C++ Parallelisation

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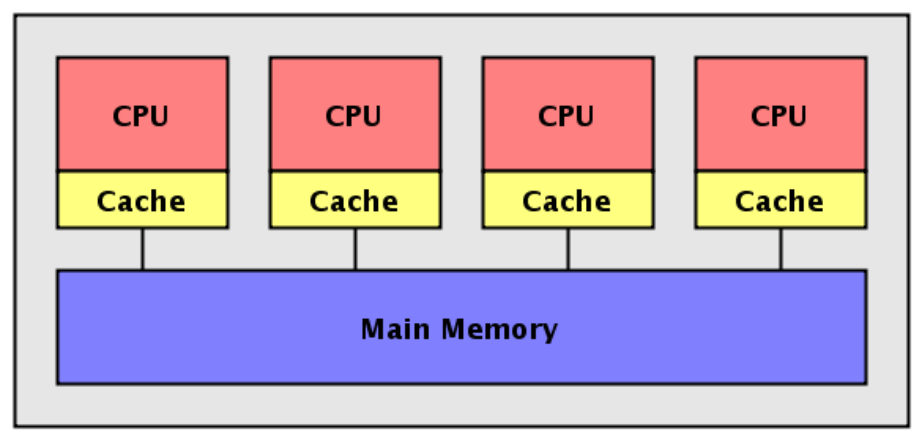
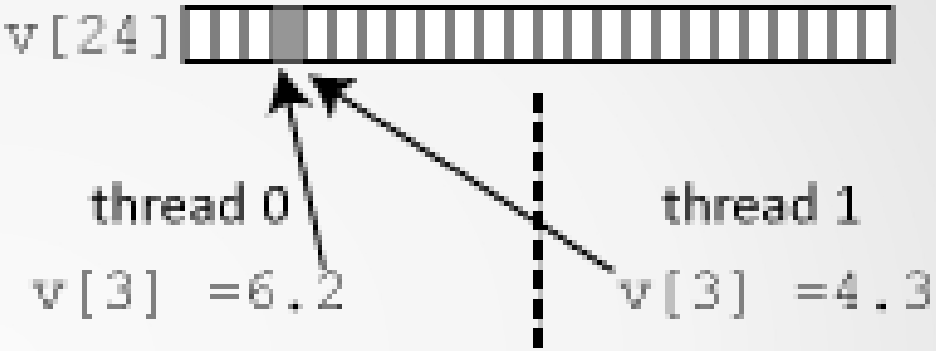
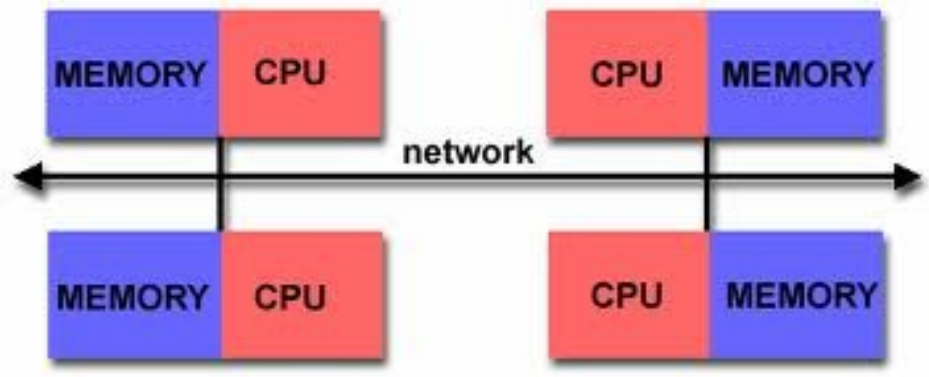
Shared memory

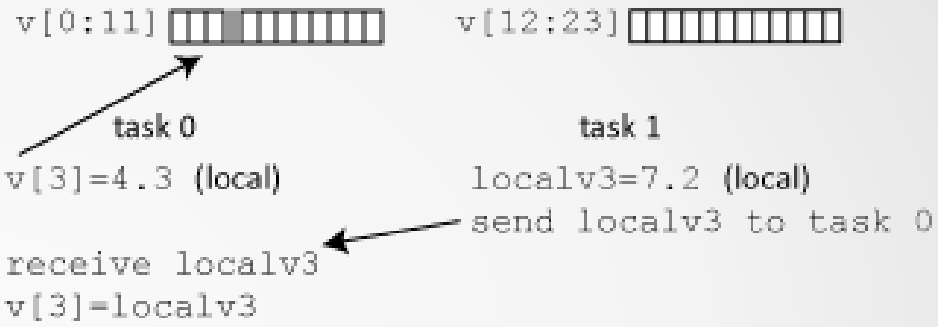




- two threads of execution can both address the same variables in a uniform manner, hereby assigning to an element of a vector whose components are in the virtual memory of the task.
- If the programmer wants thread 0 to use the value placed in the array by thread 1, he needs to use a mechanism which assures him that thread 1 has written the value before thread 0 reads it.

