Parallel Programming Tutorial - Pthread 1

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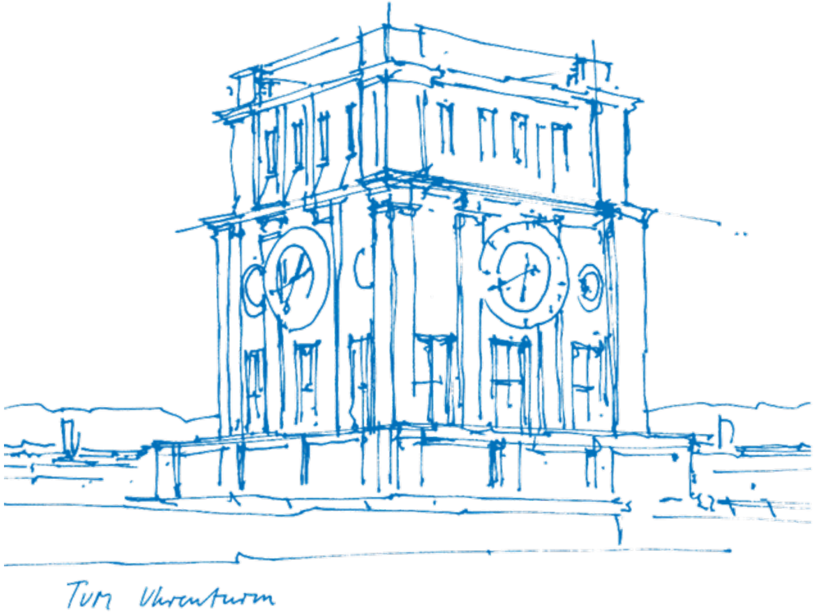

Organization

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- Tutorial starts every Monday at 4:00 PM
- Duration: as long as we need, up to 90 min
- Assignments on parallel programming techniques
- Topics
  - Pthreads (Posix Threads)
  - C++(11/14/17)
  - OpenMP (Open Multi-Processing)
  - Dependency analysis
  - MPI (Message Passing Interface)
- Code examples are in C/C++
- My email address is: andreas.wilhelm(at)in.tum.de

Assignments

Starting this week, you have two weeks time for the first assignment!

- Submission of 80% of the assignments gives 0.3 bonus
- Submission server: https://parprogr.lrr.in.tum.de/Submission
  - requires your LRZ ID and your password
  - password is not stored and only used for authentication
- Submissions will be checked for:
  - plagiarism
  - correctness (output, threads, synchronization)
  - speedup
  - memory leaks
- Assignment instructions are on the last slides
- Final exam will contain small programming tasks (max 50% of the overall questions)
- Example solutions will be presented at the following tutorial session

Assistance on Assignments

Starting this week

- Given by: Jeeta Chacko and Jophin John
- Email: jeetachacko(at)gmail.com / jophinjohn(at)outlook.com
- Room: 01.04.011
- Date and Time:
  - Wednesday 11:30AM - 1:00PM
  - Friday 11:30AM - 1:00PM
- If you have questions, write an email to Jeeta and Jophin or visit the assistance sessions

Resources

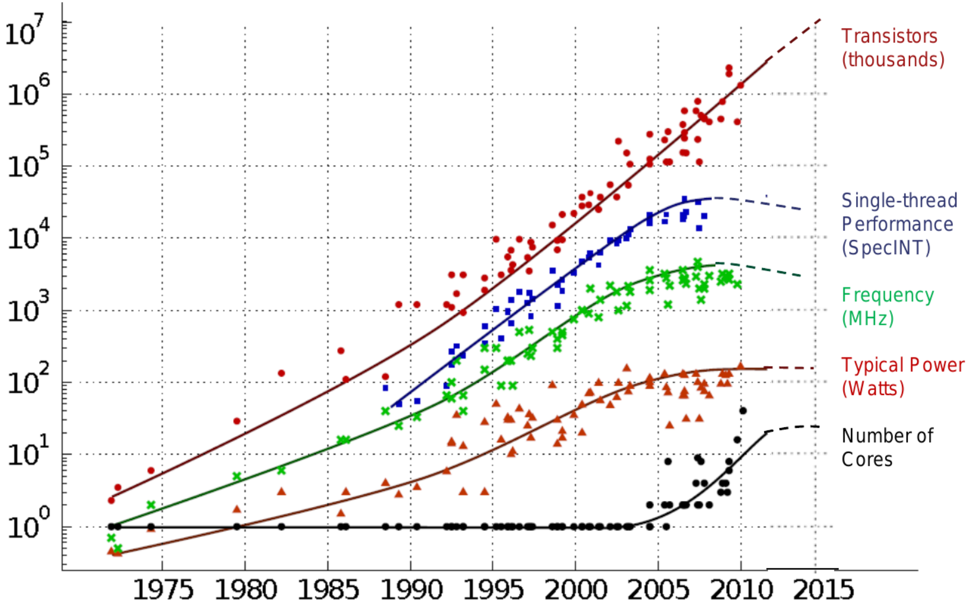
- POSIX Threads Programming
- An Introduction to Parallel Programming, by Peter Pacheco
- Programming with Posix Threads, by David Butenhof
- Patterns for Parallel Programming, by Timothy G. Mattson; Beverly A. Sanders; Berna L. Massingill
- Multithreading in Modern C++, by Rainer Grimm

