SEM - VII - 2022-23

High Performance Computing Lab

Assignment - 10

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Problem Statement 1:

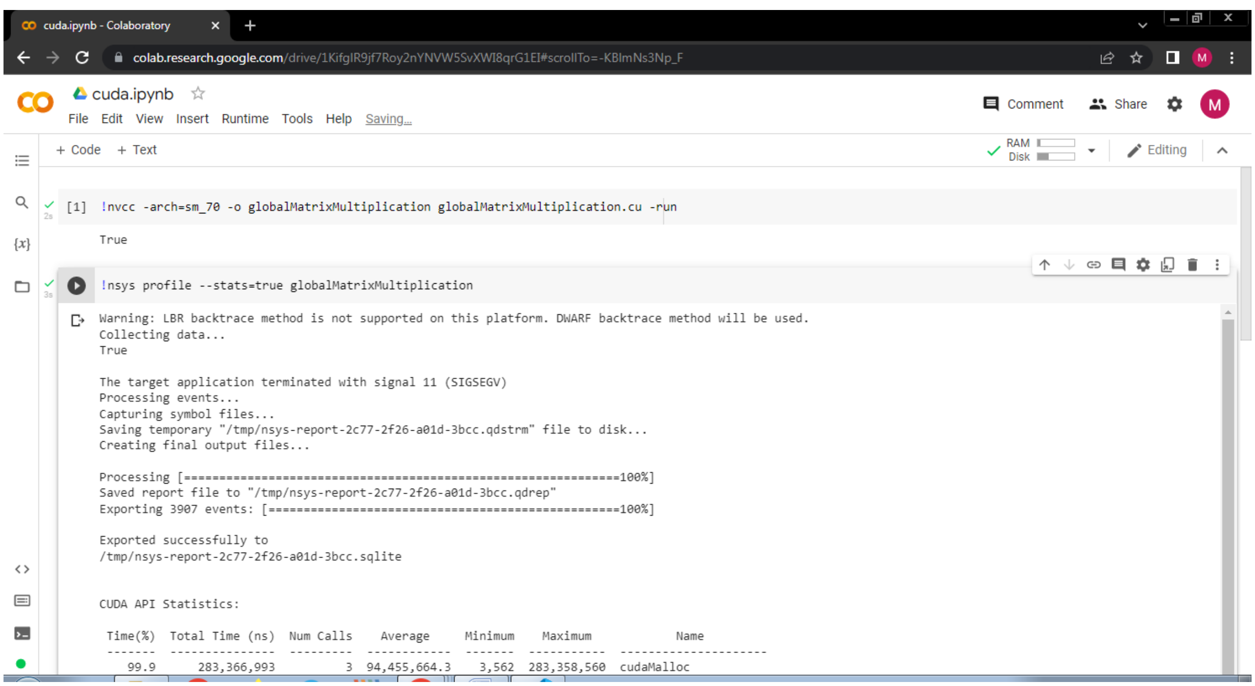
Implement Matrix-matrix Multiplication using global memory in CUDA C. Analyze and tune the program for getting maximum speed up. Do Profiling and state what part of the code takes the huge amount of time to execute.

