark dimensions (big enough to see speedup on most machines)
    int M = 1024, K = 1024, N = 1024;
    int iters = 3;
```

```
    if (argc >= 5) {
        M = atoi(argv[1]);
        K = atoi(argv[2]);
        N = atoi(argv[3]);
        iters = atoi(argv[4]);
        if (iters < 1) iters = 1;
    }

    int thread_counts[] = {1,4,16,32,64,128};

    printf("Benchmark: A=%dx%d, B=%dx%d, iters=%d\n", M, K, K, N, iters);

    double t1 = bench_matmul(M, K, N, 1, iters);
    printf("threads=%3d  time=%.6f s  speedup=1.00x\n", 1, t1);

    for (size_t i = 1; i < sizeof(thread_counts)/sizeof(thread_counts[0]); i++) {
        int th = thread_counts[i];
        double tt = bench_matmul(M, K, N, th, iters);
        printf("threads=%3d  time=%.6f s  speedup=%.2fx\n", th, tt, t1/tt);
    }

    return 0;
}
```

OUTPUT-



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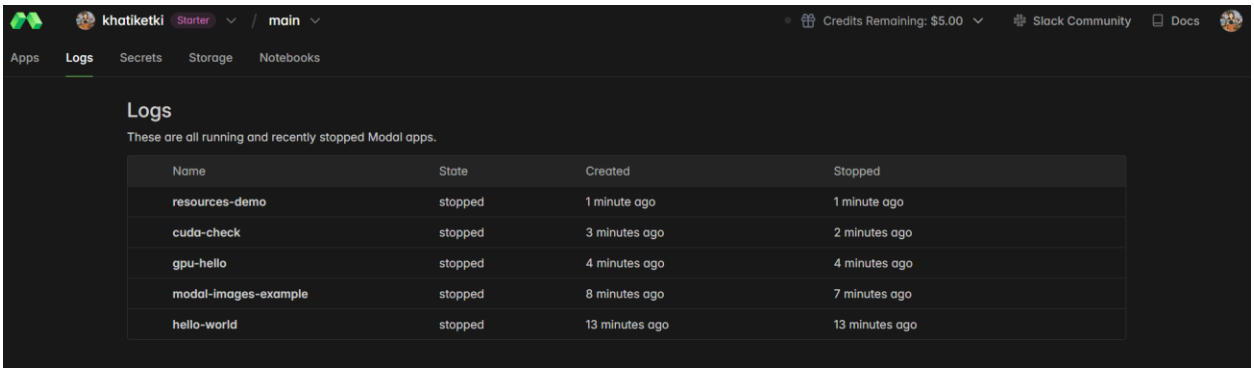


1.hello-world

```
import modal

app = modal.App("hello-world")

@app.function()
def hello():
    print("Hello from Modal!")

