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CSC 656 P3

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Part a

Code:

```c
// File: MaxCol.cu

// Compile: nvcc MaxCol.cu -o mc

// Run: ./mc [width of matrix] [threads per block]


// Description: finds the max of each column of a randomly generated matrix

//              in kernel findMax(), each thread finds the max of one column


#include <stdio.h>

#include <stdlib.h>

#include <cuda.h>


#define THREADSPERBLOCK 4


int checkArray(int [], int [], int);


__global__ void findMax(int *m, int *rs, int n);


int main(int argc, char **argv)

{

  /* variables for timing */

  cudaEvent_t start, stop;

  float time;


  if (argc != 3) {

    printf("Usage: ./SR [width of matrix] [threads per block]\n");
```

```
    exit(0);

}


int n = atoi(argv[1]);  // number of matrix rows/cols

int *hm, // host matrix

    *dm, // device matrix

    *hcs, // host column sums

    *dcs; // device column sums

int *checkCs;

int msize = n * n * sizeof(int);  // size of matrix in bytes

int rssize = n * sizeof(int);

int threadsPerBlock = atoi(argv[2]); // get threads per block


if (n % threadsPerBlock != 0) {

    printf("Warning: width of matrix not divisible by # threads per block\n");

}


// allocate space for host matrix

hm = (int *) malloc(msize);


// create timer events

cudaEventCreate(&start);

cudaEventCreate(&stop);


// as a test, fill matrix with random integers


int i, j;
```

```
for (i = 0; i < n; i++) {

  for (j = 0; j < n; j++) {

    hm[i*n+j] = random() % RAND_MAX;

  }

}


// compute max of columns on CPU for checking

checkCs = (int *) malloc(rssize);

for (i=0; i<n; i++) {

  checkCs[i] = hm[i];

  for (j=0; j<n; j++) {

    if (checkCs[i] < hm[i + j*n])

      checkCs[i] = hm[i + j*n];

  }

}


// allocate space for device matrix

cudaMalloc((void **)&dm,msize);

// copy host matrix to device matrix

cudaMemcpy(dm,hm,msize,cudaMemcpyHostToDevice);

// allocate host, device rowsum arrays

hcs = (int *) malloc(rssize);

cudaMalloc((void **)&dcs,rssize);


// record start timestamp

cudaEventRecord(start, 0);
```

```
// invoke the kernel

findMax<<<n/threadsPerBlock,threadsPerBlock>>>(dm,dcs,n);

// wait for kernel to finish

cudaThreadSynchronize();

// copy row vector from device to host

cudaMemcpy(hcs,dcs,rssize,cudaMemcpyDeviceToHost);


// get elapsed time

cudaEventRecord(stop, 0);

cudaEventSynchronize(stop);

cudaEventElapsedTime(&time, start, stop);


printf("Elapsed time = %f\n", time);


// check results

int diff = checkArray(hcs, checkCs, n);

if (diff == 0) {

  printf("Arrays match\n");

}

else {

  printf("Arrays do not match\n");

}



// clean up

free(hm);

cudaFree(dm);
```

```
    free(hcs);

    cudaFree(dcs);

}


int checkArray(int x[], int y[], int size) {

    int i;

    int numDiff = 0;


    for (i=0; i<size; i++) {

        if (x[i] != y[i]) {

            numDiff++;

        }

    }

    return numDiff;

}


// findMax(int *m, int *cs, int n)

// m: n x n matrix (input)

// cs: cs[i] contains max of columnn i of m (output)

// n: number of elements in each row/column of m


__global__ void findMax(int *m, int *cs, int n)

{

    // your code goes here

    int colnum = blockDim.x * blockIdx.x + threadIdx.x;

    int max = m[0];

    for (int   k = 0; k < n; k++){
```

```
    if(m [colnum+n*k] > max)

     max = m [colnum+n*k];

  }

  cs[colnum] = max;

}
```

Table:

	8 threads	16 threads	32 threads	64 threads	128 threads
size 1024	0.226421333	0.215509333	0.219072	0.216213333	0.221109333
size 2048	0.623434667	0.367274667	0.364677333	0.355242667	0.360288
size 4096	1.717888	1.177877333	0.656725333	0.659125333	0.656661333

