BIRZEIT UNIVERSITY

Faculty of Engineering & Technology
Electrical & Computer Engineering Department

OPERATING SYSTEMS

ENCS3390

programming task #1

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Section: 1

This programming task is about matrix multiplication.

-The 2 matrices to be multiplied have the size 100 X 100.

-The first matrix composed of my student number repeated to fill the entire matrix.

-The second matrix is(my student number * my birth year) repeated to fill the entire matrix.

Here is the implementation of filling the 2 matrices.

```
int main() {
    struct timeval start_t, end_t;  // Use struct timeval for time measurements
    int idMatrix[100][100];
    int idxBirthYearMatrix[100][100];
    int multiplicationMatrix[100][100];
    int id = 1210249;
    int ID[10]; // 1D array to contain id numbers
    int size1 = 0; //size of 1D id array

    // fill the id numbers into 1D array
    while(id > 0){
        ID[size1] = id % 10;
        size1++;
        id /= 10;
    }

    // reverse the array because it was filled reversed
    for(int i = 0; i < size1 / 2; i++){
        int temp = ID[i];
        ID[i] = ID[size1 - 1 - i];
        ID[size1 - 1 - i] = temp;
    }

    long long idMulBirth = 1210249l * 2003l;
    int idXbirthYear[20];// 1D array to contain (id * birth year) numbers
    int size2 = 0; // size of 1D id * BirthYear array

     // fill the id multiplied with the birth year into 1D array
     while(idMulBirth > 0){
         idXbirthYear[size2] = idMulBirth % 10;
         idMulBirth /= 10;
         size2++;
     }
     // reverse the array because it was filled reversed
     for(int i = 0; i < size2 / 2; i++){
         int temp = idXbirthYear[i];
         idXbirthYear[i] = idXbirthYear[size2 - 1 - i];
         idXbirthYear[size2 - 1 - i] = temp;
     }

     // fill the id matrix and id * birth year matrix
     int k = 0,l =0;
     for(int i = 0; i < 100; i++){
         for(int j = 0; j < 100; j++){
             if(k == size1) k = 0; // when the id ends start over
             if(l == size2) l = 0; // when the id * birth year number ends start over
             idMatrix[i][j] = ID[k];
             idxBirthYearMatrix[i][j] = idXbirthYear[l];
             l++;
             k++;
         }
     }
```

I used 4 approaches of multiplication:

-The naive approach

multiplying corresponding elements of two matrices and summing the products of the respective rows of the first matrix and columns of the second matrix

-this approach is the slowest approach

Here is the implementation of the naive approach:

```
gettimeofday(&start_t, NULL);  // Get the start time

// multiplication process
for (int i = 0; i < 100; i++) {
    for (int j = 0; j < 100; j++) {
        multiplicationMatrix[i][j] = 0;
        for(int k = 0; k < 100; k++){
            multiplicationMatrix[i][j] += (idMatrix[i][k] * idxBirthYearMatrix[k][j]);

        }
    }
}
gettimeofday(&end_t, NULL);  // Get the end time
double elapsed_time = (end_t.tv_sec - start_t.tv_sec) + (end_t.tv_usec - start_t.tv_usec) / 1000000.0;
printf("\nThe time of the naive approach is %f ",elapsed_time);
```

I tried calculating the execution time multiple time using gettimeofday() function:

```
The time of the naive approach is 0.002589
Process finished with exit code 0
```

```
The time of the naive approach is 0.002525
Process finished with exit code 0
```

```
The time of the naive approach is 0.002652
Process finished with exit code 0
```

```
The time of the naive approach is 0.002596
Process finished with exit code 0
```

```
The time of the naive approach is 0.002655
Process finished with exit code 0
```

The average execution time = 0.0026034 second

Throughput = 1 / average execution time = 384.113

-Multiprocess approach:

-this approach is better than the naive approach in terms of execution time (because multiple processes are working together in parallel).

