Assignment1 Report
CSE436, Summer 2016
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1. Backgrounds and Motivation

The motivation of assignment 1 is to understand the performance difference due to different storage types of matrix and compiler optimization. In this assignment, input matrices are generated using different combination of row major and column major storage types. Also, different optimization levels are utilized to determine the performance difference. At the end, each execution is measured and compared.

2. Function Implementation Description

- **matrix_addition function**

The function first checks the storage type of input matrices by checking A_rowMajor and B_rowMajor parameters. Based on these parameters, there are four different types of implementation available inside the function. Generally, matrix addition is performed by adding each element at same location of two matrices, and placing the result at same location of a result matrix.

Essentially, this can be performed by going through each element of a matrix using two for loops, and adding each item. In my implementation, first for loop is used to go through all rows. For each row, second for loop is used to access each column of a matrix. All of four implementations follow the same method to calculate matrix addition except how offsets are calculated. Assuming matrix A[N][M] has N rows and M columns, the offset is calculated using Equation 1 for a row major matrix whereas a column major matrix uses Equation 2 to calculate its offset. The method to calculate offset for both row major matrix and column major matrix are used throughout three functions.

$$A(i,j) = i * M + j \text{ [Row Major] --- } \mathbf{Equation\ 1}$$
$$A(i,j) = j * N + i \text{ [Column Major] --- } \mathbf{Equation\ 2}$$

- **matrix_multiplication**

Similar to matrix_addition function, this function also checks the storage type of input matrices using input parameters. Depending on these values, different offset calculation is used. Details of method to calculate offset is explained in matrix_addition function description.

It is important to note that matrix multiplication requires single row of matrix A to be calculated with all columns of matrix B. In code, the first for loop is setup to go through each rows of matrix A, and second for loop is placed to go through every column of matrix B. Since K represents columns of matrix A and rows of matrix B, adding third for loop with K enables function to go through each element of rows in matrix A and corresponding element of columns in matrix B. Next, two elements are multiplied, and accumulated into "sum" variable. Finally, the result will be placed in matrix C(row number of matrix A, column number of matrix B). By going through three for loops, the function achieves matrix multiplication operation.

