CMSC416: Introduction to Parallel Computing

Topic: GPGPUs and CUDA
Date: March 26, 2024

- GPGUs (General Purpose Graphics Processing Unit)
    - It was originally developed to handle computation related to graphics processing
    - useful for scientific computing
    - It is currently used for AI training, bitcoin mining, and high performance parallel computing, etc.
- Types of Accelerators
    - IBM's Cell processors
        - Used in playstation 3
    - GPUs: NVIDIA, AMD, Intel
    - FPGAs (Field Programmable Gate Arrays)
- Uses for mainstream High Performance Computing
    - 2013: NAMD, used for molecular dynamics simulations on a supercomputer with 3000 NVIDIA Tesla GPUs
        - They were able to simulate the Aids virus
- CPU Hardware
    - Each core has its own L1 cache
    - The L2 caches are shared across multiple cores
    - The L3 cache shared across all cores
- GCGPU Hardware
    - It has Many more cores
    - The L1 caches share multiple cores
    - The L2 cache shares all cores
    - Has higher instruction throughput and hides memory access latency with computation
- GPU vs CPU
    - GPU has many more cores
    - CPU has higher Clock Speed(GHz)
        - This is caused by heating
- Volta GV100
    - Cuda Core
        - Single serial execution unit
            - Can execute instructions
    - Many cores are divided into Streaming Multiprocessors
    - Streaming Multiprocessor (SM)
        - 64 FP32 cores (single precision)
        - 64 INT32 cores
        - 32 FP64 cores (double precision)
        - 8 Tensor cores
            - Used for matrix multiply

    - A CUDA capable device or GPU is a Collection of SMs
- NVLink - Sends messages very fast between GPUs

- CUDA
    - Allows developers to use C++ as a high-level programming language
    - Built around threads, blocks and grids
    - Terminology:
        - Host: CPU
            - Where you start computation
        - Device: GPU
            - This is where you offload computation to
        - CUDA Kernel: a function that gets executed on the GPU
    - You have to figure out as programmer which threads should do what
- Cuda Software abstraction
    - Thread - One serial unit of abstraction
    - Block - A Collection of threads
        - Number of threads in block <= 1024
    - Kernel Grid - A Collection of blocks
    - A Thread is executed in a CUDA core
    - A Block of threads is executed by a CUDA SM
    - A Grid is executed by the entire GPU
- Three steps to writing a CUDA kernel
    - Copy input data from host to device memory (CPU to GPU)
    - Load the GPU program (kernel) and execute it
    - Copy the results back to host memory

Example Code Copying data to GPU and then back

```
double *d_Matrix, *h_Matrix;
h_Matrix = new double[N];

cudaMalloc(&d_Matrix, sizeof(double)*N);

// ... initialize h_Matrix ...
cudaMemcpy(d_Matrix, h_Matrix, sizeof(double)*N, cudaMemcpyHostToDevice);

// ... some computation on GPU …

cudaMemcpy(h_Matrix, d_Matrix, sizeof(double)*N, cudaMemcpyDeviceToHost);

cudaFree(d_Matrix);
```

- CudaMalloc - Allocates memory on the gpu
- CudaMemcpy - Copies data to and from different places (host to device, device to host, device to device, host to host, default)
- cudaFree - frees memory allocated

- CUDA Syntax

```
__global__ void saxpy(float *x, float *y, float alpha) {
    int i = threadIdx.x;
    y[i] = alpha*x[i] + y[i];
}

int main() {
    ...
    saxpy<<<1, N>>>(x, y, alpha);
    ...
}
```

What happens when:
array size (N) > 1024?

```
<<<#blocks, threads_per_block>>>
```

- __Global__ is required
- In this case there is 1 block with N threads
- Parameters for saxpy are Array x, array y, scalar alpha
- The top block of code(saxpy) specifies what happens for a single thread
- Calling “saxpy” in main is caled the “kernel call”

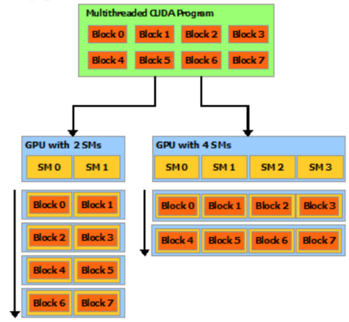
- What happens if array has > 1024 elements (A Block has a max of 1024 elements)
  - You will have each thread work on multiple parts of array
- What happens when the size of array < number of threads provided in launch parameter
  - There is an out of bounds error
  - You should put a check inside that checks if the amount of threads is <= size of array
- Compiling code
  - nvcc -o saxpy --generate-code arch=compute_80,code=sm_80 saxpy.cu
  - ./saxpy
  - saxpy.cu is the file name
  - This Compiles host and gpu code at same time

Multiple blocks

```
__global__ void saxpy(float *x, float *y, float alpha, int N) {
    int i = blockDim.x * blockIdx.x + threadIdx.x;
    if (i < N)
       y[i] = alpha*x[i] + y[i];
}


int main() {
    ...
    int threadsPerBlock = 512;
    int numBlocks = N/threadsPerBlock
                  + (N % threadsPerBlock != 0);

    saxpy<<<numBlocks, threadsPerBlock>>>(x, y, alpha, N);
    ...
}
```



Threads per block and numblocks get passed into the kernel call

- Each thread has an Id. threadId.x gives the Id of the current thread
- Each block has a block id. BlockId.x gives the Id of the current block
- Int i = blockdim.x * blockDim.x * blockDimId.x + threadId.x;
    - This line stores the global threadID in i