Course Prerequisites

- Knowledge of C/C++
  - memory management
  - pointers /references
  - global vs. static variables
- C/C++(11/14/17) books
  - (C89) The C Programming Language, Second Edition, by Brian W. Kernighan; Dennis M. Ritchie
  - (C99) C Primer Plus, Fifth Edition, by Stephen Prata
  - (C++11/14) The C++ Programming Language, Fourth Edition, by Bjarne Stroustrup
- Experience with Linux Command Line
- Resources
  - Book: The Linux Command Line
  - Basic video introduction: The Shell
- Knowing GCC
  - An Introduction to GCC, by Brian Gough

Year 2005: The Free Lunch Is Over

- A Fundamental Turn Toward Concurrency in Software
- Software doesn't get (much) faster with the next microprocessor generation
- Developers have to rewrite their software so that multiple computation units are used
- Parallel Programming is hard
  - to write - higher code complexity
  - to do it correctly - easy to introduce bugs
  - to debug - order of thread execution is undefined
  - to make it scalable - will your applications scale with additional cores?
- → Qualified developers are necessary



Original data collected and plotted by M. Horowitz, F. Labonte, O. Shacham, K. Olukotun, L. Hammond and C. Batten
Dotted line extrapolations by C. Moore

Posix Thread Programming

Posix Thread Programming

Definition: Thread

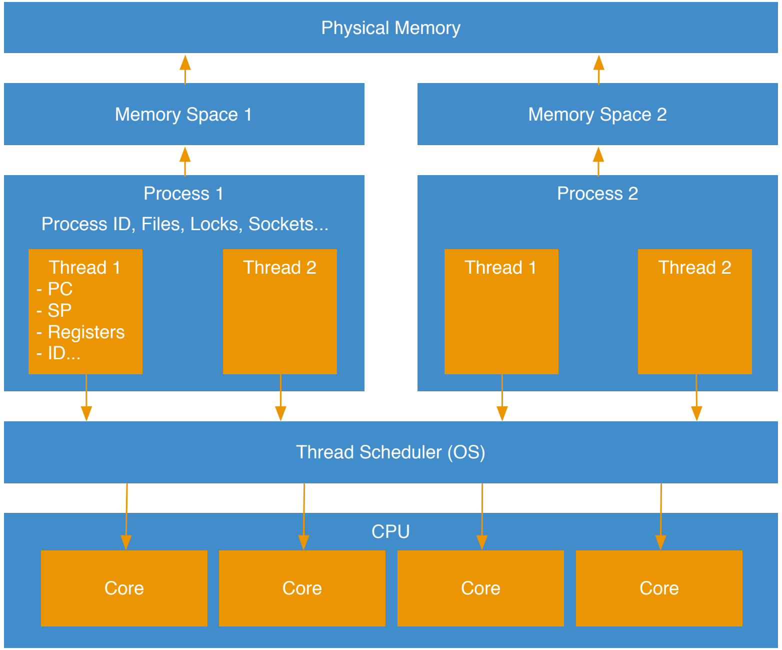
A thread is an independent stream of instructions that can be scheduled to run as such by the operating system.