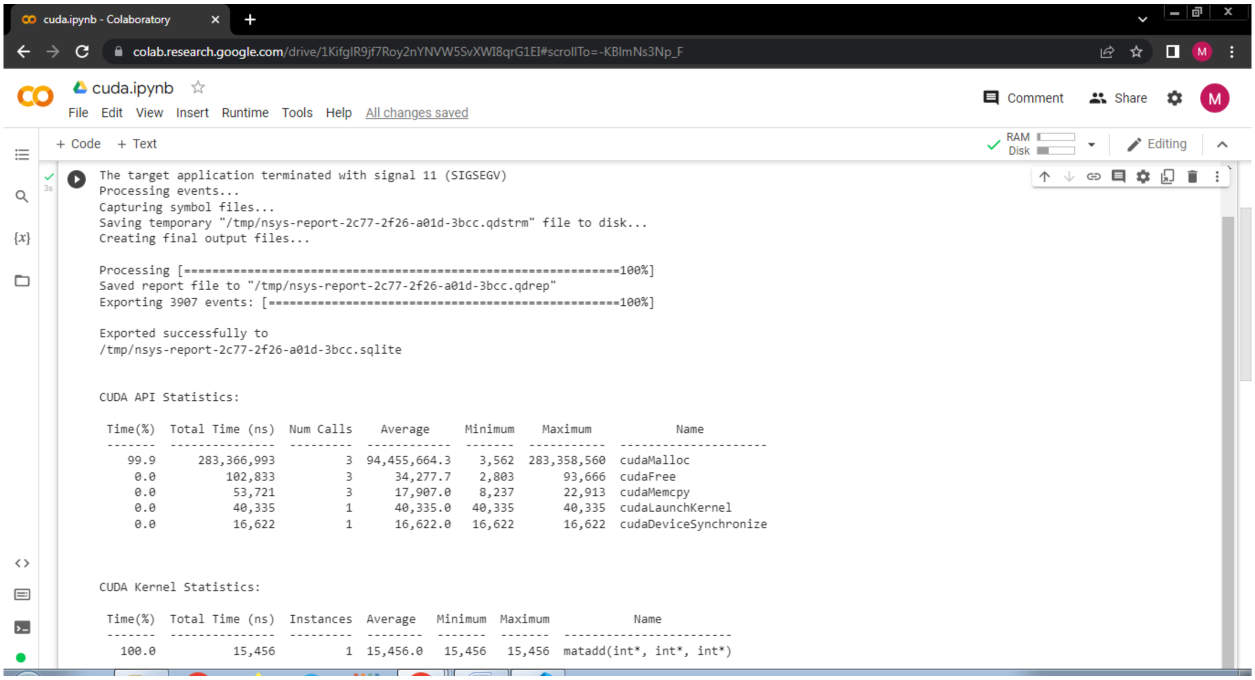
```
#include <stdio.h>

#define row1 20

#define col1 30

#define row2 30

#define col2 20

__global__ void matmul(int *l, int *m, int *n)

{

  int x = threadIdx.x;

  int y = threadIdx.y;

  int k;

  n[col2 * y + x] = 0;

  for (k = 0; k < col1; k++)
```

```
  {
      n[col2 * y + x] = n[col2 * y + x] + l[col1 * y + k] * m[col2 * k + x];
  }
}
int main()
{
  int a[row1][col1];
  int b[row2][col2];
  int c[row1][col2];
  int *d, *e, *f;
  int i, j;
  for (i = 0; i < row1; i++)
  {
      for (j = 0; j < col1; j++)
      {
          a[i][j] = 2;
      }
  }

  for (i = 0; i < row2; i++)
  {
```

```
    for (j = 0; j < col2; j++)
    {
        b[i][j] = 3;
    }
}
cudaMalloc((void **)&d, row1 * col1 * sizeof(int));
cudaMalloc((void **)&e, row2 * col2 * sizeof(int));
cudaMalloc((void **)&f, row1 * col2 * sizeof(int));
cudaMemcpy(d, a, row1 * col1 * sizeof(int), cudaMemcpyHostToDevice);
cudaMemcpy(e, b, row2 * col2 * sizeof(int), cudaMemcpyHostToDevice);
dim3 threadBlock(col2, row1);
matmul<<<1, threadBlock>>>(d, e, f);
cudaDeviceSynchronize();
cudaMemcpy(c, f, row1 * col2 * sizeof(int), cudaMemcpyDeviceToHost);
for (i = 0; i < row1; i++)
{
    for (j = 0; j < col2; j++)
    {
        if (c[i][j] != 180)
        {
            printf("False\n");
```

```
        return -1;
      }
    }
  }
  cudaFree(d);
  cudaFree(e);
  cudaFree(f);
  printf("True\n");
  return 0;
}
```





Problem Statement 2:

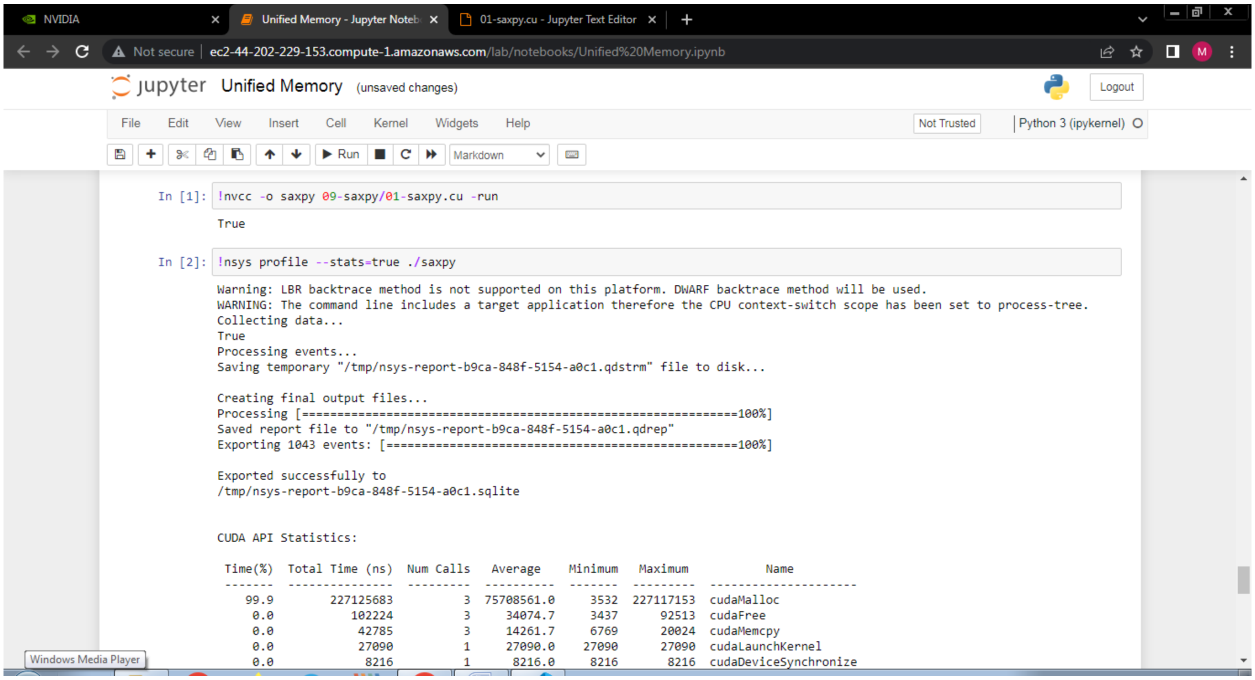
Implement Matrix-Matrix Multiplication using shared memory in CUDA C. Analyze and tune the program for getting maximum speed up. Do Profiling and state what part of the code takes the huge amount of time to execute.

