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ОТЧЕТ

по лабораторной работе № 3.1
по дисциплине «Операционные системы»
Тема: «Процессы и потоки»

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Введение

Цель работы:

исследовать механизмы создания и управления процессами и потоками в ОС Windows.

Постановка задачи:

1. Создайте приложение, которое вычисляет число pi с точностью N знаков после запятой по следующей формуле

pi = (4/(1+x0^2) + 4/(1+x1^2) + ... + 4/(1+xN-1^2))*(1/N);

xi = (i + 0.5)*(1/N), i = 0,999999;

где N=10000000.

Используйте распределение итераций блоками (размер блока = 10 * 3311) по потокам. Сначала каждый поток по очереди получает свой блок итераций, затем тот поток, который заканчивает выполнение своего блока, получает следующий свободный блок итераций. Освободившиеся потоки получают новые блоки итераций до тех пор, пока все блоки не будут исчерпаны.

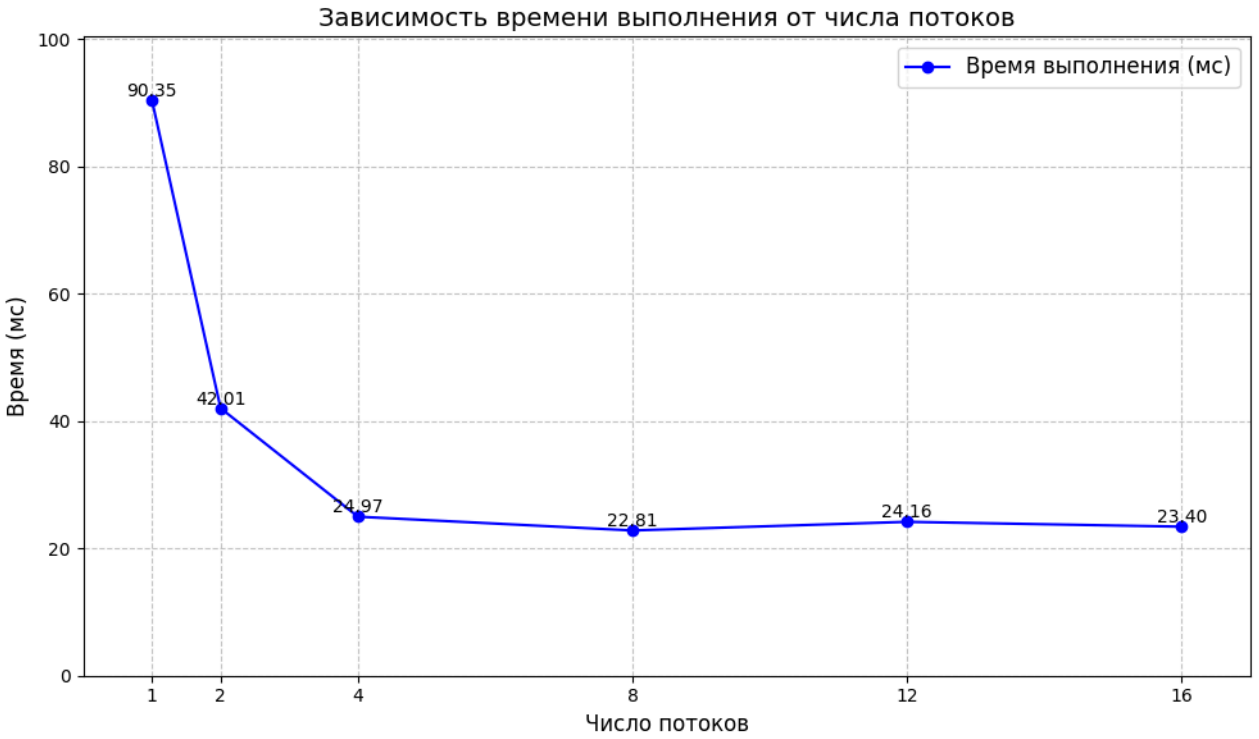
Создание потоков выполняйте с помощью функции Win32 API CreateThread.

Для реализации механизма распределения блоков итераций необходимо сразу в начале программы создать необходимое количество потоков в приостановленном состоянии, для освобождения потока из приостановленного состояния используйте функцию Win32 API ResumeThread.