POSIX Threads (Pthreads)

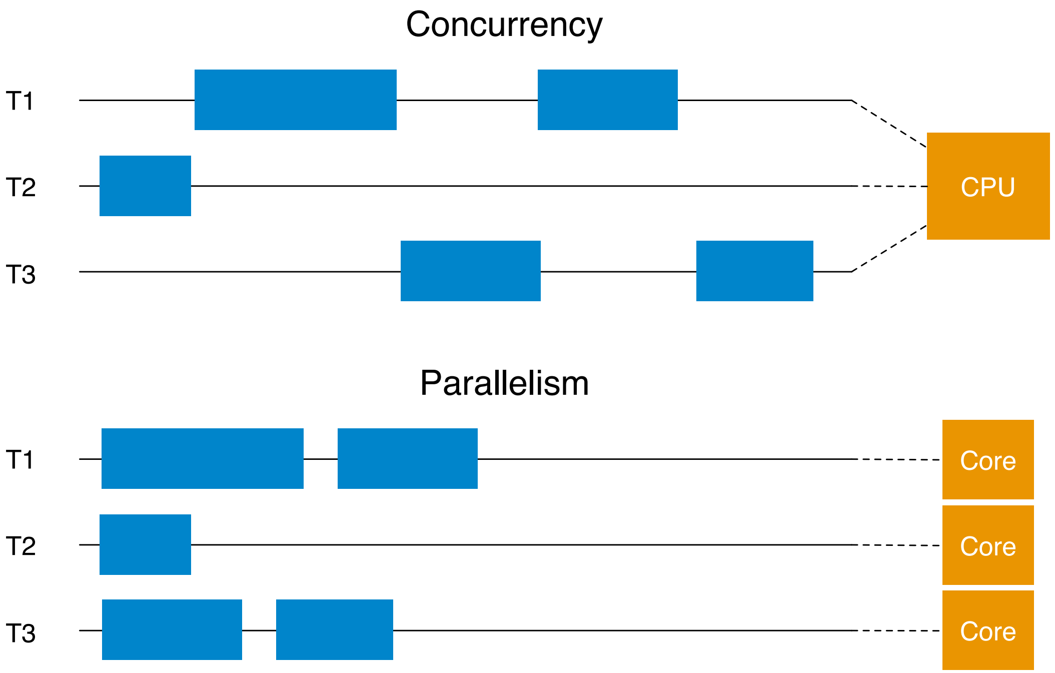
- Were defined in 1995 (IEEE Std 1003.1c-1995)
- Is an API that defines a set of types, functions and constants
- Is implemented with a `pthread.h` header and a thread library
- Natively supported by FreeBSD, NetBSD, OpenBSD, Linux, Mac OS X, Android and Solaris
- Functions can be categorized in four groups:
  - Thread management
  - Mutexes
  - Condition variables
  - Read/write locks and barriers

Why use Multithreading?

- **Performance gains**
  Parallel processing by multiple processor cores
- **Increased application throughput**
  Asynchronous system calls possible
- **Increased application responsiveness**
  Application does not need to block operations
- **Replacing process-to-process communications**
  Threads may communicate by shared-memory
- **Efficient use of system resources**
  Lightweight context switches possible
- **Separation of concerns**
  Some problems are inherently concurrent



Concurrency vs. Parallelism



Pthread Syntax / Semantics

Create Pthreads

```
int pthread_create(pthread_t *thread,
                   const pthread_attr_t *attr,
                   void *(*start_routine) (void *),
                   void *arg);
```

- pthread_t *thread,
  - Pointer to thread identifier.
- const pthread_attr_t *attr
  - Optional pointer to pthread_attr_t to define behavior, if NULL defaults are used.
- void *(*start_routine) (void *),
  - Pointer to function prototype that is started. Function takes void pointer as argument and returns a void pointer.
- void *arg
  - Pointer to the argument that is used for the executed function.

Waiting for Pthread to finish

```
int pthread_join(pthread_t thread,
                 void **retval);
```

- pthread_t thread,
  - Pointer to thread identifier, for which this function is waiting.
- void **retval
  - Optional pointer pointing to a void pointer. This can be used to return data of undefined size.