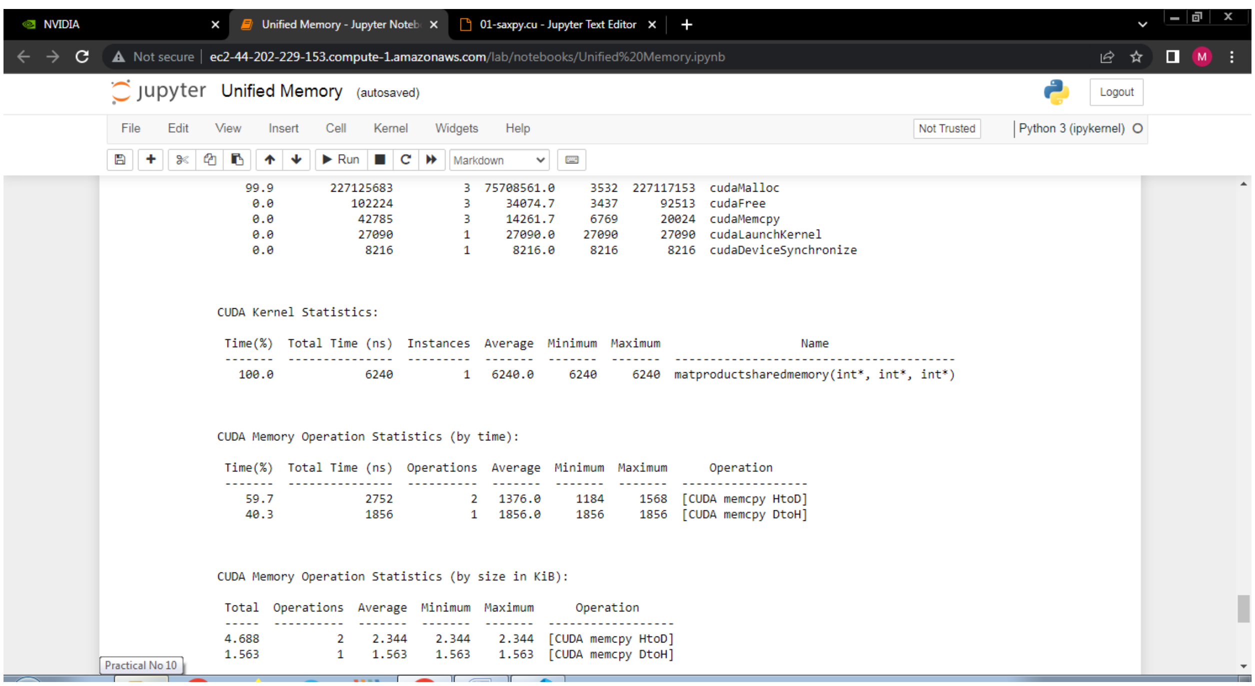
```
#include <stdio.h>

#define row1 20

#define col1 30

#define row2 30

#define col2 20

__global__ void matproductsharedmemory(int *l, int *m, int *n)

{

  int x = blockIdx.x;
```

```
  int y = blockIdx.y;

  __shared__ int p[col1];

  int i;

  int k = threadIdx.x;

  n[col2 * y + x] = 0;

  p[k] = l[col1 * y + k] * m[col2 * k + x];

  __syncthreads();

  for (i = 0; i < col1; i++)

      n[col2 * y + x] = n[col2 * y + x] + p[i];

}

int main()

{

  int a[row1][col1];

  int b[row2][col2];

  int c[row1][col2];

  int *d, *e, *f;

  int i, j;

  for (i = 0; i < row1; i++)

  {

      for (j = 0; j < col1; j++)

      {
```

```
        a[i][j] = 2;

    }

}

for (i = 0; i < row2; i++)

{

    for (j = 0; j < col2; j++)

    {

        b[i][j] = 3;

    }

}

cudaMalloc((void **)&d, row1 * col1 * sizeof(int));

cudaMalloc((void **)&e, row2 * col2 * sizeof(int));

cudaMalloc((void **)&f, row1 * col2 * sizeof(int));

cudaMemcpy(d, a, row1 * col1 * sizeof(int), cudaMemcpyHostToDevice);

cudaMemcpy(e, b, row2 * col2 * sizeof(int), cudaMemcpyHostToDevice);

dim3 grid(col2, row1);

matproductsharedmemory<<<grid, col1>>>(d, e, f);

cudaDeviceSynchronize();

cudaMemcpy(c, f, row1 * col2 * sizeof(int), cudaMemcpyDeviceToHost);

for (i = 0; i < row1; i++)

{
```

```
    for (j = 0; j < col2; j++)

    {

        if (c[i][j] != 180)

        {

            printf("False\n");

            return -1;

        }

    }

  }

  cudaFree(d);

  cudaFree(e);

  cudaFree(f);

  printf("True\n");

  return 0;

}
```