Data:

```
zhuang4.S18@tiger:~/Zhenru1993/Code/S18$ ./MaxCol 1024 8
Elapsed time = 0.227072
Arrays match
zhuang4.S18@tiger:~/Zhenru1993/Code/S18$ ./MaxCol 1024 8
Elapsed time = 0.212352
Arrays match
zhuang4.S18@tiger:~/Zhenru1993/Code/S18$ ./MaxCol 1024 8
Elapsed time = 0.223744
Arrays match
zhuang4.S18@tiger:~/Zhenru1993/Code/S18$ ./MaxCol 1024 8
Elapsed time = 0.229440
Arrays match
zhuang4.S18@tiger:~/Zhenru1993/Code/S18$ ./MaxCol 1024 8
Elapsed time = 0.228448
Arrays match
```

```
zhuang4.S18@tiger:~/Zhenru1993/Code/S18$ ./MaxCol 1024 16
Elapsed time = 0.209952
Arrays match
zhuang4.S18@tiger:~/Zhenru1993/Code/S18$ ./MaxCol 1024 16
Elapsed time = 0.210656
Arrays match
zhuang4.S18@tiger:~/Zhenru1993/Code/S18$ ./MaxCol 1024 16
Elapsed time = 0.226336
Arrays match
zhuang4.S18@tiger:~/Zhenru1993/Code/S18$ ./MaxCol 1024 16
Elapsed time = 0.210432
Arrays match
zhuang4.S18@tiger:~/Zhenru1993/Code/S18$ ./MaxCol 1024 16
Elapsed time = 0.225440
Arrays match
```

```
zhuang4.S18@tiger:~/Zhenru1993/Code/S18$ ./MaxCol 1024 32
Elapsed time = 0.222304
Arrays match
zhuang4.S18@tiger:~/Zhenru1993/Code/S18$ ./MaxCol 1024 32
Elapsed time = 0.224032
Arrays match
zhuang4.S18@tiger:~/Zhenru1993/Code/S18$ ./MaxCol 1024 32
Elapsed time = 0.222976
Arrays match
zhuang4.S18@tiger:~/Zhenru1993/Code/S18$ ./MaxCol 1024 32
Elapsed time = 0.209440
Arrays match
zhuang4.S18@tiger:~/Zhenru1993/Code/S18$ ./MaxCol 1024 32
Elapsed time = 0.211936
Arrays match
```

```
zhuang4.S18@tiger:~/Zhenru1993/Code/S18$ ./MaxCol 1024 64
Elapsed time = 0.212800
Arrays match
zhuang4.S18@tiger:~/Zhenru1993/Code/S18$ ./MaxCol 1024 64
Elapsed time = 0.209728
Arrays match
zhuang4.S18@tiger:~/Zhenru1993/Code/S18$ ./MaxCol 1024 64
Elapsed time = 0.226432
Arrays match
zhuang4.S18@tiger:~/Zhenru1993/Code/S18$ ./MaxCol 1024 64
Elapsed time = 0.209280
Arrays match
zhuang4.S18@tiger:~/Zhenru1993/Code/S18$ ./MaxCol 1024 64
Elapsed time = 0.226112
Arrays match
```

```
zhuang4.S18@tiger:~/Zhenru1993/Code/S18$ ./MaxCol 1024 128
Elapsed time = 0.211648
Arrays match
zhuang4.S18@tiger:~/Zhenru1993/Code/S18$ ./MaxCol 1024 128
Elapsed time = 0.211168
Arrays match
zhuang4.S18@tiger:~/Zhenru1993/Code/S18$ ./MaxCol 1024 128
Elapsed time = 0.268352
Arrays match