Here is the implementation of the multiprocess approach:

```c
int rows_per_child = ARRAY_SIZE / NUM_CHILDREN + 1; // Rows assigned to each child(I added 1 to avoid missing any row when the number of children is negative)
int pipe_fds[NUM_CHILDREN][2]; //create a pipe for each child
gettimeofday(&start_t, NULL);  // Get the start time

for (int i = 0; i < NUM_CHILDREN; i++) {
    if (pipe(pipe_fds[i]) == -1) {
        perror("Pipe creation failed");
        return 1;
    }
}

pid_t pids[NUM_CHILDREN]; // create pid for each child

for (int i = 0; i < NUM_CHILDREN; i++) {
    pids[i] = fork(); // creating a child
    if (pids[i] < 0) {
        printf("Fork failed");
    }
    else if (pids[i] == 0) {
        // Child process
        close(pipe_fds[i][0]);

        // To store the child result
        int ans_child[rows_per_child][ARRAY_SIZE];

        // Initialize the array elements to zero
        for (int i = 0; i < rows_per_child; i++) {
            for (int j = 0; j < ARRAY_SIZE; j++) {
                ans_child[i][j] = 0;
            }
        }
        // calculate the start and end of the rows assigned to the child
        int start_row = i * rows_per_child;
        int end_row = (i == NUM_CHILDREN - 1) ? ARRAY_SIZE : (i + 1) * rows_per_child;

        // evaluate the child multiplication
        for (int x = start_row; x < end_row; x++) {
            for (int j = 0; j < ARRAY_SIZE; j++) {
                ans_child[x - start_row][j] = 0;
                for (k = 0; k < ARRAY_SIZE; k++) {
                    ans_child[x - start_row][j] += (idMatrix[x][k] * idxBirthYearMatrix[k][j]);
                }
            }
        }

        // Write the result to the pipe
        write( fd: pipe_fds[i][1],  buf: ans_child,  nbyte: sizeof(ans_child));

        close(pipe_fds[i][1]);
        exit(0); // Exit the child process
    }
}

for (int i = 0; i < NUM_CHILDREN; i++) {
    close(pipe_fds[i][1]);
    waitpid(pids[i], NULL, 0); // wait for child process
    int temp_result[rows_per_child][ARRAY_SIZE]; // To store the child array
    read(pipe_fds[i][0], temp_result, sizeof(temp_result));
    close(pipe_fds[i][0]);
    int start_row = i * rows_per_child;
    int end_row = (i == NUM_CHILDREN - 1) ? ARRAY_SIZE : (i + 1) * rows_per_child;

    // add the partial array to the final array
    for (int x = start_row; x < end_row; x++) {
        for (int j = 0; j < ARRAY_SIZE; j++) {
            multiplicationMatrix[x][j] += temp_result[x - start_row][j];
        }
    }
}

gettimeofday(&end_t, NULL);  // Get the end time
double elapsed_time = (end_t.tv_sec - start_t.tv_sec) + (end_t.tv_usec - start_t.tv_usec) / 1000000.0;
int x = NUM_CHILDREN;
printf("\nThe time of the multiprocess approach is %f  (%d children) ", elapsed_time,x);
```

I tried calculating the execution time multiple time using gettimeofday() function:

-when the number of processes is 2:

```
The time of the multiprocess approach is 0.001885  (2 children)
Process finished with exit code 0
```

```
The time of the multiprocess approach is 0.001723  (2 children)
Process finished with exit code 0
```

```
The time of the multiprocess approach is 0.001798  (2 children)
Process finished with exit code 0
```

```
The time of the multiprocess approach is 0.001786  (2 children)
Process finished with exit code 0
```

```
The time of the multiprocess approach is 0.001769  (2 children)
Process finished with exit code 0
```

The average execution time = 0.0017922 second

Throughput = 1 / average execution time = 557.973

-when the number of processes is 4:

```
The time of the multiprocess approach is 0.001588  (4 children)
Process finished with exit code 0
```

```
The time of the multiprocess approach is 0.001740  (4 children)
Process finished with exit code 0
```

```
The time of the multiprocess approach is 0.001679  (4 children)
Process finished with exit code 0
```

```
The time of the multiprocess approach is 0.001537  (4 children)
Process finished with exit code 0
```

```
The time of the multiprocess approach is 0.001648  (4 children)
Process finished with exit code 0
```