Problem Statement 3:

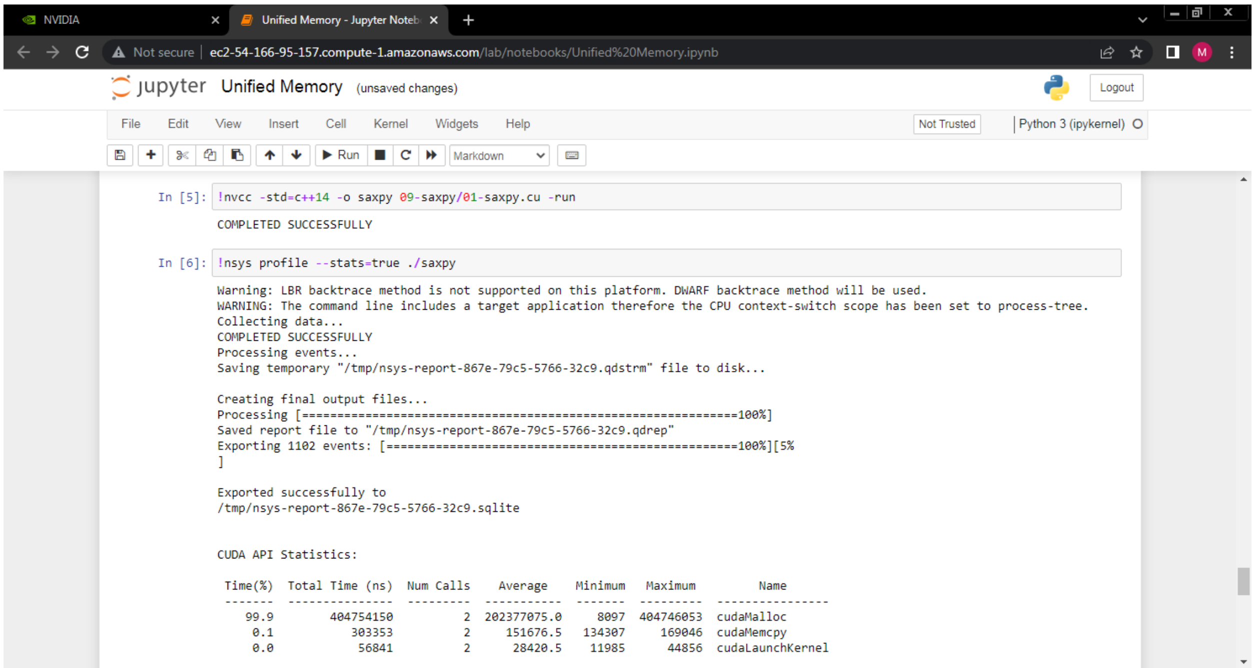
Implement Prefix sum using CUDA C. Analyze and tune the program for getting maximum speed up. Do Profiling and state what part of the code takes the huge amount of time to execute.

```
// This program computes prefix sum with warp divergence

#include <bits/stdc++.h>

using std::accumulate;

using std::generate;

using std::cout;

using std::vector;

#define SHMEM_SIZE 256

__global__ void prefixSum(int *v, int *v_r) {

  // Allocate shared memory

  __shared__ int partial_sum[SHMEM_SIZE];

  // Calculate thread ID

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

  // Load elements into shared memory

  partial_sum[threadIdx.x] = v[tid];

  __syncthreads();

  // Iterate of log base 2 the block dimension

  for (int s = 1; s < blockDim.x; s *= 2) {

    // Reduce the threads performing work by half previous the previous
```