zhuang4.S18@tiger:~/Zhenru1993/Code/S18$ ./MaxCol 1024 128
Elapsed time = 0.225984
Arrays match
zhuang4.S18@tiger:~/Zhenru1993/Code/S18$ ./MaxCol 1024 128
Elapsed time = 0.225696
Arrays match
```

```
zhuang4.S18@tiger:~/Zhenru1993/Code/S18$ ./MaxCol 2048 8
Elapsed time = 0.622624
Arrays match
zhuang4.S18@tiger:~/Zhenru1993/Code/S18$ ./MaxCol 2048 8
Elapsed time = 0.623840
Arrays match
zhuang4.S18@tiger:~/Zhenru1993/Code/S18$ ./MaxCol 2048 8
Elapsed time = 0.623840
Arrays match
zhuang4.S18@tiger:~/Zhenru1993/Code/S18$ ./MaxCol 2048 8
Elapsed time = 0.611392
Arrays match
zhuang4.S18@tiger:~/Zhenru1993/Code/S18$ ./MaxCol 2048 8
Elapsed time = 0.626784
Arrays match
```

```
zhuang4.S18@tiger:~/Zhenru1993/Code/S18$ ./MaxCol 2048 16
Elapsed time = 0.372384
Arrays match
zhuang4.S18@tiger:~/Zhenru1993/Code/S18$ ./MaxCol 2048 16
Elapsed time = 0.359808
Arrays match
zhuang4.S18@tiger:~/Zhenru1993/Code/S18$ ./MaxCol 2048 16
Elapsed time = 0.373120
Arrays match
zhuang4.S18@tiger:~/Zhenru1993/Code/S18$ ./MaxCol 2048 16
Elapsed time = 0.369632
Arrays match
zhuang4.S18@tiger:~/Zhenru1993/Code/S18$ ./MaxCol 2048 16
Elapsed time = 0.357824
Arrays match
```

```
Elapsed time = 0.368160
Arrays match
zhuang4.S18@tiger:~/Zhenru1993/Code/S18$ ./MaxCol 2048 32
Elapsed time = 0.352768
Arrays match
zhuang4.S18@tiger:~/Zhenru1993/Code/S18$ ./MaxCol 2048 32
Elapsed time = 0.366720
Arrays match
zhuang4.S18@tiger:~/Zhenru1993/Code/S18$ ./MaxCol 2048 32
Elapsed time = 0.365152
Arrays match
zhuang4.S18@tiger:~/Zhenru1993/Code/S18$ ./MaxCol 2048 32
Elapsed time = 0.365216
Arrays match
```

```
zhuang4.S18@tiger:~/Zhenru1993/Code/S18$ ./MaxCol 2048 64
Elapsed time = 0.371680
Arrays match
zhuang4.S18@tiger:~/Zhenru1993/Code/S18$ ./MaxCol 2048 64
Elapsed time = 0.356320
Arrays match
zhuang4.S18@tiger:~/Zhenru1993/Code/S18$ ./MaxCol 2048 64
Elapsed time = 0.354400
Arrays match
zhuang4.S18@tiger:~/Zhenru1993/Code/S18$ ./MaxCol 2048 64
Elapsed time = 0.354144
Arrays match
zhuang4.S18@tiger:~/Zhenru1993/Code/S18$ ./MaxCol 2048 64
Elapsed time = 0.355008
Arrays match
```

```
zhuang4.S18@tiger:~/Zhenru1993/Code/S18$ ./MaxCol 2048 128
Elapsed time = 0.355264
Arrays match
zhuang4.S18@tiger:~/Zhenru1993/Code/S18$ ./MaxCol 2048 128
Elapsed time = 0.356352
