Hw2: 2024-27759 장효형

1. Theoretical Peak Performance of CPU

   (a) Intel(R) Xeon(R) Silver 4216 CPU @ 2.10GHz

   (b) 2개

   (c) **Base**: 2.1GHz, **boost**: 3200MHz. **Reason**: to classify workloads and provide adequate performance per each workloads with proper expenses and heat. **Boosted Conditions**: when the maximum performance is needed(such as complex calculation), considering heat, using cores, electricity consumptions, etc.

   (d) **Physical Cores:** 32**, Logical Cores:** 64. **Performance calculation uses:** logical cores. **Why**?: Each logical cores(threads) can perform FP operations independently.

   (e) 64(ref: https://www.intel.com/content/www/us/en/architecture-and-technology/avx-512-overview.html)

   (f) AVX512(32) * num_logical_cores(64) * base_clock_frequency(2.1GHz) = 4300GFLOPS. AVX512를 사용하지 않을 때에는 64 * 2.1GHz = 134.4GHz

2. Matrix Multiplication using Pthread

   (a) 자신의 병렬화 방식에 대한 설명: threading A's rows, blocking A's columns(=B's rows) with 'num_batches' number, to limit the FP values loaded on the cache at each time, reducing the cache miss. Each datapoints are sub-divided into 8 sub instruction lines. This is introduced considering instruction pipeline. Finally, the calculation is conducted with i(rows of A, M) > blocks(columns of A, a part of K) > batches(columns of A, a part of K) > j(columns of B, N)

   (b) 아래 그림은 임의의 행렬 연산에 대해 스레드의 개수를 1,2,4,8,16,32,64,128,256으로 2배씩 늘려 측정한 연산 속도이다. 스레드 수가 16 정도까지 늘어날 때에는 거의 스레드의 개수에 반비례하여 줄어듦을 확인할 수 있으나 그 이상으로는 성능 향상이 크게 일어나지 않음을 알 수 있다. 이는 스레드를 만들고 합치는 과정, 스레드 간의 communication 등의 latency 때문으로 생각할 수 있다.

```
shpc125@elogin3:~/hw2$ srun --nodes=1 --exclusive numactl --physcpubind 0-63 ./main -v -t 1 2048 2048 2048 | grep "Avg. time"
srun: job 855107 queued and waiting for resources
srun: job 855107 has been allocated resources
Avg. time: 1.612353 sec
shpc125@elogin3:~/hw2$ srun --nodes=1 --exclusive numactl --physcpubind 0-63 ./main -v -t 2 2048 2048 2048 | grep "Avg. time"
srun: job 855108 queued and waiting for resources
srun: job 855108 has been allocated resources
Avg. time: 1.001220 sec
shpc125@elogin3:~/hw2$ srun --nodes=1 --exclusive numactl --physcpubind 0-63 ./main -v -t 4 2048 2048 2048 | grep "Avg. time"
srun: job 855109 queued and waiting for resources
srun: job 855109 has been allocated resources
Avg. time: 0.490084 sec
shpc125@elogin3:~/hw2$ srun --nodes=1 --exclusive numactl --physcpubind 0-63 ./main -v -t 8 2048 2048 2048 | grep "Avg. time"
srun: job 855110 queued and waiting for resources
srun: job 855110 has been allocated resources
Avg. time: 0.262701 sec
shpc125@elogin3:~/hw2$ srun --nodes=1 --exclusive numactl --physcpubind 0-63 ./main -v -t 16 2048 2048 2048 | grep "Avg. time"
srun: job 855111 queued and waiting for resources
srun: job 855111 has been allocated resources
Avg. time: 0.225505 sec
shpc125@elogin3:~/hw2$ srun --nodes=1 --exclusive numactl --physcpubind 0-63 ./main -v -t 32 2048 2048 2048 | grep "Avg. time"
srun: job 855112 queued and waiting for resources
srun: job 855112 has been allocated resources
Avg. time: 0.144451 sec
shpc125@elogin3:~/hw2$ srun --nodes=1 --exclusive numactl --physcpubind 0-63 ./main -v -t 64 2048 2048 2048 | grep "Avg. time"
srun: job 855113 queued and waiting for resources
srun: job 855113 has been allocated resources
Avg. time: 0.115199 sec
shpc125@elogin3:~/hw2$ srun --nodes=1 --exclusive numactl --physcpubind 0-63 ./main -v -t 128 2048 2048 2048 | grep "Avg. time"
srun: job 855114 queued and waiting for resources
srun: job 855114 has been allocated resources
Avg. time: 0.107048 sec
shpc125@elogin3:~/hw2$ srun --nodes=1 --exclusive numactl --physcpubind 0-63 ./main -v -t 2568 2048 2048 2048 | grep "Avg. time"
srun: job 855115 queued and waiting for resources
srun: job 855115 has been allocated resources
num_threads must be <= 256
srun: error: a10: task 0: Exited with exit code 1
shpc125@elogin3:~/hw2$ srun --nodes=1 --exclusive numactl --physcpubind 0-63 ./main -v -t 256 2048 2048 2048 | grep "Avg. time"
srun: job 855116 queued and waiting for resources
srun: job 855116 has been allocated resources
Avg. time: 0.110193 sec
```

(c) (b)의 행렬 조건에서 가장 높은 성능을 보인 스레드 개수는 128개로, 총 약 145GFLOPS의 성능을 보인다. 이는 128 * 2.1GHz = 268.8GHz의 절반 가량의 성능으로, cpu의 성능을 충분히 활용하지 못함을 확인할 수 있다. 이를 improve하기 위해서는 보다 더 효과적인 caching 전략(예: 행렬을 transpose하기, num_batch 수를 empirical하게 실험하여 최적으로 조정하기) 등을 활용하고, 불필요한 변수 등을 제거하거나 dependency resolution 등의 최적화 전략을 이용해볼 수 있겠다.

```
shpc125@elogin3:~/hw2$ srun --nodes=1 --exclusive numactl --physcpubind 0-63 ./main -v -t 128 2048 2048 2048
srun: job 855133 queued and waiting for resources
srun: job 855133 has been allocated resources
Options:
  Problem size: M = 2048, N = 2048, K = 2048
  Number of threads: 128
  Number of iterations: 1
  Print matrix: off
  Validation: on

Initializing... done!
Calculating...(iter=0) 0.117846 sec
Validating...
Result: VALID
Avg. time: 0.117846 sec
Avg. throughput: 145.781937 GFLOPS
shpc125@elogin3:~/hw2$
```