Distributed memory





- Each task owns part of the data, and other tasks must send a message to the owner in order to update that data.
- These may be two tasks on the same computer so that they could just share memory, but the programmer is treating them as though they were not.
- Virtual address space is not shared.

C++ libraries for parallelisation

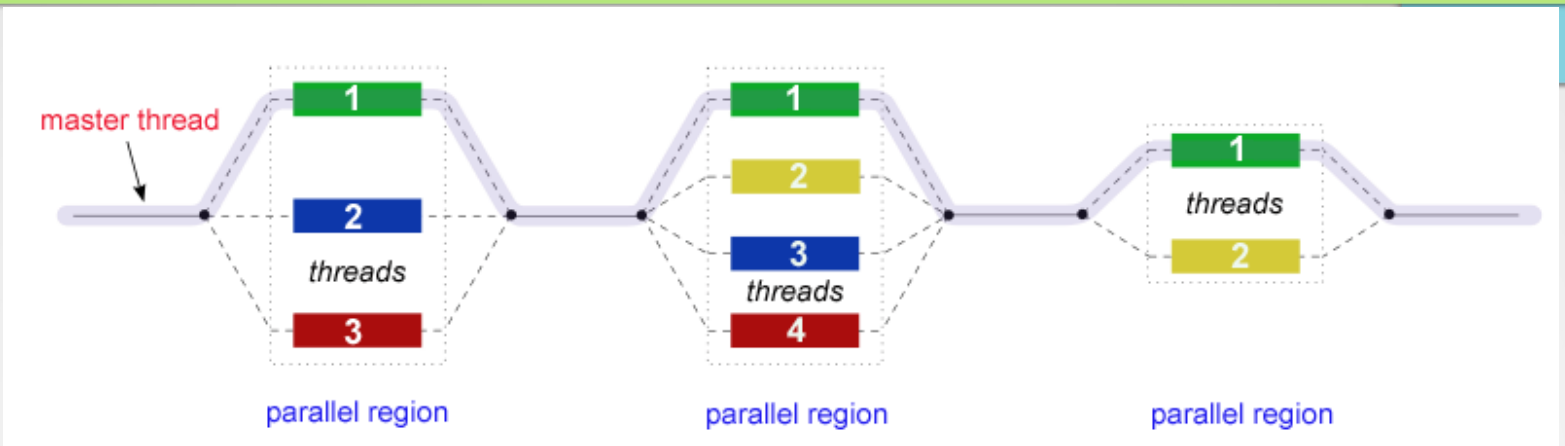
- **Shared memory**
  - OpenMP
  - C++11 Threads
  - Posix Threads
  - Intel TBB
- **Distributed Memory**
  - MPI
- **GPU**
  - CUDA
  - OpenCL
  - OpenACC
  - AMP

- Open Multi-Processing is an API to explicitly direct multi-threaded, shared memory parallelism
- Comprised of three primary API components:
  - Compiler Directives – Pragmas (pre-processor macros)
  - Runtime Library Routines
  - Environment Variables
- OpenMP is not:
  - For distributed memory parallel systems (by itself)
  - Guaranteed to make the most efficient use of shared memory
- **The programmer is responsible for synchronizing input and output.**

Thread based parallelism

- OpenMP programs accomplish parallelism exclusively through the use of threads.
- A thread of execution is the smallest unit of processing that can be scheduled by an operating system.
- Threads exist within the resources of a single process. Without the process, they cease to exist.
- Typically, the number of threads match the number of machine processors/cores. However, the actual use of threads is up to the application.

Fork – Join Model



- FORK: the master thread then creates a team of parallel threads.
- The statements in the program that are enclosed by the parallel region construct are then executed in parallel among the various team threads.
- JOIN: When the team threads complete the statements in the parallel region construct, they synchronize and terminate, leaving only the master thread.
- The number of parallel regions and the threads that comprise them are arbitrary.