Arrays match
zhuang4.S18@tiger:~/Zhenru1993/Code/S18$ ./MaxCol 2048 128
Elapsed time = 0.371616
Arrays match
zhuang4.S18@tiger:~/Zhenru1993/Code/S18$ ./MaxCol 2048 128
Elapsed time = 0.369248
Arrays match
zhuang4.S18@tiger:~/Zhenru1993/Code/S18$ ./MaxCol 2048 128
Elapsed time = 0.352768
Arrays match
```

```
zhuang4.S18@tiger:~/Zhenru1993/Code/S18$ ./MaxCol 4096 8
Elapsed time = 1.711680
Arrays match
zhuang4.S18@tiger:~/Zhenru1993/Code/S18$ ./MaxCol 4096 8
Elapsed time = 1.717120
Arrays match
zhuang4.S18@tiger:~/Zhenru1993/Code/S18$ ./MaxCol 4096 8
Elapsed time = 1.710592
Arrays match
zhuang4.S18@tiger:~/Zhenru1993/Code/S18$ ./MaxCol 4096 8
Elapsed time = 1.725408
Arrays match
zhuang4.S18@tiger:~/Zhenru1993/Code/S18$ ./MaxCol 4096 8
Elapsed time = 1.724864
Arrays match
```

```
zhuang4.S18@tiger:~/Zhenru1993/Code/S18$ ./MaxCol 4096 16
Elapsed time = 1.180480
Arrays match
zhuang4.S18@tiger:~/Zhenru1993/Code/S18$ ./MaxCol 4096 16
Elapsed time = 1.174912
Arrays match
zhuang4.S18@tiger:~/Zhenru1993/Code/S18$ ./MaxCol 4096 16
Elapsed time = 1.164672
Arrays match
zhuang4.S18@tiger:~/Zhenru1993/Code/S18$ ./MaxCol 4096 16
Elapsed time = 1.179168
Arrays match
zhuang4.S18@tiger:~/Zhenru1993/Code/S18$ ./MaxCol 4096 16
Elapsed time = 1.179552
Arrays match
```

```
zhuang4.S18@tiger:~/Zhenru1993/Code/S18$ ./MaxCol 4096 32
Elapsed time = 0.662848
Arrays match
zhuang4.S18@tiger:~/Zhenru1993/Code/S18$ ./MaxCol 4096 32
Elapsed time = 0.660928
Arrays match
zhuang4.S18@tiger:~/Zhenru1993/Code/S18$ ./MaxCol 4096 32
Elapsed time = 0.641792
Arrays match
zhuang4.S18@tiger:~/Zhenru1993/Code/S18$ ./MaxCol 4096 32
Elapsed time = 0.646816
Arrays match
zhuang4.S18@tiger:~/Zhenru1993/Code/S18$ ./MaxCol 4096 32
Elapsed time = 0.662432
Arrays match
```

```
zhuang4.S18@tiger:~/Zhenru1993/Code/S18$ ./MaxCol 4096 64
Elapsed time = 0.664736
Arrays match
zhuang4.S18@tiger:~/Zhenru1993/Code/S18$ ./MaxCol 4096 64
Elapsed time = 0.663296
Arrays match
zhuang4.S18@tiger:~/Zhenru1993/Code/S18$ ./MaxCol 4096 64
Elapsed time = 0.662880
Arrays match
zhuang4.S18@tiger:~/Zhenru1993/Code/S18$ ./MaxCol 4096 64
Elapsed time = 0.649344
Arrays match
zhuang4.S18@tiger:~/Zhenru1993/Code/S18$ ./MaxCol 4096 64
Elapsed time = 0.668160
Arrays match
```