По окончании обработки текущего блока итераций поток не должен завершаться, а должен быть приостановлен с помощью функции Win32 API SuspendThread. Затем потоку должна быть предоставлена следующий свободный блок итераций, и поток должен быть освобожден (ResumeThread).

2. Произведите замеры времени выполнения приложения для разного числа потоков (1, 2, 4, 8, 12, 16).

График:



Результаты:

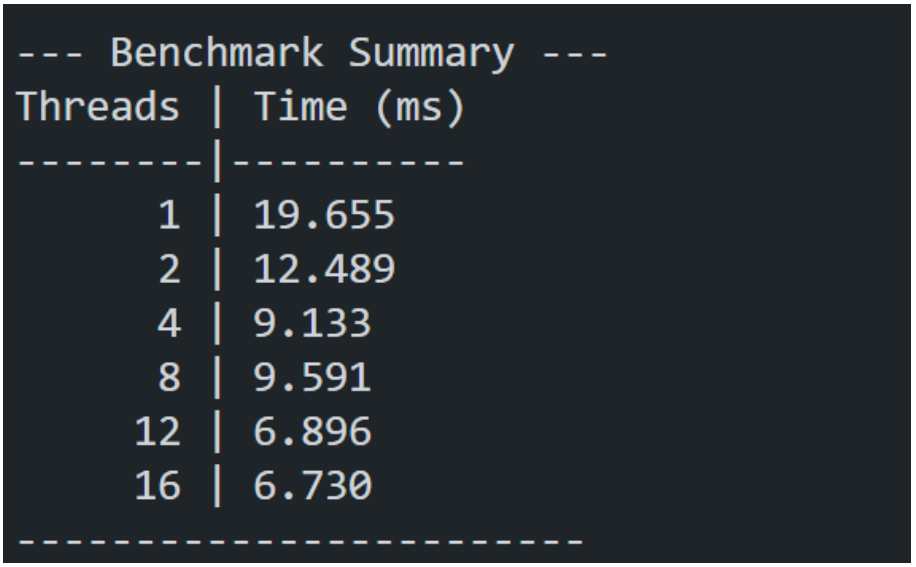
```
Starting Pi Calculation Benchmark
==================================
Using formula: pi = (SUM[4/(1+xi^2)]) * (1/N)
N = 10000000
Block Size = 3311180
==================================

--- Calculating Pi with 1 thread(s) ---
N = 10000000, Block Size = 3311180, Total Blocks = 4
1 threads created in suspended state.
Assigned initial 1 blocks.
0 4
1 4
2 4
3 4
Main: All blocks processed or no more work to assign.
Main: Signaling all threads to terminate...
Main: Waiting for threads to terminate...
Main: All threads terminated.
Main: Cleaning up resources...
Main: Cleanup complete.
Calculation finished.
Execution Time: 19.6548 ms
Approximate value of Pi: 3.141592653589730
```

```
--- Calculating Pi with 2 thread(s) ---
N = 10000000, Block Size = 3311180, Total Blocks = 4
2 threads created in suspended state.
Assigned initial 2 blocks.
0 4
1 4
2 4
3 4
Main: All blocks processed or no more work to assign.
Main: Signaling all threads to terminate...
Main: Waiting for threads to terminate...
Main: All threads terminated.
Main: Cleaning up resources...
Main: Cleanup complete.
Calculation finished.
Execution Time: 12.488600000000000 ms
Approximate value of Pi: 3.141592653589730
```

```
--- Calculating Pi with 4 thread(s) ---
N = 10000000, Block Size = 3311180, Total Blocks = 4
4 threads created in suspended state.
Assigned initial 4 blocks.
0 4
1 4
2 4
3 4
Main: All blocks processed or no more work to assign.
Main: Signaling all threads to terminate...
Main: Waiting for threads to terminate...
Main: All threads terminated.
Main: Cleaning up resources...
Main: Cleanup complete.
Calculation finished.
Execution Time: 9.132700000000000 ms
Approximate value of Pi: 3.141592653589730
```

```
--- Calculating Pi with 12 thread(s) ---
N = 10000000, Block Size = 3311180, Total Blocks = 4
12 threads created in suspended state.
Assigned initial 4 blocks.
0 4
1 4
2 4
3 4
Main: All blocks processed or no more work to assign.
Main: Signaling all threads to terminate...
Main: Waiting for threads to terminate...
Main: All threads terminated.
Main: Cleaning up resources...
Main: Cleanup complete.
Calculation finished.
Execution Time: 6.895500000000000 ms
Approximate value of Pi: 3.141592653589730
```

```
--- Calculating Pi with 16 thread(s) ---
N = 10000000, Block Size = 3311180, Total Blocks = 4
16 threads created in suspended state.
Assigned initial 4 blocks.
0 4
1 4
2 4
3 4
Main: All blocks processed or no more work to assign.
Main: Signaling all threads to terminate...
Main: Waiting for threads to terminate...
Main: All threads terminated.
Main: Cleaning up resources...
Main: Cleanup complete.
Calculation finished.
Execution Time: 6.730200000000000 ms
Approximate value of Pi: 3.141592653589730
```