OpenMP: General code structure

```
#include <omp.h>
int main ()  {
      int var1, var2, var3;
      // Serial code . . .
      // Beginning of parallel section. Fork a team of threads.
      //Specify variable scoping
#pragma omp parallel private(var1, var2) shared(var3) {
      //  Parallel section executed by all threads
      // Run-time Library calls
      // All threads join master thread and disband
  }
// Resume serial code ..
}
```

Hello World Example

“g++ -fopenmp hello.cc -o hello”

PARALLEL region construct

#pragma omp parallel [clause ...] newline

private (list)

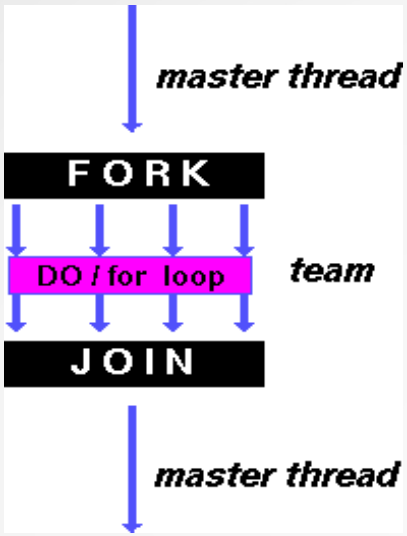
shared (list)

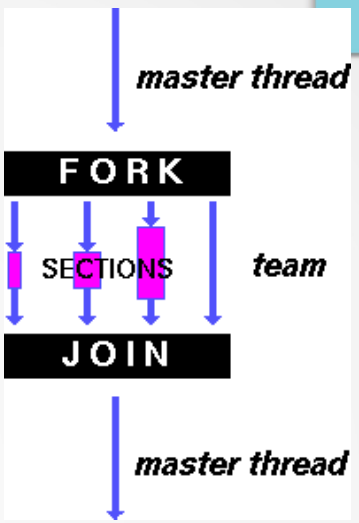
- default (private|shared)

- **Private** – Variable is private to each thread
- **Shared** – variable is shared between threads
- **omp_set_num_threads(4);**

- A parallel region is a block of code that will be executed by multiple threads
- When a thread reaches a PARALLEL directive, it creates a team of threads and becomes the master of the team. The master is a member of that team and has thread number 0 within that team.

Work sharing construct





- A work-sharing construct divides the execution of the enclosed code region among the members of the team that encounter it.
- Work-sharing constructs do not launch new threads
- There is no implied barrier upon entry to a work-sharing construct, however there is an implied barrier at the end of a work sharing construct.

#pragma omp for [clause ...]
schedule (type [,chunk])

- SCHEDULE: Describes how iterations of the loop are divided among the threads in the team.
- STATIC: Loop iterations are divided into pieces of size chunk and then statically assigned to threads.
- DYNAMIC: Loop iterations are divided into pieces of size chunk, and dynamically scheduled among the threads; when a thread finishes one chunk, it is dynamically assigned another.
- GUIDED: Iterations are dynamically assigned to threads in blocks as threads request them until no blocks remain to be assigned. The size of the initial block is proportional to:
  - number_of_iterations / number_of_threads
- Subsequent blocks are proportional to
  - number_of_iterations_remaining / number_of_threads

Example 2: Array addition

Adding two arrays of c[N] = a[N]+b[N]

Example 3:

Sum += a[N] * b[N]

What went wrong with Example 3?

- Addition was happening in as and when a thread was executed.
- Although the variable “sum” is shared, the print statement doesn't wait for all the threads to be completed.
- OpenMP has a feature called “reduction”: A private copy for each list variable is created for each thread. At the end of the reduction, the reduction variable is applied to all private copies of the shared variable, and the final result is written to the global shared variable.
  - reduction(+:result)

Exercise

- OpenMP implementation of Matrix multiplication
- Threads share row iterations according to a predefined chunk size.

$$C[m][n] = a[m][k] * b[k][n]$$

Atomic, Barrier and Critical

- **#pragma omp barrier**
  - to add a barrier to wait for all threads to finish before proceeding
- **#pragma omp critical**
  - Only one thread has access at a given time. Useful for writing to a memory location.
- **#pragma omp atomic**
  - the ATOMIC directive specifies that a specific memory location must be updated atomically, rather than letting multiple threads attempt to write to it. In essence, this directive provides a mini-CRITICAL section

C++11 (Threads)

- Perhaps one of the biggest change to the language is the addition of multithreading support. Before C++11 – OpenMP, MPI to target multicore systems.
- Std::threads
  - The class thread represents a single thread of execution. Threads allow multiple pieces of code to run asynchronously and simultaneously.
- The C+11 standard provides std::mutex primitive. A mutex object also provides member functions – lock() and unlock( ) - to explicitly lock or unlock a mutex. The most common use of a mutex is when one wants to protect a particular block of code. To this end the C++ standard library provides the std::lock_guard<> template

References

- people.ds.cam.ac.uk/nmm1/OpenMP/
- https://computing.llnl.gov/tutorials/openMP/