The average execution time = 0.0016384 second

Throughput = 1 / average execution time = 610.352

-when the number of processes is 6:

```
The time of the multiprocess approach is 0.001629  (6 children)
Process finished with exit code 0
```

```
The time of the multiprocess approach is 0.001544  (6 children)
Process finished with exit code 0
```

```
The time of the multiprocess approach is 0.001536  (6 children)
Process finished with exit code 0
```

```
The time of the multiprocess approach is 0.001577  (6 children)
Process finished with exit code 0
```

```
The time of the multiprocess approach is 0.001654  (6 children)
Process finished with exit code 0
```

The average execution time = 0.001588 second

Throughput = 1 / average execution time = 629.723

-when the number of processes is 8:

```
The time of the multiprocess approach is 0.001780  (8 children)
Process finished with exit code 0
```

```
The time of the multiprocess approach is 0.001729  (8 children)
Process finished with exit code 0
```

```
The time of the multiprocess approach is 0.001717  (8 children)
Process finished with exit code 0
```

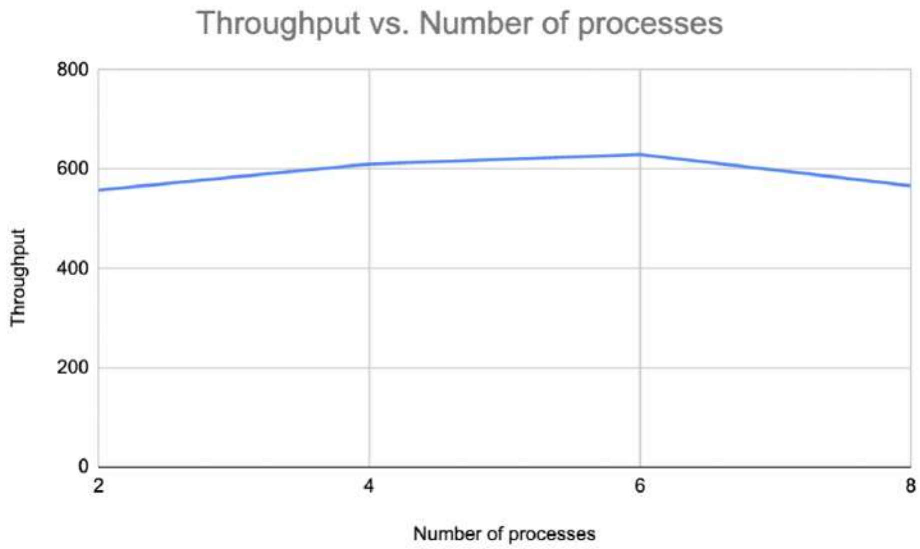
```
The time of the multiprocess approach is 0.001836  (8 children)
Process finished with exit code 0
```

```
The time of the multiprocess approach is 0.001762  (8 children)
Process finished with exit code 0
```

The average execution time = 0.0017648 second

Throughput = 1 / average execution time = 566.636

The best number of processes for the best performance is 6



-joinable Multithreads approach:
-this approach is the best approach (in terms of execution time and performance)
Here is the implementation of the multithreads approach:

```
    int splitIndex = 100 / NumberOfThreads;
    pthread_t th[NumberOfThreads];

    gettimeofday(&start_t, NULL);  // Get the start time

    for (int i = 0; i < NumberOfThreads; i++) {
        int start = i * splitIndex;
        int end = (i == NumberOfThreads - 1) ? 100 : (i + 1) * splitIndex;
        struct Task *t = (struct Task *)malloc( size: sizeof(struct Task));
        t->start = start;
        t->end = end;
        // Create threads to process tasks
        if (pthread_create(&th[i], NULL, startThread, (void *)t) != 0) {
            printf("Failed to create the thread");
        }
    }

    // Wait for all threads to finish
    for (int i = 0; i < NumberOfThreads; i++) {
        if (pthread_join(th[i], NULL) != 0) {
            printf("Failed to join the thread");
        }
    }

    gettimeofday(&end_t, NULL);  // Get the end time

    // Calculate the elapsed time in seconds
    double elapsed_time = (end_t.tv_sec - start_t.tv_sec) + (end_t.tv_usec - start_t.tv_usec) / 1000000.0;

    printf("\nThe time of the multithreading approach is %f seconds", elapsed_time);
```