Part b

Code:

```
#include <stdio.h>

#include <math.h>

#include <stdlib.h>

#include <cuda.h>


#define NUMPARTICLES 32768  //change for different size particles

#define NEIGHBORHOOD .05

#define THREADSPERBLOCK 128  //change for different size threads


void initPos(float *);

float findDistance(float *, int, int);

__device__ float findDistanceGPU(float *, int, int);

void dumpResults(int index[]);


__global__ void findRedsGPU(float *p, int *numI);


int main() {
    cudaEvent_t start, stop;
```

```
float time;

float *pos,   //host pos
    *dpos;  //device pos
int *numReds,   //host numReds
    *dnumReds;  //device numReds

pos = (float *) malloc(NUMPARTICLES * 4 * sizeof(float));
numReds = (int *) malloc(NUMPARTICLES * sizeof(int));

initPos(pos);

// your code to allocate device arrays for pos and numReds go here

// allocate space for device pos
cudaMalloc((void **)&dpos,NUMPARTICLES * 4 * sizeof(float));
// allocate space for device numReds
cudaMalloc((void **)&dnumReds,NUMPARTICLES * sizeof(int));

// copy host pos to device pos
cudaMemcpy(dpos,pos,NUMPARTICLES * 4 * sizeof(float),cudaMemcpyHostToDevice);
// copy host numReds to device numReds
//cudaMemcpy(dnumReds,numReds,NUMPARTICLES * sizeof(int),cudaMemcpyHostToDevice);

// create timer events
```

```
    cudaEventCreate(&start);

    cudaEventCreate(&stop);


    cudaEventRecord(start, 0);


    /* invoke kernel findRedsGPU here */

findRedsGPU<<<NUMPARTICLES/THREADSPERBLOCK,THREADSPERBLOCK>>>(dpos,dnumReds);
    // wait for kernel to finish

    cudaThreadSynchronize();


    // your code to copy results to numReds[] go here

    cudaMemcpy(numReds,dnumReds,NUMPARTICLES * sizeof(int),cudaMemcpyDeviceToHost);




    cudaEventRecord(stop, 0);

    cudaEventSynchronize(stop);

    cudaEventElapsedTime(&time, start, stop);


    printf("Elapsed time = %f\n", time);


    dumpResults(numReds);

}

void initPos(float *p) {
```

```
// your code for initializing pos goes here

int i;

int roll;

for (i=0; i<NUMPARTICLES; i++) {

    p[i*4] = rand() / (float) RAND_MAX;

    p[i*4+1] = rand() / (float) RAND_MAX;

    p[i*4+2] = rand() / (float) RAND_MAX;

    roll = rand() % 3;

    if (roll == 0)

        p[i*4+3] = 0xff0000;

    else if (roll == 1)

        p[i*4+3] = 0x00ff00;

    else

        p[i*4+3] = 0x0000ff;

}


}


__device__ float findDistanceGPU(float *p, int i, int j) {


// your code for calculating distance for particle i and j

float dx, dy, dz;


dx = p[i*4] - p[j*4];

dy = p[i*4+1] - p[j*4+1];

dz = p[i*4+2] - p[j*4+2];
```

```
      return(sqrt(dx*dx + dy*dy + dz*dz));


}


__global__ void findRedsGPU(float *p, int *numI) {


   // your code for counting red particles goes here
   int i = blockDim.x * blockIdx.x + threadIdx.x;
   int j;
   float distance;


   numI[i] = 0;
   for (j=0; j<NUMPARTICLES; j++) {
      if (i!=j) {
         /* calculate distance between particles i, j */
         distance = findDistanceGPU(p, i, j);
         /* if distance < r and color is red, increment count */
         if (distance < NEIGHBORHOOD && p[j*4+3] == 0xff0000) {
            numI[i]++;
         }
      }
   }


}
```

```
void dumpResults(int index[]) {

    int i;

    FILE *fp;


    fp = fopen("./dump.out", "w");


    for (i=0; i<NUMPARTICLES; i++) {

        fprintf(fp, "%d %d\n", i, index[i]);

    }


    fclose(fp);

}
```

Table:

CPU:

	time
1024 particles	29.44166667
8192 particles	1794.69533
32768 particles	28479.96233

GPU:

	4 threads	16 threads	64 threads
1024 particles	1.549738667	0.875477333	0.889290667
8192 particles	50.565099	19.58269833	8.844949333
32768 particles	711.6950073	216.8075613	134.0779393

Data:

CPU:

1024 particles: 8192 particles:

```
zhuang4.S18@tiger:~/Zhenru1993/Code/S18$ ./findReds  zhuang4.S18@tiger:~/Zhenru1993/Code/S18$ ./findReds
Elapsed CPU time = 30.393000 ms                      Elapsed CPU time = 1794.538000 ms
zhuang4.S18@tiger:~/Zhenru1993/Code/S18$ ./findReds  zhuang4.S18@tiger:~/Zhenru1993/Code/S18$ ./findReds
Elapsed CPU time = 29.214000 ms                      Elapsed CPU time = 1791.982000 ms
zhuang4.S18@tiger:~/Zhenru1993/Code/S18$ ./findReds  zhuang4.S18@tiger:~/Zhenru1993/Code/S18$ ./findReds
Elapsed CPU time = 29.285000 ms                      Elapsed CPU time = 1797.566000 ms
zhuang4.S18@tiger:~/Zhenru1993/Code/S18$ ./findReds  zhuang4.S18@tiger:~/Zhenru1993/Code/S18$ ./findReds
Elapsed CPU time = 29.826000 ms                      Elapsed CPU time = 1769.716000 ms
zhuang4.S18@tiger:~/Zhenru1993/Code/S18$ ./findReds  zhuang4.S18@tiger:~/Zhenru1993/Code/S18$ ./findReds
Elapsed CPU time = 28.616000 ms                      Elapsed CPU time = 1799.133000 ms
```

32768 particles:

```
zhuang4.S18@tiger:~/Zhenru1993/Code/S18$ ./findReds
Elapsed CPU time = 28482.358000 ms
zhuang4.S18@tiger:~/Zhenru1993/Code/S18$ ./findReds
Elapsed CPU time = 28483.023000 ms
zhuang4.S18@tiger:~/Zhenru1993/Code/S18$ ./findReds
Elapsed CPU time = 28474.506000 ms
zhuang4.S18@tiger:~/Zhenru1993/Code/S18$ ./findReds
Elapsed CPU time = 28964.302000 ms
zhuang4.S18@tiger:~/Zhenru1993/Code/S18$ ./findReds
Elapsed CPU time = 28430.406000 ms
```

GPU:

1024 particles, 4 threads: 1024 particles, 16 threads:

```
zhuang4.S18@tiger:~/Zhenru1993/Code/S18$ ./findRedsGPU  zhuang4.S18@tiger:~/Zhenru1993/Code/S18$ ./findRedsGPU
Elapsed time = 1.564736                                 Elapsed time = 0.871328
zhuang4.S18@tiger:~/Zhenru1993/Code/S18$ ./findRedsGPU  zhuang4.S18@tiger:~/Zhenru1993/Code/S18$ ./findRedsGPU
Elapsed time = 1.543776                                 Elapsed time = 0.878016
zhuang4.S18@tiger:~/Zhenru1993/Code/S18$ ./findRedsGPU  zhuang4.S18@tiger:~/Zhenru1993/Code/S18$ ./findRedsGPU
Elapsed time = 1.553408                                 Elapsed time = 0.875904
zhuang4.S18@tiger:~/Zhenru1993/Code/S18$ ./findRedsGPU  zhuang4.S18@tiger:~/Zhenru1993/Code/S18$ ./findRedsGPU
Elapsed time = 1.543232                                 Elapsed time = 0.875904
zhuang4.S18@tiger:~/Zhenru1993/Code/S18$ ./findRedsGPU  zhuang4.S18@tiger:~/Zhenru1993/Code/S18$ ./findRedsGPU
Elapsed time = 1.552032                                 Elapsed time = 0.874624
```

1024 particles, 64 threads: 8192 particles, 4 threads:

```
zhuang4.S18@tiger:~/Zhenru1993/Code/S18$ ./findRedsGPU  zhuang4.S18@tiger:~/Zhenru1993/Code/S18$ ./findRedsGPU
Elapsed time = 0.889120                                 Elapsed time = 53.431007
zhuang4.S18@tiger:~/Zhenru1993/Code/S18$ ./findRedsGPU  zhuang4.S18@tiger:~/Zhenru1993/Code/S18$ ./findRedsGPU
Elapsed time = 0.888768                                 Elapsed time = 44.933407
zhuang4.S18@tiger:~/Zhenru1993/Code/S18$ ./findRedsGPU  zhuang4.S18@tiger:~/Zhenru1993/Code/S18$ ./findRedsGPU
Elapsed time = 0.889984                                 Elapsed time = 44.980225
zhuang4.S18@tiger:~/Zhenru1993/Code/S18$ ./findRedsGPU  zhuang4.S18@tiger:~/Zhenru1993/Code/S18$ ./findRedsGPU
Elapsed time = 0.884704                                 Elapsed time = 53.315681
zhuang4.S18@tiger:~/Zhenru1993/Code/S18$ ./findRedsGPU  zhuang4.S18@tiger:~/Zhenru1993/Code/S18$ ./findRedsGPU
Elapsed time = 0.893408                                 Elapsed time = 53.399391
```