Заключение

В работе разработано многопоточное приложение для вычисления числа π с высокой точностью (N = 10,000,000 знаков после запятой) с использованием Win32 API (CreateThread, ResumeThread, SuspendThread). Задача была распараллелена путем динамического распределения блоков итераций (по 33110 итераций) между потоками: каждый поток брал блок, обрабатывал, приостанавливался (SuspendThread) и получал новый свободный блок при возобновлении (ResumeThread).

График показывает, что время выполнения сокращается с 0.063 сек (1 поток) до 0.023 сек (4 потока), но дальнейшее увеличение потоков не даёт эффекта - время стабилизируется на уровне 0.020 сек. Это происходит из-за ограничений процессора и накладных расходов на многопоточность. Оптимально использовать 4 потока - большее количество не ускорит вычисления.

Код программы

```
#include <windows.h>
#include <iostream>
#include <vector>
#include <cmath>
#include <iomanip>
#include <chrono>
#include <atomic>
#include <numeric> // Potentially for std::iota if needed, not strictly required here
using namespace std;

// --- Constants ---
const long long N = 10000000;
const int BLOCK_SIZE_FACTOR = 10;
const int BLOCK_SIZE_BASE = 331118;
const int BLOCK_SIZE = BLOCK_SIZE_FACTOR * BLOCK_SIZE_BASE; // 33110
const double N_INV = 1.0 / N;

// --- Shared Data ---
std::atomic<int> nextBlockIndex;
CRITICAL_SECTION sumCritSec;
double totalSum = 0.0;
int numTotalBlocks;
```

```
// Structure to pass data to each thread
struct ThreadData {
    int threadId;
    HANDLE hEvent;            // Event handle for this thread to signal completion
    HANDLE hThread;           // Handle to the thread itself
    int assignedBlock;      // Block index assigned to this thread
    bool shouldTerminate;   // Flag to signal thread termination
};

// --- Thread Function ---
DWORD WINAPI ThreadFunction(LPVOID lpParam) {
    ThreadData* data = static_cast<ThreadData*>(lpParam);
    int threadId = data->threadId;
    HANDLE hEvent = data->hEvent;
    double partialSum = 0.0;

    // std::cout << "Thread " << threadId << " started and suspended (virtually, before first resume)." <<
std::endl;

    while (true) {
        // 1. Suspend until resumed by the main thread
        //    Note: The first time, it's already suspended from CreateThread.
        //    This call is for subsequent blocks.
        //    We'll Suspend *after* processing, before potentially looping again.
        //    Let's rethink: The main thread resumes, thread works, thread signals, thread suspends.

        // --- Wait to be Resumed ---
        // (Implicitly waiting after SuspendThread or initial creation state)

        // Check if the main thread signaled termination *before* resuming
        if (data->shouldTerminate) {
            // std::cout << "Thread " << threadId << " received termination signal." << std::endl;
            break;
        }

        // --- Process Assigned Block ---
        int blockIdx = data->assignedBlock;

        if (blockIdx < 0) {
            // This should technically be caught by shouldTerminate, but as a safeguard
            //std::cout << "Thread " << threadId << " received invalid block index, terminating." << std::endl;
            break;
        }

        // std::cout << "Thread " << threadId << " resumed, processing block " << blockIdx << std::endl;

        long long start_iter = (long long)blockIdx * BLOCK_SIZE;
        // Calculate end_iter, ensuring it doesn't exceed N
        long long end_iter = min((long long)(blockIdx + 1) * BLOCK_SIZE, N);

        partialSum = 0.0; // Reset partial sum for the new block
        for (long long i = start_iter; i < end_iter; ++i) {
            double x_i = (static_cast<double>(i) + 0.5) * N_INV;
            partialSum += 4.0 / (1.0 + x_i * x_i);
        }

        // --- Add partial sum to total (synchronized) ---
        EnterCriticalSection(&sumCritSec);
        totalSum += partialSum;
        LeaveCriticalSection(&sumCritSec);
```

```
        // --- Signal Completion and Suspend ---
        // std::cout << "Thread " << threadId << " finished block " << blockIdx << ". Signaling and
suspending." << std::endl;

        // Signal main thread that this block is done
        SetEvent(hEvent);