And here is the startThread function:

```
// struct task to add to the thread pool
typedef struct Task {
    int start, end;
} Task;


// Thread function to process tasks
void *startThread(void *task) {
    struct Task *myTask = (struct Task*)task;

    // Process the task
    for (int x = myTask->start; x < myTask->end; x++) {
        for (int j = 0; j < 100; j++) {
            for (int k = 0; k < 100; k++) {
                multiplicationMatrix[x][j] += (idMatrix[x][k] * idxBirthYearMatrix[k][j]);
            }
        }
    }

    pthread_exit(NULL);

}
```

I tried calculating the execution time multiple time using gettimeofday() function:

-when the number of threads is 2:

```
The time of the multithreading approach is 0.001145 seconds
Process finished with exit code 0
```

```
The time of the multithreading approach is 0.001133 seconds
Process finished with exit code 0
```

```
The time of the multithreading approach is 0.001081 seconds
Process finished with exit code 0
```

```
The time of the multithreading approach is 0.001091 seconds
Process finished with exit code 0
```

```
The time of the multithreading approach is 0.001122 seconds
Process finished with exit code 0
```

The average execution time = 0.0011144 second

Throughput = 1 / average execution time = 897.343

-when the number of threads is 4:

```
The time of the multithreading approach is 0.000931 seconds
Process finished with exit code 0
```

```
The time of the multithreading approach is 0.000958 seconds
Process finished with exit code 0
```

```
The time of the multithreading approach is 0.001017 seconds
Process finished with exit code 0
```

```
The time of the multithreading approach is 0.000951 seconds
Process finished with exit code 0
```

```
The time of the multithreading approach is 0.000816 seconds
Process finished with exit code 0
```

The average execution time = 0.0009346 second

Throughput = 1 / average execution time = 1069.976

-when the number of threads is 6:

```
The time of the multithreading approach is 0.000770 seconds
Process finished with exit code 0
```

```
The time of the multithreading approach is 0.000845 seconds
Process finished with exit code 0
```

```
The time of the multithreading approach is 0.000887 seconds
Process finished with exit code 0
```

```
The time of the multithreading approach is 0.000779 seconds
Process finished with exit code 0
```

```
The time of the multithreading approach is 0.000783 seconds
Process finished with exit code 0
```

The average execution time = 0.0008128 second

Throughput = 1 / average execution time = 1230.315

-when the number of threads is 8:

```
The time of the multithreading approach is 0.000705 seconds
Process finished with exit code 0
```

```
The time of the multithreading approach is 0.000638 seconds
Process finished with exit code 0
```

```
The time of the multithreading approach is 0.000773 seconds
Process finished with exit code 0
```

```
The time of the multithreading approach is 0.000775 seconds
Process finished with exit code 0
```

```
The time of the multithreading approach is 0.000661 seconds
Process finished with exit code 0
```

The average execution time = 0.0007104 second

Throughput = 1 / average execution time = 1407.657

-when the number of threads is 10:

```
The time of the multithreading approach is 0.000701 seconds
Process finished with exit code 0
```

```
The time of the multithreading approach is 0.000697 seconds
Process finished with exit code 0
```

```
The time of the multithreading approach is 0.000703 seconds
Process finished with exit code 0
```

```
The time of the multithreading approach is 0.000675 seconds
Process finished with exit code 0
```

```
The time of the multithreading approach is 0.000691 seconds
Process finished with exit code 0
```

The average execution time = 0.0006934 second

Throughput = 1 / average execution time = 1442.169

-when the number of threads is 12:

```
The time of the multithreading approach is 0.000654 seconds
Process finished with exit code 0
```

```
The time of the multithreading approach is 0.000780 seconds
Process finished with exit code 0
```

```
The time of the multithreading approach is 0.000665 seconds
Process finished with exit code 0
```

```
The time of the multithreading approach is 0.000680 seconds
Process finished with exit code 0
```

```
The time of the multithreading approach is 0.000722 seconds
Process finished with exit code 0
```