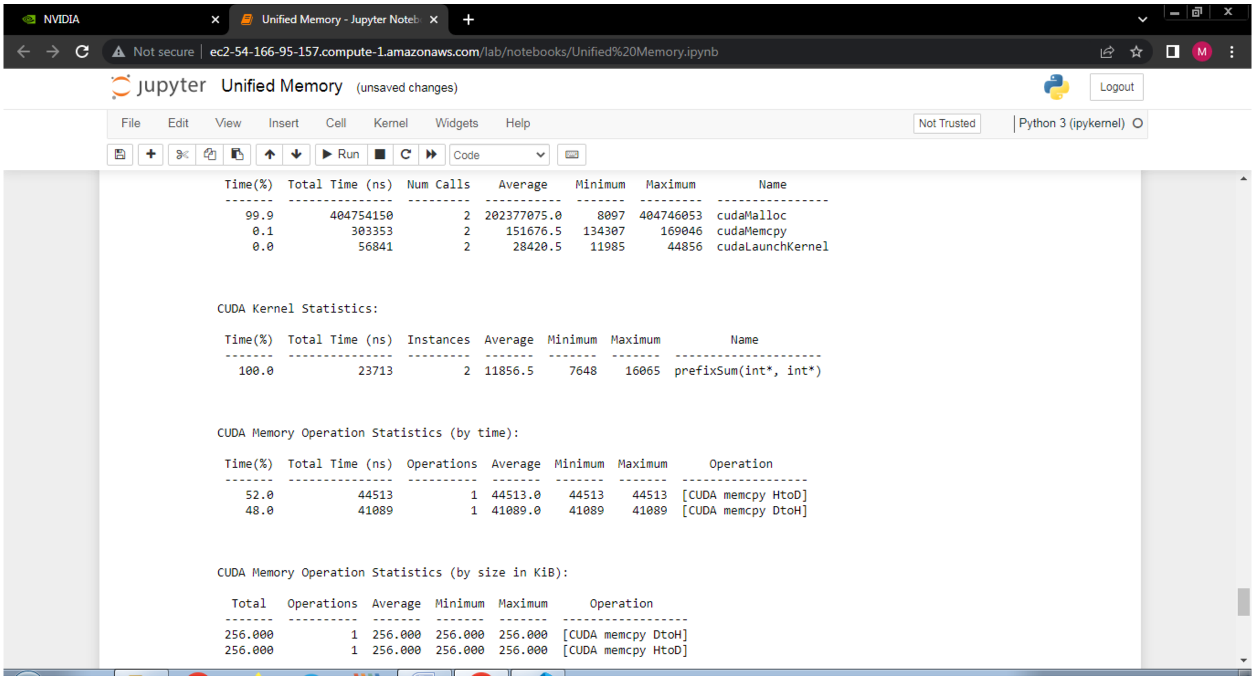
```
    // iteration each cycle
    if (threadIdx.x % (2 * s) == 0) {
        partial_sum[threadIdx.x] += partial_sum[threadIdx.x + s];
    }
    __syncthreads();
  }
  // Let the thread 0 for this block write it's result to main memory
  // Result is inexed by this block
  if (threadIdx.x == 0) {
    v_r[blockIdx.x] = partial_sum[0];
  }
}
int main() {
  // Vector size
  int N = 1 << 16;
  size_t bytes = N * sizeof(int);
  // Host data
  vector<int> h_v(N);
  vector<int> h_v_r(N);
 // Initialize the input data
 generate(begin(h_v), end(h_v), [](){ return rand() % 10; });
```

```
// Allocate device memory

int *d_v, *d_v_r;

cudaMalloc(&d_v, bytes);

cudaMalloc(&d_v_r, bytes);



// Copy to device

cudaMemcpy(d_v, h_v.data(), bytes, cudaMemcpyHostToDevice);



// TB Size

const int TB_SIZE = 256;

// Grid Size (No padding)

int GRID_SIZE = N / TB_SIZE;

// Call kernels

prefixSum<<<GRID_SIZE, TB_SIZE>>>(d_v, d_v_r);

prefixSum<<<1, TB_SIZE>>> (d_v_r, d_v_r);

// Copy to host;

cudaMemcpy(h_v_r.data(), d_v_r, bytes, cudaMemcpyDeviceToHost);

// Print the result

assert(h_v_r[0] == std::accumulate(begin(h_v), end(h_v), 0));

cout << "COMPLETED SUCCESSFULLY\n";

return 0;
```

```
}
```