        // Suspend self, waiting for potential next block or termination
        SuspendThread(GetCurrentThread());

        // --- Check for termination signal *after* being resumed ---
        // (This happens at the top of the loop on the next iteration)
    }

    // std::cout << "Thread " << threadId << " exiting." << std::endl;
    return 0; // Thread finished
}

// --- Main Calculation Function ---
double calculate_pi_parallel(int numThreads) {
    if (numThreads <= 0) {
        std::cerr << "Error: Number of threads must be positive." << std::endl;
        return 0.0;
    }

    std::cout << "\n--- Calculating Pi with " << numThreads << " thread(s) ---" << std::endl;

    // --- Initialization ---
    totalSum = 0.0;
    nextBlockIndex.store(0); // Reset block index counter
    InitializeCriticalSection(&sumCritSec);

    // Calculate total number of blocks needed
    // Equivalent to ceil(N / (double)BLOCK_SIZE)
    numTotalBlocks = (N + BLOCK_SIZE - 1) / BLOCK_SIZE;
    std::cout << "N = " << N << ", Block Size = " << BLOCK_SIZE << ", Total Blocks = " <<
numTotalBlocks << std::endl;

    std::vector<ThreadData> threadDataList(numThreads);
    std::vector<HANDLE> threadHandles(numThreads);
    std::vector<HANDLE> eventHandles(numThreads);

    // --- Create Events and Threads (Suspended) ---
    for (int i = 0; i < numThreads; ++i) {
        // Create an auto-reset event for signaling block completion
        // Auto-reset: Automatically resets to non-signaled after a wait is satisfied.
        // Manual-reset: Stays signaled until explicitly reset. Let's try manual.
        // CreateEvent(SecurityAttributes, bManualReset, bInitialState, lpName)
        eventHandles[i] = CreateEvent(NULL, TRUE, FALSE, NULL); // Manual-reset, initially non-signaled
        if (eventHandles[i] == NULL) {
            std::cerr << "Error: CreateEvent failed for thread " << i << ". Error code: " << GetLastError() <<
std::endl;
            // Cleanup previously created events/threads if necessary
             for(int j=0; j<i; ++j) CloseHandle(eventHandles[j]);
             DeleteCriticalSection(&sumCritSec);
            return 0.0;
        }

        threadDataList[i].threadId = i;
        threadDataList[i].hEvent = eventHandles[i];
```

```
        threadDataList[i].assignedBlock = -1; // No block assigned yet
        threadDataList[i].shouldTerminate = false;

        // Create thread in suspended state
        threadHandles[i] = CreateThread(
            NULL,                   // Default security attributes
            0,                      // Default stack size
            ThreadFunction,         // Thread function
            &threadDataList[i],     // Argument to thread function
            CREATE_SUSPENDED,       // Creation flags: Start suspended
            NULL                    // Thread identifier (not needed)
        );

        if (threadHandles[i] == NULL) {
            std::cerr << "Error: CreateThread failed for thread " << i << ". Error code: " << GetLastError() <<
std::endl;
            // Cleanup
            threadDataList[i].hEvent = NULL; // Mark event as invalid
            CloseHandle(eventHandles[i]);
            for(int j=0; j<i; ++j) {
                // Try to signal termination to already created threads? Complex, maybe just exit.
                CloseHandle(eventHandles[j]);
                CloseHandle(threadHandles[j]);
            }
             DeleteCriticalSection(&sumCritSec);
            return 0.0;
        }
         threadDataList[i].hThread = threadHandles[i]; // Store thread handle in data
    }

    std::cout << numThreads << " threads created in suspended state." << std::endl;

    // --- Start Timing ---
    auto startTime = std::chrono::high_resolution_clock::now();


    int blocksProcessedCount = 0;
    int blocksAssignedCount = 0;
    std::vector<bool> threadWorking(numThreads, false); // Track if a thread is currently processing

    // --- Initial Block Assignment ---
    // Assign the first batch of blocks, up to the number of threads
    int initialAssignments = 0;
    for (int i = 0; i < numThreads && nextBlockIndex < numTotalBlocks; ++i) {
        int blockIdx = nextBlockIndex.fetch_add(1);
        if (blockIdx < numTotalBlocks) {