The average execution time = 0.0007002 second

Throughput = 1 / average execution time = 1428.163

-when the number of threads is 14:

```
The time of the multithreading approach is 0.000739 seconds
Process finished with exit code 0
```

```
The time of the multithreading approach is 0.000706 seconds
Process finished with exit code 0
```

```
The time of the multithreading approach is 0.000752 seconds
Process finished with exit code 0
```

```
The time of the multithreading approach is 0.000648 seconds
Process finished with exit code 0
```

```
The time of the multithreading approach is 0.000679 seconds
Process finished with exit code 0
```

The average execution time = 0.0007048 second

Throughput = 1 / average execution time = 1418.842

-when the number of threads is 16:

```
The time of the multithreading approach is 0.000771 seconds
Process finished with exit code 0
```

```
The time of the multithreading approach is 0.000778 seconds
Process finished with exit code 0
```

```
The time of the multithreading approach is 0.000887 seconds
Process finished with exit code 0
```

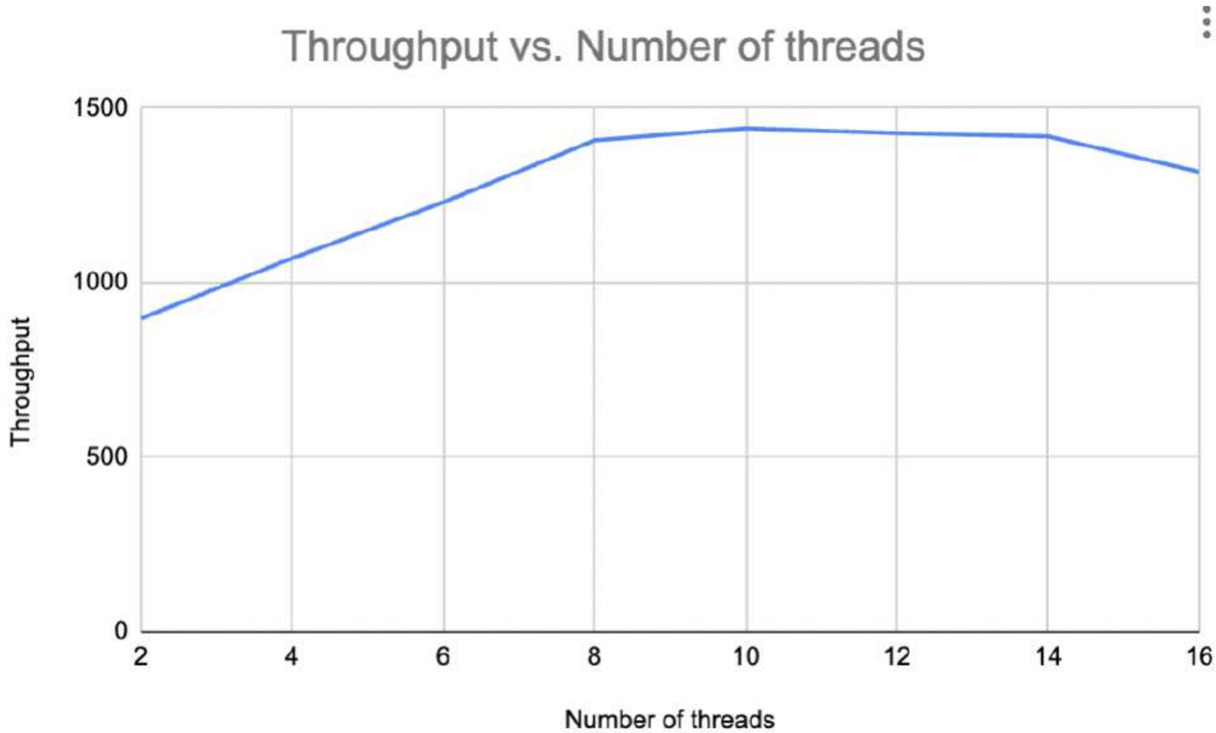
```
The time of the multithreading approach is 0.000740 seconds
Process finished with exit code 0
```

```
The time of the multithreading approach is 0.000799 seconds
Process finished with exit code 0
```

The average execution time = 0.000795 second

Throughput = 1 / average execution time = 1317.523

The best number of processes for the best performance is (8-14):



-detached Multithreads approach:

Detached threads operate independently of the main program. Once created, detached threads do not require explicit waiting for their completion.