Create Pthreads - Example

```c
#include <stdio.h>
#include <pthread.h>

void* hello(void* args)
{
  printf("Hello World from pthread!\n");
  return NULL;
}

int main()
{
  pthread_t thread;

  pthread_create(&thread, NULL, &hello, NULL);
  printf("Hello World from main!\n");
  pthread_join(thread, NULL);
}
```

Compile & Output

```
gcc -pthread -Wall -o hello_world hello_world.c
```

```
Hello World from main!
Hello World from pthread!
```

More than One: Hello World with Pthreads Ver. 1

```c
#include <stdlib.h>

int main()
{
  int num_threads = 3;
  pthread_t *thread = (pthread_t*) malloc(num_threads * sizeof(*thread));

  for (int i = 0; i < num_threads; i++)
    pthread_create(thread + i , NULL, &hello , NULL );

  for (int i = 0; i < num_threads; i++)
    pthread_join(thread[i], NULL );
}
```

Output

```
[user]$ ./hello_world_2
Hello World from pthread!
Hello World from pthread!
Hello World from pthread!
```

Single Argument: Hello World with Pthreads Ver. 2

```
void * hello(void *ptr)
{
  int arg = *(int*)ptr;
  printf(”Hello World from pthread %d!\n”, arg);
  return NULL;
}
```

Single Argument: Hello World with Pthreads Ver. 2

```c
int main()
{
  int num_threads = 3;
  pthread_t *thread;
  int *arg;

  thread = (pthread_t*) malloc(num_threads * sizeof(*thread));
  arg = (int*) malloc(num_threads * sizeof(*arg));

  for (int i = 0; i < num_threads; i++) {
    arg[i] = i;
    pthread_create(thread + i, NULL, &hello, arg + i);
  }

  for (int i = 0; i < num_threads; i++)
      pthread_join(thread[i], NULL );

  free(thread);
  free(arg);
}
```

Output

```
[user]$ ./hello_world_3
Hello World from pthread 0!
Hello World from pthread 1!
Hello World from pthread 2!
```

Many Arguments: Hello World with Pthreads Ver. 3

```
struct pthread_args
{
  long thread_id;
  long num_threads;
};

void * hello(void *ptr) {
  struct pthread_args *arg = (struct pthread_args*)ptr;
  printf("Hello World from %ld of %ld PID = %d TID = %li!\n",
    arg->thread_id,
    arg->num_threads,
    getpid(),
    pthread_self());

  return NULL ;
}
```

Many Arguments: Hello World with Pthreads Ver. 3

```c
#include <unistd.h>
int main() {
  long num_threads = 3;
  pthread_t *thread;
  struct pthread_args *arg;
  thread = (pthread_t*) malloc(num_threads * sizeof(*thread));
  arg = (struct pthread_args*) malloc(num_threads * sizeof(*arg));

  for (int i = 0; i < num_threads; i++) {
    arg[i].thread_id = i;
    arg[i].num_threads = num_threads;
    pthread_create(thread + i, NULL, &hello, arg + i);
  }

  for (int i = 0; i < num_threads; i++)
    pthread_join(thread[i], NULL );

  free(thread);
  free(arg)
}
```

Output

```
[user]$ ./hello_world_4
Hello World from pthread 1 of 3 PID = 23750 TID = 23752!
Hello World from pthread 0 of 3 PID = 23750 TID = 23751!
Hello World from pthread 2 of 3 PID = 23750 TID = 23753!
```

Return Result from Pthread in struct Argument

```c
struct pthread_args
{
  int in, out;
};

void * triple(void *ptr)
{
  struct pthread_args *arg = ptr;
  arg->out = 3 * arg->in;
  return NULL;
}
```

Return Result from Pthread in struct Argument

```c
int main() {
  int num_threads = 3; pthread_t *thread;
  struct pthread_args *arg;

  thread = (pthread_t*) malloc(num_threads * sizeof(*thread));
  arg = (struct pthhread_args*) malloc(num_threads * sizeof(*arg));

  for (int i = 0; i < num_threads; i++){
    arg[i].in = i;
    pthread_create(thread + i, NULL, &triple , arg + i);
  }

  for (int i = 0; i < num_threads; i++){
    pthread_join(thread[i], NULL );
    printf("Triple of %d is %d\n",
            arg[i].in ,
            arg[i].out);
  }
  free(thread);
  free(arg);
}
```