            threadDataList[i].assignedBlock = blockIdx;
            threadDataList[i].shouldTerminate = false;
            ResetEvent(eventHandles[i]); // Ensure event is non-signaled before starting
            ResumeThread(threadHandles[i]);
            // std::cout << "Main: Assigned initial block " << blockIdx << " to thread " << i << " and resumed."
<< std::endl;
            threadWorking[i] = true;
            blocksAssignedCount++;
            initialAssignments++;
        } else {
            // Should not happen if nextBlockIndex started at 0, but as a safeguard
             nextBlockIndex.store(numTotalBlocks); // Ensure no more blocks are fetched
             break;
        }
    }
```

```
    std::cout << "Assigned initial " << initialAssignments << " blocks." << std::endl;


    // --- Main Management Loop ---
    // Continue as long as not all blocks have been processed
    while (blocksProcessedCount < numTotalBlocks) {

        // Wait for *any* thread  to signal completion
        // We only wait on events of threads that we know are working
        std::vector<HANDLE> workingEvents;
        for(int i=0; i< numThreads; ++i) {
            if(threadWorking[i]) {
                workingEvents.push_back(eventHandles[i]);
            }
        }
        cout << blocksProcessedCount << " " << numTotalBlocks << endl;
        if (workingEvents.empty()) {
            // This might happen if numThreads > numTotalBlocks and all blocks are done
            // or if something went wrong.
            if (blocksProcessedCount < numTotalBlocks) {
                std::cerr << "Warning: No threads seem to be working, but not all blocks are processed." <<
std::endl;
            }
            break; // Exit loop if no threads are working
        }

        DWORD waitResult = WaitForMultipleObjects(
            workingEvents.size(),    // Number of handles to wait on
            workingEvents.data(),  // Array of handles
            FALSE,                // Wait for ANY object (not all)
            INFINITE              // Wait indefinitely
        );

        if (waitResult >= WAIT_OBJECT_0 && waitResult < (WAIT_OBJECT_0 + workingEvents.size())) {
            // An event was signaled
            int signaledEventIndex = waitResult - WAIT_OBJECT_0;
            HANDLE signaledEvent = workingEvents[signaledEventIndex];

            // Find which thread corresponds to this event
            int finishedThreadId = -1;
            for (int i = 0; i < numThreads; ++i) {
                if (eventHandles[i] == signaledEvent) {
                    finishedThreadId = i;
                    break;
                }
            }

            if (finishedThreadId != -1) {
                blocksProcessedCount++;
                 //std::cout << "Main: Thread " << finishedThreadId << " finished a block. Blocks processed: "
<< blocksProcessedCount << "/" << numTotalBlocks << std::endl;

                // --- Assign Next Block (if available) ---
                int blockIdx = nextBlockIndex.fetch_add(1);


                if (blockIdx < numTotalBlocks) {
                    // Assign new block and resume
                    threadDataList[finishedThreadId].assignedBlock = blockIdx;
                    threadDataList[finishedThreadId].shouldTerminate = false;
                     ResetEvent(eventHandles[finishedThreadId]); // Reset event before resuming
```

```
                ResumeThread(threadHandles[finishedThreadId]);
                // std::cout << "Main: Assigned block " << blockIdx << " to thread " << finishedThreadId << "
and resumed." << std::endl;
                threadWorking[finishedThreadId] = true; // Still working
                blocksAssignedCount++;
            } else {
                // No more blocks, thread is done with work
                // std::cout << "Main: No more blocks to assign to thread " << finishedThreadId << ". It
remains suspended for now." << std::endl;
                 threadWorking[finishedThreadId] = false; // Mark as not working
                // We don't necessarily need to signal termination yet,
                // just don't give it more work. It's already suspended.
            }
        } else {