Here is the implementation of the multithreads approach:

```
#define NumberOfThreads 4
int multiplicationMatrix[100][100] = {0}; // Result matrix
int idMatrix[100][100];
int idxBirthYearMatrix[100][100];

// struct task to add to the thread pool
typedef struct Task {
    int start, end;
} Task;


void *startThread(void *task) {
    struct Task *myTask = (struct Task*)task;

    // Process the task
    for (int x = myTask->start; x < myTask->end; x++) {
        for (int j = 0; j < 100; j++) {
            for (int k = 0; k < 100; k++) {
                multiplicationMatrix[x][j] += (idMatrix[x][k] * idxBirthYearMatrix[k][j]);
            }
        }
    }

    pthread_exit(NULL);

}
```

And here is the main program:

```
    int splitIndex = 100 / NumberOfThreads;
    pthread_t th[NumberOfThreads];

// Loop to create and launch multiple threads
    for (int i = 0; i < NumberOfThreads; i++) {
        // Calculate the start and end indices for the current thread
        int start = i * splitIndex;
        int end = (i == NumberOfThreads - 1) ? 100 : (i + 1) * splitIndex;

        // Allocate memory for a task structure to hold thread-specific data
        struct Task *t = (struct Task *)malloc( size: sizeof(struct Task));

        // Set the start and end indices in the task structure
        t->start = start;
        t->end = end;

        // Initialize thread attributes
        pthread_attr_t attr;
        pthread_attr_init(&attr);

        // Set the thread to be detached to operate independently
        pthread_attr_setdetachstate(&attr, PTHREAD_CREATE_DETACHED);

        // Create a new thread and pass the startThread function with the task as an argument
        if (pthread_create(&th[i], &attr, startThread, (void *)t) != 0) {
            printf("Failed to create the thread");
        }

        // Destroy thread attributes after thread creation
        pthread_attr_destroy(&attr);
    }
```

-In a detached thread approach, measuring execution time can be challenging due to the lack of synchronization with the main program.

-If we do not allow enough time for all threads to execute, the result might be incorrect because some threads may not have finished.

```
untitled10
/Users/shahdyahya/Desktop/untitled10/cmake-build-debug/untitled10
Final Matrix :
538 1076 538 1076 269 538 2152 1883 1076 1883 538 1076 538 1076 269 538 2152 1883 1076 1883 538 1076 538 1076 269 538 2152 1883 1076 1883 538 1076 538 1076 269 538 2152
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```

Conclusion:

Naive Approach:

Method: Multiplying corresponding elements of two matrices without using child processes or threads.

Performance: Slowest approach.

Average Execution Time: 0.0026034 seconds.

This approach is straightforward but lacks parallelism, leading to slower execution.

Multiple Child Processes:

Method: Using multiple child processes for parallel execution.

Performance: Improved over the naive approach.

Best Performance: 6 processes with an average execution time of 0.001588 seconds.

Increasing the number of processes improved performance, but there may be diminishing returns beyond a certain point due to overhead.

Multiple Joinable Threads:

Method: Employing multiple joinable threads for parallel execution.

Performance: Best approach among the tested methods.

Best Performance: (8-12) threads with an average execution time of 0.0006934 seconds.

Thread-based parallelism performed better than process-based parallelism in terms of execution time.

Multiple Detached Threads:

Method: Using multiple detached threads for parallel execution.

Performance: Not explicitly measured due to challenges in timing detached threads.

Detached threads operate independently of the main program, making it challenging to measure execution time accurately.