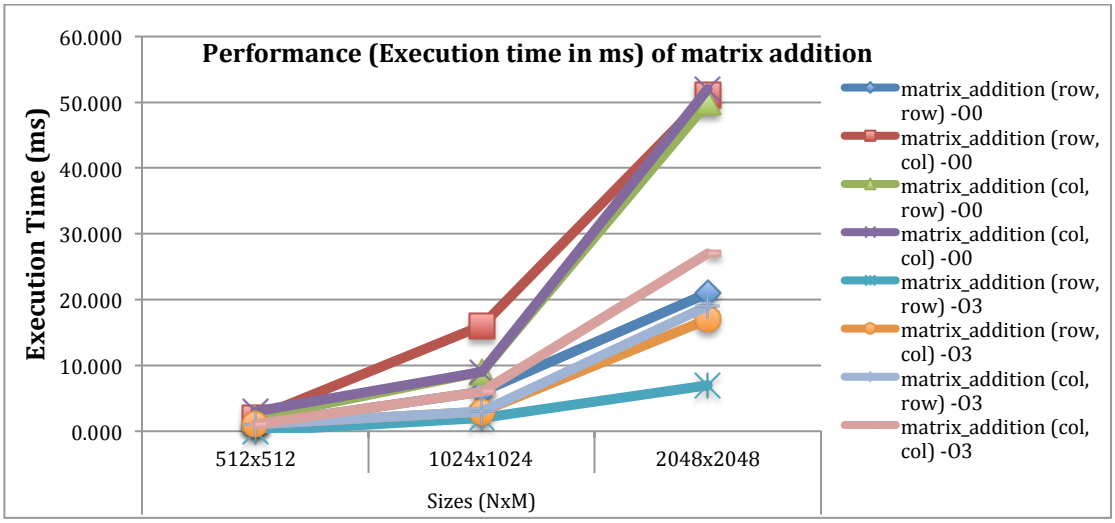
- **mv_multiplication**

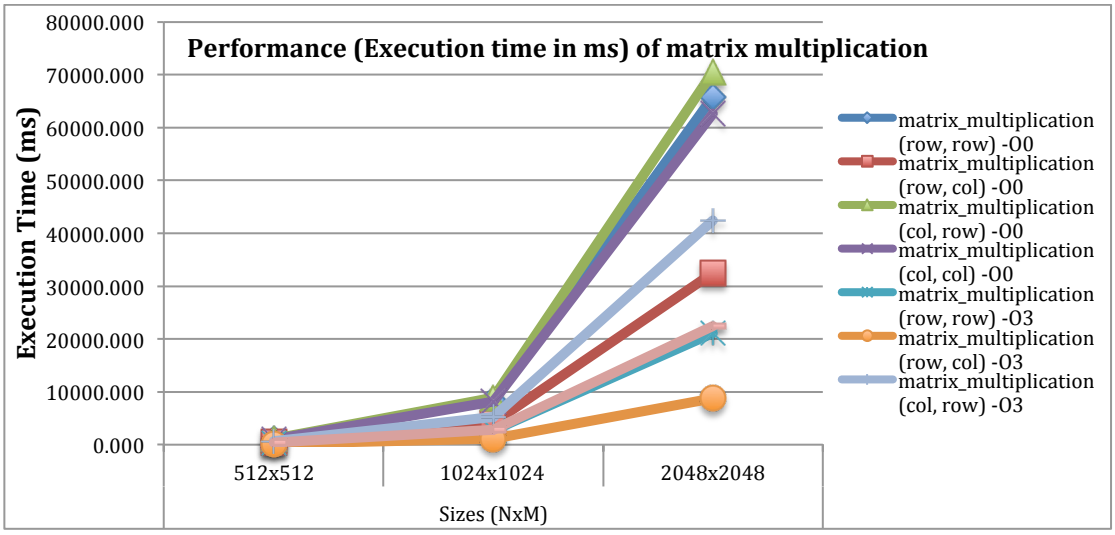
mv_multiplication function also starts with checking the storage type of first matrix using input parameter. This function only has two implementations as only first matrix has option to be row major or column major. The implementation of the function is similar to matrix_multiplication function except second input matrix is a vector (i.e. only has one column).

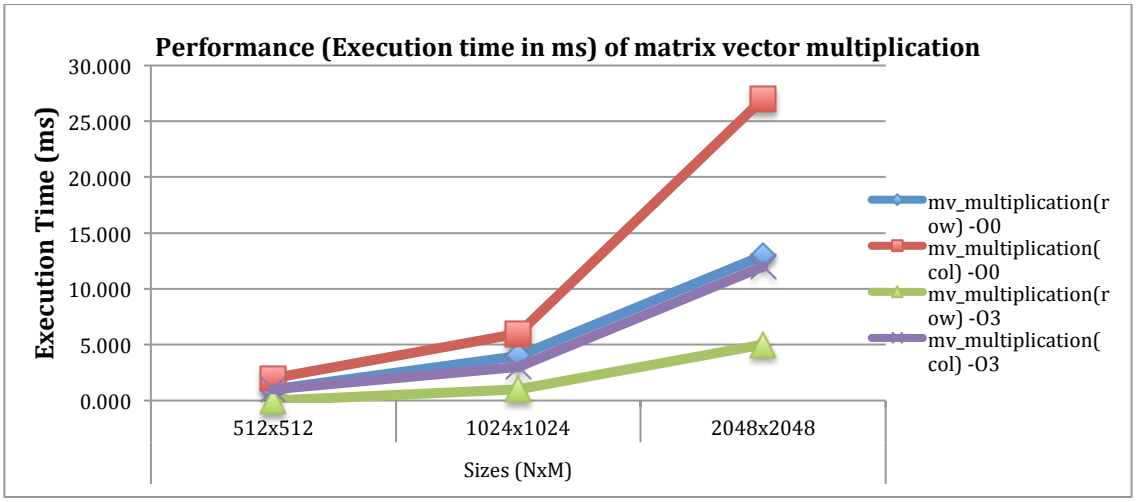
The first for loop goes through every row of matrix A, and second for loop iterates through every column element of matrix A and every row element of vector B. Next, the two elements are multiplied, and accumulated into "sum" variable, and stored into result vector C(row number of matrix A). By repeating this process, the function achieves mv multiplication.