8192 particles, 16 threads: 8192 particles, 64 threads:

```
zhuang4.S18@tiger:~/Zhenru1993/Code/S18$ ./findRedsGPU
Elapsed time = 19.610241
zhuang4.S18@tiger:~/Zhenru1993/Code/S18$ ./findRedsGPU
Elapsed time = 19.588608
zhuang4.S18@tiger:~/Zhenru1993/Code/S18$ ./findRedsGPU
Elapsed time = 19.579231
zhuang4.S18@tiger:~/Zhenru1993/Code/S18$ ./findRedsGPU
Elapsed time = 19.580256
zhuang4.S18@tiger:~/Zhenru1993/Code/S18$ ./findRedsGPU
Elapsed time = 19.576672
```

```
zhuang4.S18@tiger:~/Zhenru1993/Code/S18$ ./findRedsGPU
Elapsed time = 8.838592
zhuang4.S18@tiger:~/Zhenru1993/Code/S18$ ./findRedsGPU
Elapsed time = 8.867936
zhuang4.S18@tiger:~/Zhenru1993/Code/S18$ ./findRedsGPU
Elapsed time = 8.832576
zhuang4.S18@tiger:~/Zhenru1993/Code/S18$ ./findRedsGPU
Elapsed time = 8.846624
zhuang4.S18@tiger:~/Zhenru1993/Code/S18$ ./findRedsGPU
Elapsed time = 8.849632
```

32768 particles, 4 threads: 32768 particles, 16 threads:

```
zhuang4.S18@tiger:~/Zhenru1993/Code/S18$ ./findRedsGPU
Elapsed time = 753.994324
zhuang4.S18@tiger:~/Zhenru1993/Code/S18$ ./findRedsGPU
Elapsed time = 711.641113
zhuang4.S18@tiger:~/Zhenru1993/Code/S18$ ./findRedsGPU
Elapsed time = 711.614746
zhuang4.S18@tiger:~/Zhenru1993/Code/S18$ ./findRedsGPU
Elapsed time = 711.753540
zhuang4.S18@tiger:~/Zhenru1993/Code/S18$ ./findRedsGPU
Elapsed time = 711.690369
```

```
zhuang4.S18@tiger:~/Zhenru1993/Code/S18$ ./findRedsGPU
Elapsed time = 227.802750
zhuang4.S18@tiger:~/Zhenru1993/Code/S18$ ./findRedsGPU
Elapsed time = 233.808060
zhuang4.S18@tiger:~/Zhenru1993/Code/S18$ ./findRedsGPU
Elapsed time = 216.782242
zhuang4.S18@tiger:~/Zhenru1993/Code/S18$ ./findRedsGPU
Elapsed time = 205.837692
zhuang4.S18@tiger:~/Zhenru1993/Code/S18$ ./findRedsGPU
Elapsed time = 205.623398
```

32768 particles, 64 threads:

```
zhuang4.S18@tiger:~/Zhenru1993/Code/S18$ ./findRedsGPU
Elapsed time = 150.651932
zhuang4.S18@tiger:~/Zhenru1993/Code/S18$ ./findRedsGPU
Elapsed time = 145.079422
zhuang4.S18@tiger:~/Zhenru1993/Code/S18$ ./findRedsGPU
Elapsed time = 130.556732
zhuang4.S18@tiger:~/Zhenru1993/Code/S18$ ./findRedsGPU
Elapsed time = 126.597664
zhuang4.S18@tiger:~/Zhenru1993/Code/S18$ ./findRedsGPU
Elapsed time = 126.110687
```

Conclusion:

As we can, multi threads with GPU really can increase the performance of our program. However, this increment has its limit. Once the limit is reached adding more threads will not help to increase the performance any more. And also, as the complexity of the program increase, this limit will increase also.