Computação Paralela

Mest. Int. Engenharia Computacional

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OpenMP

- **Open** *specifications for* **Multi Processing** *via collaborative work between interested parties from the hardware and software industry, government and academia*

OpenMP

- **Shared Memory Programming Model**
- Cooperation of several hardware and software companies (Sun, Intel, Fujitsu, IBM, AMD, HP, SGI, …)
- Parallel Programming API for multiprocessor / multicore architectures
- Languages: C/C++ or Fortran
- OS: Unix/Linux or Windows
- **OpenMP is a specification not an implementation!**

OpenMP objectives

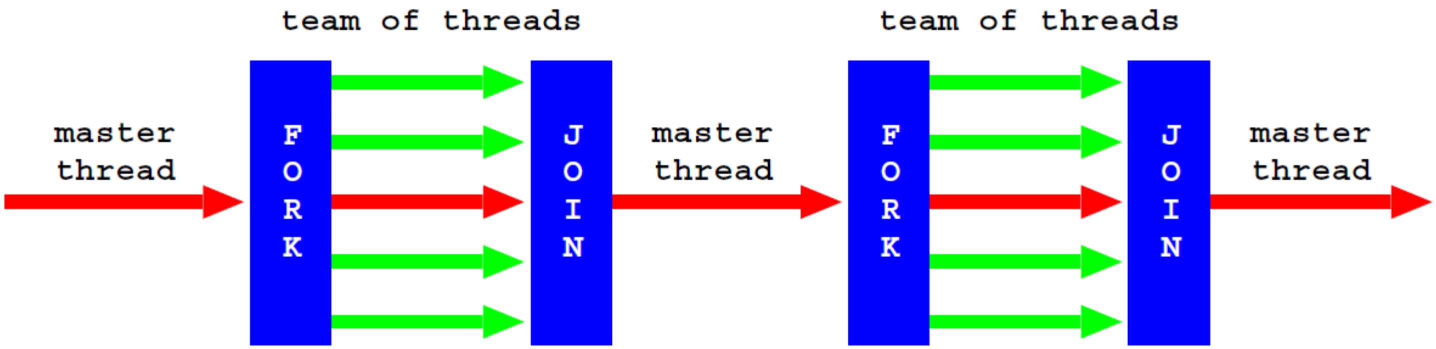
- Portable programming model for shared memory architectures
- Simple set of programming directives
- Enable incremental parallelism for sequential programs
- Efficient implementations for different problems

OpenMP Programming model

- Explicit parallelism
  - Programmer is responsible for annotating execution tasks and synchronization points
  - Embedded compiler directives
- Implicit multithreading
  - Process is a set of threads that communicate through shared variables
  - Creation and termination of threads is performed implicitly by the execution environment
    - Global address space is shared by all threads
    - Variables may be shared or private for each thread

OpenMP fork-join execution

- Program initiates with a single (master) thread
- Executes sequentially until parallel region defined by OpenMP constructor, and then:
  - Master thread forks “team of threads”
  - Parallel region code is executed concurrently by all threads (including master thread)
  - There is an implicit barrier at the end of parallel region
  - “team of threads” terminates and master thread continues sequentially



From CP@FCUP

OpenMP API

- API includes
  - Compiler directives: **`#pragma omp <directive>`**
  - Library of functions declared at **`omp.h`**
  - Environment variables (**`OMP_NUM_THREADS`**; …)
- OpenMP code
  - Must include **`omp.h`** header file

    ```
    #include <omp.h>
    ```
  - To compile with gcc use -fopenmp option

    ```
    gcc -fopenmp myprog.c …
    ```

omp parallel directive

`#pragma omp parallel [clause, …]`

- Defines parallel region
- Number of threads determined by:
  - Only master if **`if(expr)`** clause is used and **`expr`** is false
  - Number defined by **`num_threads(expr)`** clause
  - Number defined by last call to **`omp_set_num_threads(expr)`**
  - Number defined by environment variable **`OMP_NUM_THREADS`**
  - Implementation dependent