Return Result from Pthread as Pointer to Memory

```

void * triple(void *ptr) {

  int *out = (int*) malloc(sizeof(*out));
  *out = 3 * (*(int*)ptr);

  return (void*)out;
}
```

Return Result from Pthread as Pointer to Memory

```c
int main() {
  int num_threads = 3, *in;
  pthread_t *thread;

  thread = (pthread_t*) malloc(num_threads * sizeof(*thread));
  in = (int*) malloc(num_threads * sizeof(*in));

  for (int i = 0; i < num_threads; i++) {
    in[i] = i;
    pthread_create(thread + i, NULL, &triple, in + i);
  }

  for (int i = 0; i < num_threads; i++) {
    int *out;
    pthread_join(thread[i], (void*)&out);
    printf("Triple of %d is %d\n", in[i], *out);
    free(out);
  }
  free(thread);
  free(in);
}
```

What have we covered so far?

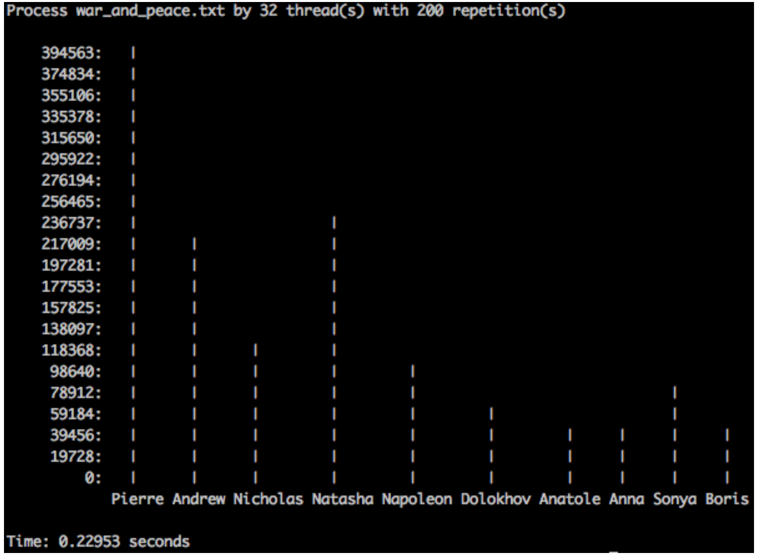
- Creating new threads with pthread_create
- Waiting for threads to finish with pthread_join
- Passing arguments to a pthread function
- Returning results from pthread function

Assignment 1: Actors in “War and Peace”

Assignment: histogram

Starting this week, you have two weeks time. Submission Server is not yet ready, will be announced in Moodle!

- `histogram` counts the occurences of ten famous actors in the book “War and Peace”
- Therefore, `get_histogram` iterates over all words and compares each word with the actor names
- The task is to parallelize `get_histogram`



```
Process war_and_peace.txt by 32 thread(s) with 200 repetition(s)

    394563:   |
    374834:   |
    355106:   |
    335378:   |
    315650:   |
    295922:   |
    276194:   |
    256465:   |
    236737:   |                      |
    217009:   |      |               |
    197281:   |      |               |
    177553:   |      |               |
    157825:   |      |               |
    138097:   |      |               |
    118368:   |      |      |        |
     98640:   |      |      |        |        |
     78912:   |      |      |        |        |                             |
     59184:   |      |      |        |        |        |                    |
     39456:   |      |      |        |        |        |        |     |     |     |
     19728:   |      |      |        |        |        |        |     |     |     |
         0:   |      |      |        |        |        |        |     |     |     |
            Pierre Andrew Nicholas Natasha Napoleon Dolokhov Anatole Anna Sonya Boris

Time: 0.22953 seconds
```

Assignment: histogram

Usage of the program

- Sequential:

```
./histogram_seq war_and_peace.txt <#threads> <#repetitions>
```

- Parallel:

```
./histogram_par war_and_peace.txt <#threads> <#repetitions>
```

Assignment: histogram - get_histogram()

```
void get_histogram(int nBlocks, block_t *block, int* hist, int num_threads)
{
    char current_word[20] = "";
    int c = 0;

    for (int i = 0; i < nBlocks; i++) {  // loop over all blocks
        for (int j=0; j < BLOCKSIZE; j++) {  // loop over all characters

            if(isalpha(blocks[i][j])){  //  add character to current word
                current_word[c++] = blocks[i][j];
            } else {  // the end of the current word
                current_word[c] = '\0';
                for(int k = 0; k < NNAMES; k++) {
                    if(!strcmp(current_word, names[k]))
                        hist[k]++;
                }
                c = 0;
            }
        }
    }
}
```