            std::cerr << "Error: Could not find thread for signaled event." << std::endl;
            // Potentially problematic state, maybe break?
            break;
        }

    } else if (waitResult >= WAIT_ABANDONED_0 && waitResult < (WAIT_ABANDONED_0 +
workingEvents.size())) {
         std::cerr << "Error: Wait abandoned for an event. Thread might have terminated unexpectedly." <<
std::endl;
         // Handle error - maybe try to find which thread and mark it as not working
         break; // Exit loop on error
    }
    else {
        // WAIT_TIMEOUT or WAIT_FAILED
        std::cerr << "Error: WaitForMultipleObjects failed or timed out (INFINITE shouldn't timeout).
Error code: " << GetLastError() << std::endl;
        break; // Exit loop on error
    }
  }

  std::cout << "Main: All blocks processed or no more work to assign." << std::endl;

  // --- Stop Timing ---
  auto endTime = std::chrono::high_resolution_clock::now();
  std::chrono::duration<double, std::milli> duration = endTime - startTime;


  // --- Shutdown Threads ---
  std::cout << "Main: Signaling all threads to terminate..." << std::endl;
  for (int i = 0; i < numThreads; ++i) {
    threadDataList[i].shouldTerminate = true;
    // We need to resume any thread that might be suspended
    // so it can check the termination flag and exit.
    // It's generally safe to resume a thread that's already running.
    // If a thread already exited, ResumeThread might return an error, which is okay.
    ResumeThread(threadHandles[i]);
  }

  std::cout << "Main: Waiting for threads to terminate..." << std::endl;
  // Wait for all thread *handles* (not events) to signal termination
  WaitForMultipleObjects(numThreads, threadHandles.data(), TRUE, INFINITE); // Wait for ALL to
complete
  std::cout << "Main: All threads terminated." << std::endl;


  // --- Cleanup ---
  std::cout << "Main: Cleaning up resources..." << std::endl;
```

```
    for (int i = 0; i < numThreads; ++i) {
        CloseHandle(threadHandles[i]);
        CloseHandle(eventHandles[i]);
    }
    DeleteCriticalSection(&sumCritSec);
    std::cout << "Main: Cleanup complete." << std::endl;

    // --- Calculate Final Pi and Return ---
    double pi_approx = totalSum * N_INV;

    std::cout << "Calculation finished." << std::endl;
    std::cout << "Execution Time: " << duration.count() << " ms" << std::endl;
    std::cout << "Approximate value of Pi: " << std::fixed << std::setprecision(15) << pi_approx <<
std::endl;

    return duration.count(); // Return time for reporting
}

// --- Main Function ---
int main() {
    // List of thread counts to test
    std::vector<int> threadCounts = {1, 2, 4, 8, 12, 16};


    std::cout << "Starting Pi Calculation Benchmark" << std::endl;
    std::cout << "==================================" << std::endl;
    std::cout << "Using formula: pi = (SUM[4/(1+xi^2)]) * (1/N)" << std::endl;
    std::cout << "N = " << N << std::endl;
    std::cout << "Block Size = " << BLOCK_SIZE << std::endl;
    std::cout << "==================================" << std::endl;


    std::vector<double> executionTimes;
    executionTimes.reserve(threadCounts.size());

    for (int count : threadCounts) {
        double time_ms = calculate_pi_parallel(count);
        if (time_ms > 0) { // Store time if calculation was successful
            executionTimes.push_back(time_ms);
        } else {
            // Handle error case if needed, maybe push a sentinel value or skip
            executionTimes.push_back(-1.0); // Indicate failure for this count
            std::cerr << "Calculation failed for " << count << " threads. Skipping." << std::endl;
        }
    }

    // --- Print Summary ---
    std::cout << "\n--- Benchmark Summary ---" << std::endl;
    std::cout << "Threads | Time (ms)" << std::endl;
    std::cout << "--------|----------" << std::endl;
    for (size_t i = 0; i < threadCounts.size(); ++i) {
        std::cout << std::setw(7) << threadCounts[i] << " | ";
        if (executionTimes[i] >= 0) {
            std::cout << std::fixed << std::setprecision(3) << executionTimes[i] << std::endl;
        } else {
            std::cout << "Failed" << std::endl;
        }
    }
    std::cout << "------------------------" << std::endl;

    return 0;
```

}