if __name__ == "__main__":
    with app.run():
        hello.remote()
```

OUTPUT-

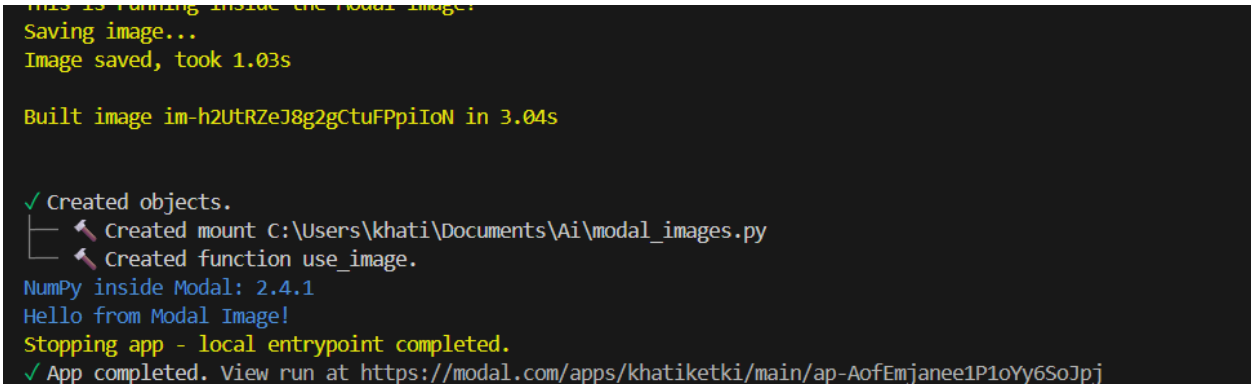
```
Token written to C:\Users\khati/.modal.toml in profile khatiketki.
PS C:\Users\khati\Documents\Ai> python -m modal run Helloworld.py
>>
✓ Initialized. View run at https://modal.com/apps/khatiketki/main/ap-cCdqVvoDjY4nkMnUsSSP8N
✓ Created objects.
├── 🔨 Created mount C:\Users\khati\Documents\Ai\Helloworld.py
└── 🔨 Created function hello.
Hello from Modal!
Stopping app - local entrypoint completed.
✓ App completed. View run at httpython -m modal token newketki/main/ap-cCdqVvoDjY4nkMnUsSSP8N
>> C:\Users\khati\Documents\Ai>
The web browser should have opened for you to authenticate and get an API token.
If it didn't, please copy this URL into your web browser manually:

https://modal.com/token-flow/tf-maxSKAokQqQi5sgUfAKWiw

Web authentication finished successfully!