Assignment: histogram - Provided Files

- Makefile
  - contains rules to build executables
  - available targets: parallel, sequential, all (default), clean
  - 'mode=debug make [target]' to build debug version, use 'make clean' before
- main.c
  - main function - argument handling + file handling + call `get_histogram()`
- histogram.h
  - Header file for histogram.c and histogram_*.c
- histogram.c
  - Defines helper functions
- histogram_seq.c
  - Sequential version of `get_histogram()`.
- student/histogram_par.c
  - Implement the parallel version in this file

Assignment: histogram - Provided Files

- war_and_peace.txt
  - Input data: The book war and peace.
- unit_test.c
  - The unit tests that execute both the serial and parallel version to compare results.

Assignment: Extract, Build, and Run

1. Extract all files to the current directory

   ```
   tar -xvf assignment1.tar.gz
   ```

2. Build the program

   ```
   make [sequential] [parallel] [unit_test]
   ```

   - sequential: build the sequential program
   - parallel: build the parallel program
   - unit_test: builds the unit tests

3. Run the sequential program (100 repetitions)

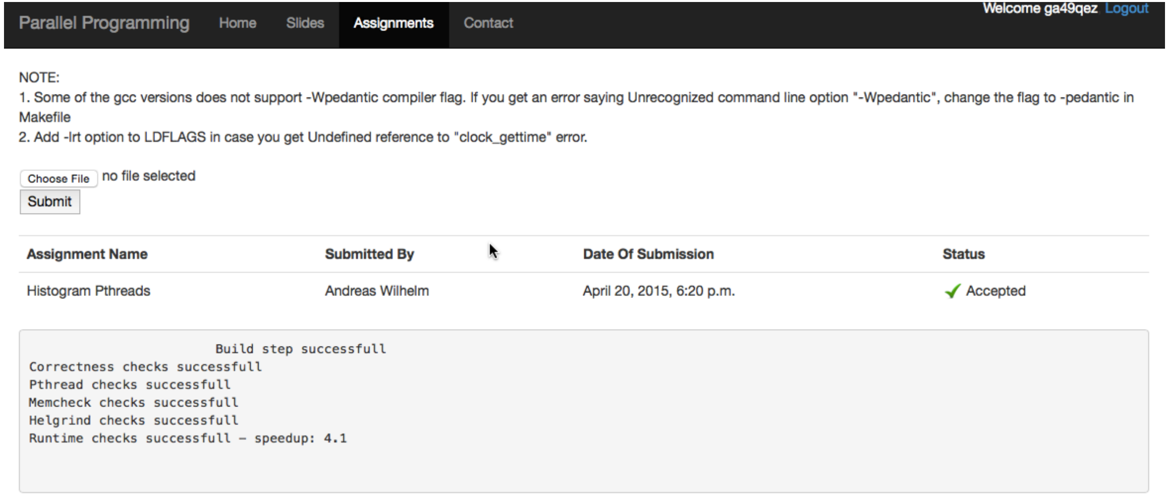
   ```
   student/histogram_seq war_and_peace.txt 1 100
   ```

4. Run the parallel program (with N threads and 100 repetitions)

   ```
   student/histogram_par war_and_peace.txt N 100
   ```

Submission

1. Log into the website
2. Go to Assigments
3. Use the link for Assignment 1
4. Upload your `histogram_par.c` file
5. Press Submit



NOTE:
1. Some of the gcc versions does not support -Wpedantic compiler flag. If you get an error saying Unrecognized command line option "-Wpedantic", change the flag to -pedantic in Makefile
2. Add -lrt option to LDFLAGS in case you get Undefined reference to "clock_gettime" error.

Assignment Name	Submitted By	Date Of Submission	Status
Histogram Pthreads	Andreas Wilhelm	April 20, 2015, 6:20 p.m.	✓ Accepted

```
                        Build step successfull
Correctness checks successfull
Pthread checks successfull
Memcheck checks successfull
Helgrind checks successfull
Runtime checks successfull - speedup: 4.1
```