NVIDIA
Unified Memory - Jupyter Noteb
Not secure | ec2-54-166-95-157.compute-1.amazonaws.com/lab/notebooks/Unified%20Memory.ipynb
jupyter Unified Memory (unsaved changes)
Logout
File Edit View Insert Cell Kernel Widgets Help
Not Trusted
Python 3 (ipykernel)
Run
Markdown
In [5]: !nvcc -std=c++14 -o saxpy 09-saxpy/01-saxpy.cu -run
COMPLETED SUCCESSFULLY
In [6]: !nsys profile --stats=true ./saxpy
Warning: LBR backtrace method is not supported on this platform. DWARF backtrace method will be used.
WARNING: The command line includes a target application therefore the CPU context-switch scope has been set to process-tree.
Collecting data...
COMPLETED SUCCESSFULLY
Processing events...
Saving temporary "/tmp/nsys-report-867e-79c5-5766-32c9.qdstrm" file to disk...
Creating final output files...
Processing [==100%]
Saved report file to "/tmp/nsys-report-867e-79c5-5766-32c9.qdrep"
Exporting 1102 events: [===100%][5%
]
Exported successfully to
/tmp/nsys-report-867e-79c5-5766-32c9.sqlite
CUDA API Statistics:
Time(%) Total Time (ns) Num Calls Average Minimum Maximum Name
------- -------------- --------- ----------- ------- --------- ----------------
99.9 404754150 2 202377075.0 8097 404746053 cudaMalloc
0.1 303353 2 151676.5 134307 169046 cudaMemcpy
0.0 56841 2 28420.5 11985 44856 cudaLaunchKernel



```
 Time(%)  Total Time (ns)  Num Calls    Average    Minimum   Maximum         Name
 -------  ---------------  ---------  -----------  -------  ---------  ----------------
    99.9        404754150          2  202377075.0     8097  404746053  cudaMalloc
     0.1           303353          2     151676.5   134307     169046  cudaMemcpy
     0.0            56841          2      28420.5    11985      44856  cudaLaunchKernel


CUDA Kernel Statistics:

 Time(%)  Total Time (ns)  Instances  Average  Minimum  Maximum           Name
 -------  ---------------  ---------  -------  -------  -------  --------------------
   100.0            23713          2  11856.5     7648    16065  prefixSum(int*, int*)


CUDA Memory Operation Statistics (by time):

 Time(%)  Total Time (ns)  Operations  Average  Minimum  Maximum      Operation
 -------  ---------------  ----------  -------  -------  -------  ------------------
    52.0            44513           1  44513.0    44513    44513  [CUDA memcpy HtoD]
    48.0            41089           1  41089.0    41089    41089  [CUDA memcpy DtoH]


CUDA Memory Operation Statistics (by size in KiB):

  Total   Operations  Average  Minimum  Maximum      Operation
 -------  ----------  -------  -------  -------  ------------------
 256.000           1  256.000  256.000  256.000  [CUDA memcpy DtoH]
 256.000           1  256.000  256.000  256.000  [CUDA memcpy HtoD]
```

Problem Statement 4:

Implement 2D Convolution using shared memory using CUDA C. Analyze and tune the program for getting maximum speed up. Do Profiling and state what part of the code takes the huge amount of time to execute.

```
// This program implements 2D convolution in CUDA

#include <bits/stdc++.h>

// 7 x 7 convolutional mask

#define MASK_DIM 7

// Amount the the matrix will hang over the matrix

#define MASK_OFFSET (MASK_DIM / 2)

// Allocate mask in constant memory

__constant__ int mask[7 * 7];
```

```
// 2D Convolution Kernel
// Takes:
//  matrix: Input matrix
//  result: Convolution result
//  N:      Dimensions of the matrices
__global__ void convolution_2d(int *matrix, int *result, int N) {
 // Calculate the global thread positions
 int row = blockIdx.y * blockDim.y + threadIdx.y;
 int col = blockIdx.x * blockDim.x + threadIdx.x;
 // Starting index for calculation
 int start_r = row - MASK_OFFSET;
 int start_c = col - MASK_OFFSET;
 // Temp value for accumulating the result
 int temp = 0;
 // Iterate over all the rows
 for (int i = 0; i < MASK_DIM; i++) {
   // Go over each column
   for (int j = 0; j < MASK_DIM; j++) {
     // Range check for rows
     if ((start_r + i) >= 0 && (start_r + i) < N) {
       // Range check for columns
```

```
      if ((start_c + j) >= 0 && (start_c + j) < N) {
        // Accumulate result
        temp += matrix[(start_r + i) * N + (start_c + j)] *
                mask[i * MASK_DIM + j];
      }
    }
  }
 }
 // Write back the result
 result[row * N + col] = temp;
}
// Initializes an n x n matrix with random numbers
// Takes:
//  m : Pointer to the matrix
//  n : Dimension of the matrix (square)
void init_matrix(int *m, int n) {
 for (int i = 0; i < n; i++) {
   for (int j = 0; j < n; j++) {
     m[n * i + j] = rand() % 100;
   }
 }
```