Token is connected to the khatiketki workspace.
Verifying token against https://api.modal.com
Token verified successfully!
Token written to C:\Users\khati/.modal.toml in profile khatiketki.
```

2.modal_images.py

```
import modal


# Define a custom Modal image
image = (
    modal.Image.debian_slim(python_version="3.11")
    .apt_install("git")      # install additional system packages
    .pip_install("numpy")    # example: add a pip package
    .run_commands(
        "echo 'This is running inside the Modal Image!'"
    )
)


app = modal.App("modal-images-example")


# Define a function that uses that image
@app.function(image=image)
```

```
def use_image():
    import numpy as np
    print("NumPy inside Modal:", np.__version__)
    print("Hello from Modal Image!")

if __name__ == "__main__":
    with app.run():
        use_image.remote()
```

OUTPUT-

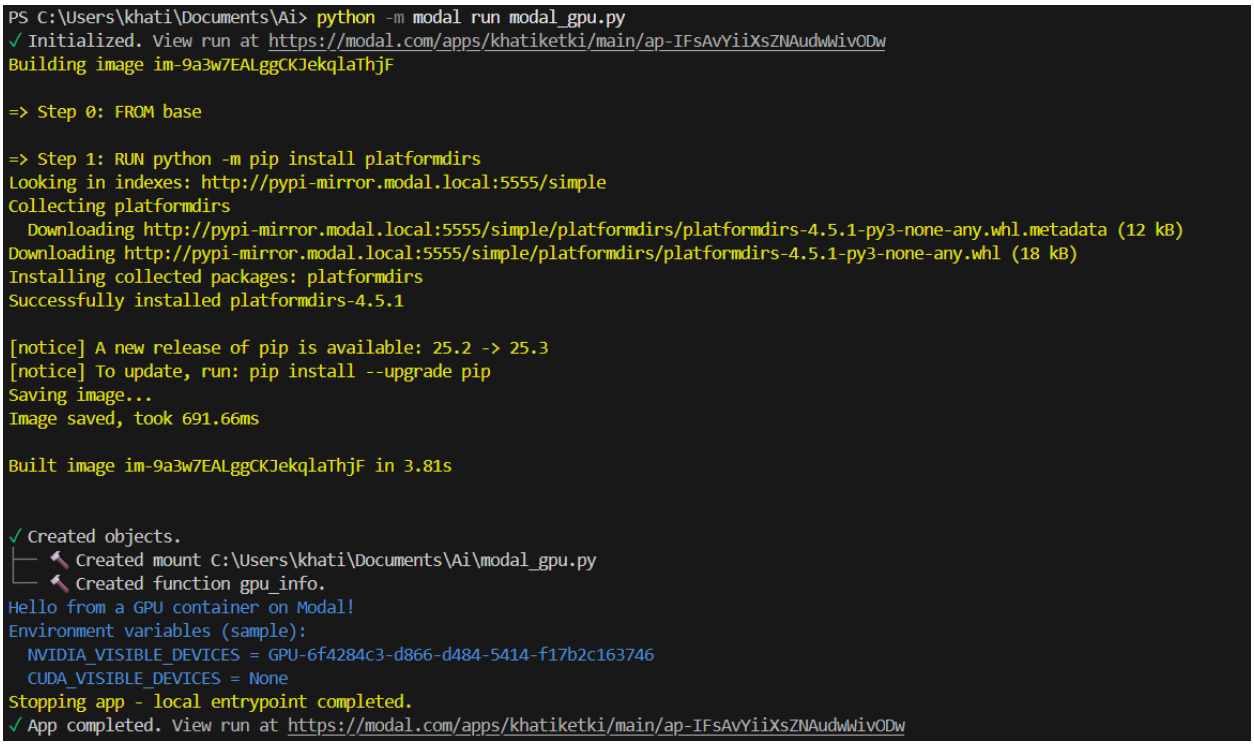


3.modal_gpy.py