3. Performance Report

All executions of assignment 1 code are performed on **lennon.secs.oakland.edu** Linux server via VPN connection. Bash script was prepared to automatically perform six variants of test runs, and save the result into a text file. Following three figures shows the performance of each function.







- **Performance Different due to Storage Type**

The cache system plays the key role in performance difference due to storage type. The cache uses locality of reference as key concept. The one of concept is "spatial locality", which stores surrounding of accessed data into cache. If next data is found in cache, it is significantly efficient than accessing the RAM (Reference 2). In matrix_addition, all matrices access each element in row first, then next column. Therefore, both input matrices being

row major gets best performance. Having column major matrix as input makes the function perform slower due to increasing number of RAM access.

For matrix_multilication, the first input matrix is accessed by row whereas second input matrix is access by column by nature of how matrix multiplication is defined. Therefore, first matrix being row major and second matrix being column major has highest cache hit rate, resulting in best performance time among four possible storage types (about ½ faster). The opposite combination of storage type gets the worst performance. For mv_multiplication, row major input matrix and column major input vector is ideal; however, this combination is not available. Between the two implementations, row major input matrix has better performance as elements are accessed by row.

- **Performance Difference due to Optimization Level**

In this assignment, same code was compiled using different optimization flag, level 0 and level 3. At flag level 0, there is no optimization, and documentation states that this level is only good for debugging purpose. GNU GCC complier uses optimization flag level 2 as default if this option is not specified. At flag level 2, most of optimization flags are enabled that will not increase the size of code. At optimization flag level 3, more aggressive optimization is performed. The following list shows some of noticeable optimization performed by compiler. (Reference 1)

- Replace function call with inline function. This increases the speed as program has fewer branch instructions.
- Perform loop distribution. By distributing the loop, it reducing the number of time the program needs to check the end loop condition.
- Perform "function cloning". If the function is called several times with similar parameters, the compiler creates similar function with less parameter (making unchanged parameters as constant), and call modified function.
- Replace standard C library function with faster alternative.
- Remove unused parameters, dead logics, and re-order of instruction
- Eliminate save and load of registers that are not used by called function.
- Perform "partial redundancy elimination", which means removing the duplicated code.

With these optimization techniques, the program ran faster (about 2.5 times) than the one without any optimization. When the size of executable file is compared, one with flag level 3 was slightly larger as flag level 3 includes optimization that requires more code (replacing function with inline function, loop distribution, etc.).

- **Number of Flops Calculation**

Inside main function, MFLOPS was calculated with execution time. In order to calculate MFLOPS, it is necessary to understand number of flops performed by each function. Table 1 below summarizes the equations used for calculation.

Function	# of flop
matrix_addition	M * N
matrix_multilication	M * N * (2 * K - 1)
mv_multiplication	(2 * M - 1) * N

Table1: Number of flops performed by each function

Note: When calculating MFLOPS for matrix_multiplication, there is a possibility of an overflow with a large number (ex. 2048 * 2048) at (M * N * (2 * K – 1)) as all variables are declared as int. M variable is type casted with long to avoid an overflow.

4. Conclusion

Executing aggressive optimization by compiler or selecting wise storage types for matrices significantly increase the performance of the code. Choosing storage type that follows how each input matrix being accessed by function improves the cache hit rate, and reduces the execution time by half. With aggressive optimization, the code was able to run about 2.5 times faster compared to no optimization version. Moreover, more complex operation has greater improvement on performance. However, it is important to note that compiler optimization may break the code if the code becomes parallelized. This is because optimization includes the re-order of instruction and changing the flow of program. Overall, the assignment demonstrated the effectiveness of storage type and code optimization.

References

1. Options That Control Optimization (https://gcc.gnu.org/onlinedocs/gcc/Optimize-Options.html)
2. Introduction to Caches (https://www.cs.umd.edu/class/sum2003/cmsc311/Notes/Memory/introCache.html)