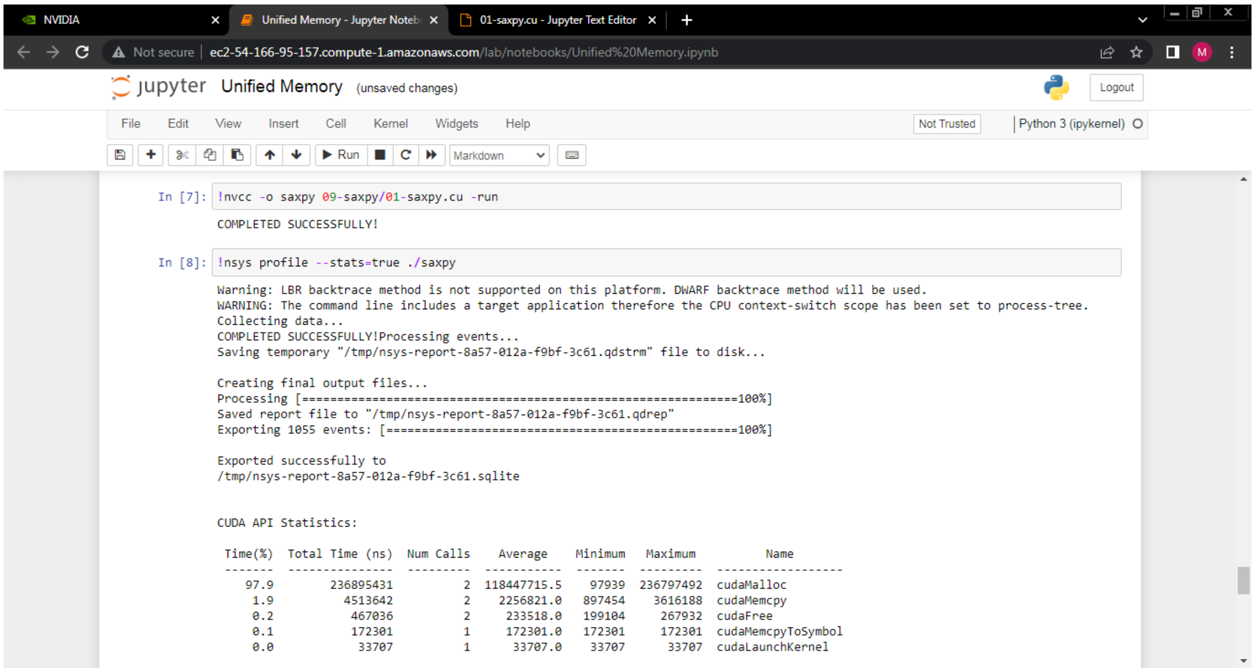
```
}
// Verifies the 2D convolution result on the CPU
// Takes:
//  m:      Original matrix
//  mask:   Convolutional mask
//  result: Result from the GPU
//  N:      Dimensions of the matrix
void verify_result(int *m, int *mask, int *result, int N) {
 // Temp value for accumulating results
 int temp;
 // Intermediate value for more readable code
 int offset_r;
 int offset_c;
 // Go over each row
 for (int i = 0; i < N; i++) {
  // Go over each column
  for (int j = 0; j < N; j++) {
   // Reset the temp variable
   temp = 0;
   // Go over each mask row
   for (int k = 0; k < MASK_DIM; k++) {
```

```
    // Update offset value for row
    offset_r = i - MASK_OFFSET + k;
    // Go over each mask column
    for (int l = 0; l < MASK_DIM; l++) {
      // Update offset value for column
      offset_c = j - MASK_OFFSET + l;
      // Range checks if we are hanging off the matrix
      if (offset_r >= 0 && offset_r < N) {
        if (offset_c >= 0 && offset_c < N) {
          // Accumulate partial results
          temp += m[offset_r * N + offset_c] * mask[k * MASK_DIM + l];
        }
      }
    }
   }
   // Fail if the results don't match
   assert(result[i * N + j] == temp);
  }
 }
}
int main() {
```

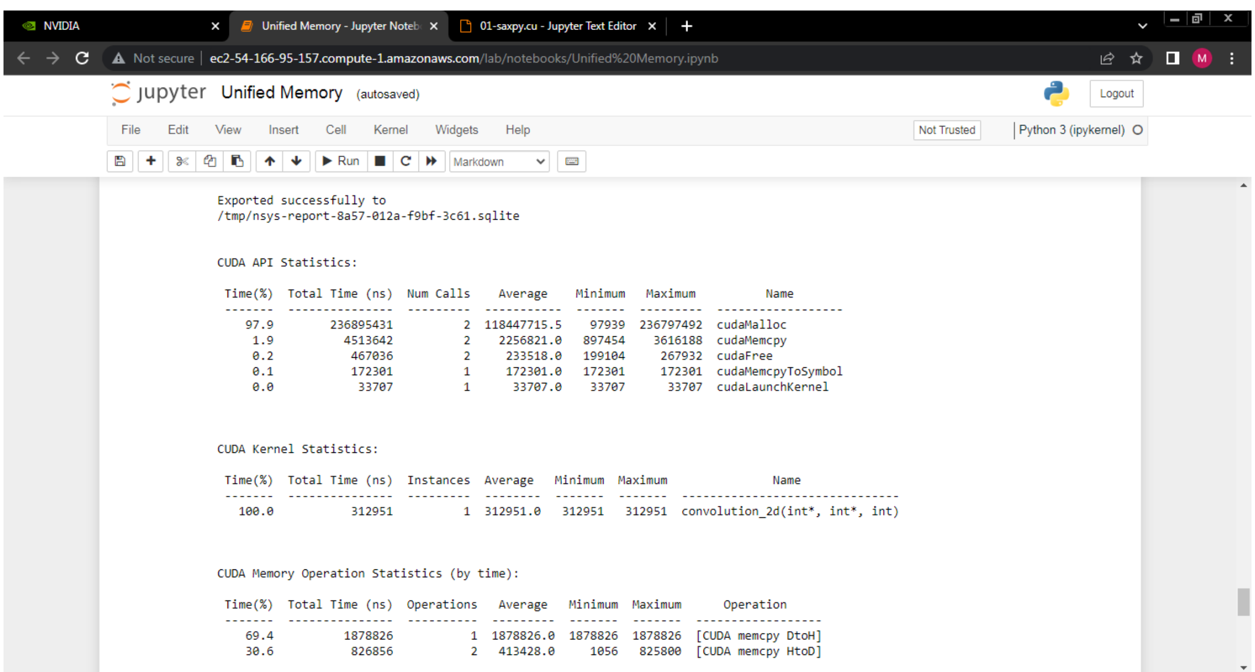
```
// Dimensions of the matrix (2 ^ 10 x 2 ^ 10)

int N = 1 << 10;

// Size of the matrix (in bytes)

size_t bytes_n = N * N * sizeof(int);

// Allocate the matrix and initialize it

int *matrix = new int[N * N];

int *result = new int[N * N];

init_matrix(matrix, N);

// Size of the mask in bytes

size_t bytes_m = MASK_DIM * MASK_DIM * sizeof(int);

// Allocate the mask and initialize it

int *h_mask = new int[MASK_DIM * MASK_DIM];

init_matrix(h_mask, MASK_DIM);

// Allocate device memory

int *d_matrix;

int *d_result;

cudaMalloc(&d_matrix, bytes_n);

cudaMalloc(&d_result, bytes_n);

// Copy data to the device

cudaMemcpy(d_matrix, matrix, bytes_n, cudaMemcpyHostToDevice);

cudaMemcpyToSymbol(mask, h_mask, bytes_m);
```

```
// Calculate grid dimensions

int THREADS = 16;

int BLOCKS = (N + THREADS - 1) / THREADS;

// Dimension launch arguments

dim3 block_dim(THREADS, THREADS);

dim3 grid_dim(BLOCKS, BLOCKS);

// Perform 2D Convolution

convolution_2d<<<grid_dim, block_dim>>>(d_matrix, d_result, N);

// Copy the result back to the CPU

cudaMemcpy(result, d_result, bytes_n, cudaMemcpyDeviceToHost);

// Functional test

verify_result(matrix, h_mask, result, N);

std::cout << "COMPLETED SUCCESSFULLY!";

// Free the memory we allocated

delete[] matrix;

delete[] result;

delete[] h_mask;

cudaFree(d_matrix);

cudaFree(d_result);

return 0;

}
```