```
import modal

app = modal.App("gpu-hello")

# Small image: only installs tiny package
image = modal.Image.debian_slim(python_version="3.11").pip_install("platformdirs")
```

```
@app.function(image=image, gpu="any")  # request any available GPU
def gpu_info():
    import os
    print("Hello from a GPU container on Modal!")
    # This won't guarantee CUDA libs, but proves GPU scheduling works.
    print("Environment variables (sample):")
    for k in ["NVIDIA_VISIBLE_DEVICES", "CUDA_VISIBLE_DEVICES"]:
        print(f"  {k} = {os.getenv(k)}")


if __name__ == "__main__":
    with app.run():
        gpu_info.remote()
```

OUTPUT-

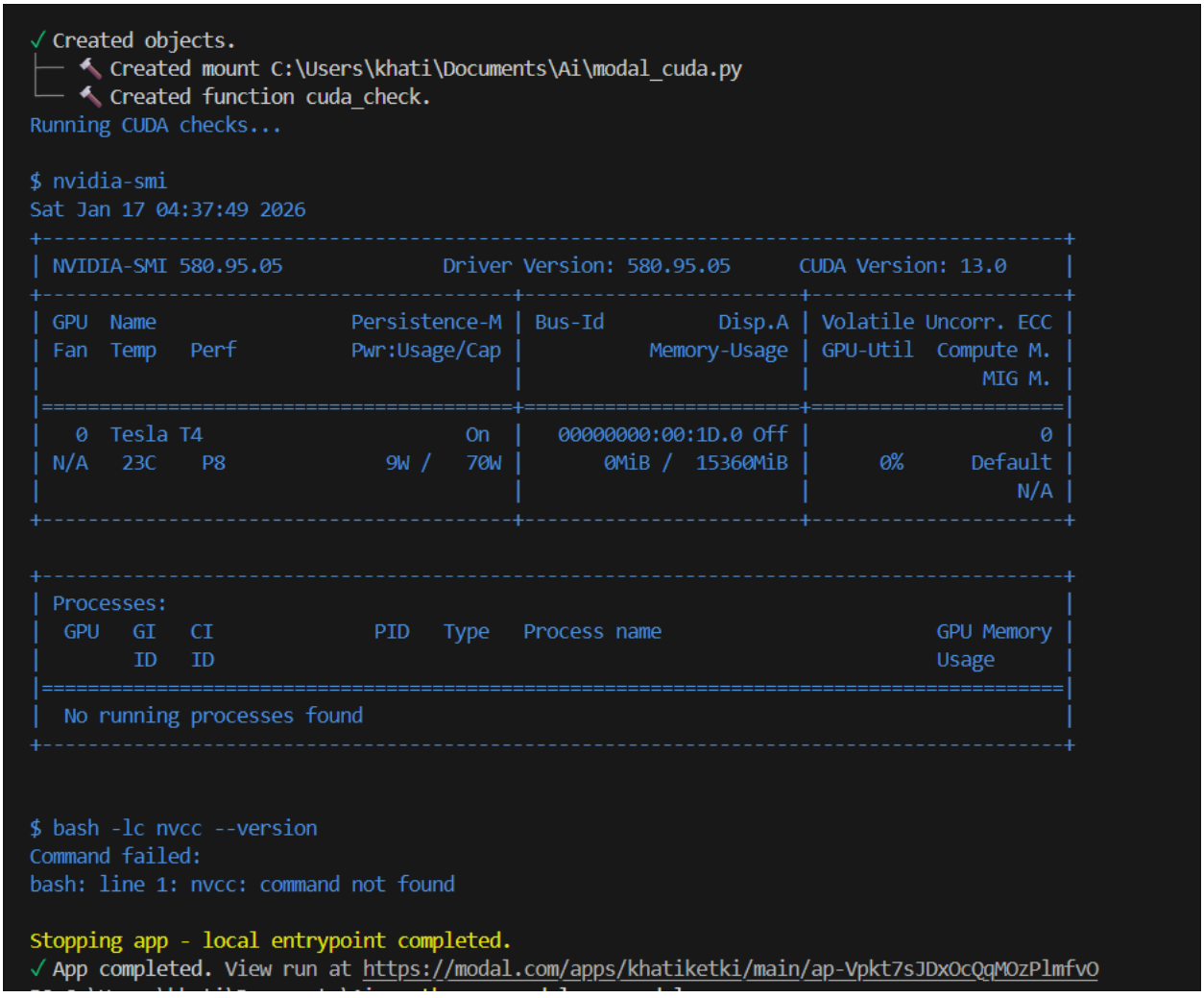


4.modal_cuda.py

```
import modal

app = modal.App("cuda-check")

# Image with CUDA tools; this is the typical pattern.
# We keep it minimal and just run `nvidia-smi` and `nvcc --version` checks.
image = (
  modal.Image.debian_slim(python_version="3.11")
  .apt_install("pciutils")  # lightweight; optional
)

@app.function(image=image, gpu="any")
def cuda_check():
  import subprocess

  print("Running CUDA checks...")

  # nvidia-smi is usually present on GPU containers; if not, we show the error
  for cmd in [["nvidia-smi"], ["bash", "-lc", "nvcc --version"]]:
    try:
      out = subprocess.check_output(cmd, stderr=subprocess.STDOUT, text=True)
      print(f"\n$ {' '.join(cmd)}\n{out}")
    except subprocess.CalledProcessError as e:
```

```
        print(f"\n$ {' '.join(cmd)}\nCommand failed:\n{e.output}")
    except FileNotFoundError:
        print(f"\n$ {' '.join(cmd)}\nNot found in this image/container.")


if __name__ == "__main__":
    with app.run():
        cuda_check.remote()
```

OUTPUT-



5.modal_resources.py

```
import modal
import time

app = modal.App("resources-demo")

image = modal.Image.debian_slim(python_version="3.11")

# Configure resources: keep it small to avoid burning credits
@app.function(
  image=image,
  cpu=1,          # request 1 CPU
  memory=512,       # 512 MiB RAM
  timeout=60,       # 60 seconds max
)
def resource_demo():
  print("Resources demo running.")
  print("Doing a tiny bit of work...")
  t0 = time.time()
  s = 0
  for i in range(5_000_00):  # small loop
    s += i % 7
  print("Done. checksum =", s, "elapsed =", round(time.time() - t0, 3), "sec")

if __name__ == "__main__":
```

```
with app.run():
    resource_demo.remote()
```

Output-