[redacted]




```
In [7]: !nvcc -o saxpy 09-saxpy/01-saxpy.cu -run

COMPLETED SUCCESSFULLY!

In [8]: !nsys profile --stats=true ./saxpy

Warning: LBR backtrace method is not supported on this platform. DWARF backtrace method will be used.
WARNING: The command line includes a target application therefore the CPU context-switch scope has been set to process-tree.
Collecting data...
COMPLETED SUCCESSFULLY!Processing events...
Saving temporary "/tmp/nsys-report-8a57-012a-f9bf-3c61.qdstrm" file to disk...

Creating final output files...
Processing [==============================================================100%]
Saved report file to "/tmp/nsys-report-8a57-012a-f9bf-3c61.qdrep"
Exporting 1055 events: [==================================================100%]

Exported successfully to
/tmp/nsys-report-8a57-012a-f9bf-3c61.sqlite


CUDA API Statistics:

 Time(%)  Total Time (ns)  Num Calls    Average    Minimum   Maximum          Name
 -------  ---------------  ---------  -----------  -------  ---------  ------------------
    97.9        236895431          2  118447715.5    97939  236797492  cudaMalloc
     1.9          4513642          2    2256821.0   897454    3616188  cudaMemcpy
     0.2           467036          2     233518.0   199104     267932  cudaFree
     0.1           172301          1     172301.0   172301     172301  cudaMemcpyToSymbol
     0.0            33707          1      33707.0    33707      33707  cudaLaunchKernel
```




```
Exported successfully to
/tmp/nsys-report-8a57-012a-f9bf-3c61.sqlite


CUDA API Statistics:

 Time(%)  Total Time (ns)  Num Calls    Average    Minimum   Maximum          Name
 -------  ---------------  ---------  -----------  -------  ---------  ------------------
    97.9        236895431          2  118447715.5    97939  236797492  cudaMalloc
     1.9          4513642          2    2256821.0   897454    3616188  cudaMemcpy
     0.2           467036          2     233518.0   199104     267932  cudaFree
     0.1           172301          1     172301.0   172301     172301  cudaMemcpyToSymbol
     0.0            33707          1      33707.0    33707      33707  cudaLaunchKernel


CUDA Kernel Statistics:

 Time(%)  Total Time (ns)  Instances  Average   Minimum  Maximum                Name
 -------  ---------------  ---------  --------  -------  -------  ------------------------------
   100.0           312951          1  312951.0   312951   312951  convolution_2d(int*, int*, int)


CUDA Memory Operation Statistics (by time):

 Time(%)  Total Time (ns)  Operations   Average   Minimum  Maximum      Operation
 -------  ---------------  ----------  ---------  -------  -------  ------------------
    69.4          1878826           1  1878826.0  1878826  1878826  [CUDA memcpy DtoH]
    30.6           826856           2   413428.0     1056   825800  [CUDA memcpy HtoD]
```

Github Link : https://github.com/pavanshinde7494/HPC-Assignment