Hello.c

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

int main ()
{
    #pragma omp parallel
    {
    int ID = omp_get_thread_num();

    printf("Hello (%d) ", ID);
    printf("World (%d) \n", ID);
    }
}
```

OpenMP basic functions

- **`int omp_get_thread_num(void);`**
  - Returns thread id from 0 to n-1, where n is the number of threads
  - Master thread has id 0
- **`int omp_get_num_threads(void);`**
  - Returns the number of active threads
- **`void omp_set_num_threads(int num_threads);`**
  - Specifies the maximum number of threads to be used in the next parallel regions
  - Can only be called from sequential code

Shared and private variables

```
#pragma omp parallel shared(list1) private(list2)
```

- Shared variables
  - Shared by all threads
  - Avoid race conditions!
- Private variables
  - Duplicated in each thread
  - Initial value is undefined
  - Value after parallel region is undefined
- Variables are shared by default
  - Can be changed by using **`default(mod)`** clause
    - **`mod`**: **`private`**, **`shared`**, **`none`**
- Variables declared inside parallel region are private

Fistprivate variables

```
#pragma omp parallel fistprivate(list)
```

- Firstprivate variables
  - Duplicated in each thread
  - Initial value is copied from value of variable with the same name
  - Can be used to improve efficiency
    - Latency of reading private variable may be lower than latency of reading shared variable by all threads

Example: Dot product

```
int dot_product(int* u, int* v, int n) {
    int r = 0;
    for (int i = 0; i < n; i++) {
        r += u[i] * v[i];
    }
    return r;
}
```

- Partition iterations / vector among threads
- Reduction of partial results

Example: Dot product

First version (incorrect!):

```
int dot_product(int* u, int* v, int n) {
  int r = 0;
  #pragma omp parallel
  {
    int rank = omp_get_thread_num();
    int my_n = n / omp_get_num_threads();
    for (int i = rank * my_n; i < (rank+1)*my_n; i++)
      r += u[i] * v[i];
  }
  return r;
}
```

- Manual partition
- Error prone

Example: Dot product

Better version:

```
int dot_product(int* u, int* v, int n) {
  int r = 0;
  #pragma omp parallel
  {
    #pragma omp for reduction(+:r)
    for (int i = 0; i < n; i++)
      r += u[i] * v[i];
  }
  return r;
}
```

- **`#pragma omp for`**
  - distributes iterations among threads
- Reduction is automatically performed by using **`reduction`** clause
- Scheduling may be controlled through **`schedule`** clause

Example: Dot product

Even better version:

```
int dot_product(int* u, int* v, int n) {
  int r = 0;
  #pragma omp parallel for reduction(+:r)
  for (int i = 0; i < n; i++) {
    r += u[i] * v[i];
  }
  return r;
}
```

- `#pragma omp parallel for`
  - creates parallel region and distributes iterations among threads

OpenMP Reduction

- OpenMP reduction clause:
  - **`reduction (op : list)`**
- Inside a parallel or a work-sharing construct:
  - A local copy of each list variable is made and initialized depending on the "op" (e.g. 0 for "+").
  - Updates occur on the local copy.
  - Local copies are reduced into a single value and combined with the original global value.
- The variables in "list" must be shared in the enclosing parallel region.

```
double ave=0.0, A[MAX]; int i;
#pragma omp parallel for reduction (+:ave)
for (i=0;i< MAX; i++) {
   ave + = A[i];
}
ave = ave/MAX;
```

OpenMP Reduction

Operator	Initial value
+	0
*	1
-	0
min	Largest pos. number
max	Most neg. number

C/C++ only

Operator	Initial value
&	1
|	0
^	0
&&	1
||	0

OpenMP Mutual Exclusion

- OpenMP has constructs to enable mutual exclusion among threads
- 3 different ways:
  - **`omp critical`**
    - Defines critical region
    - Can be used for any code
  - **`omp atomic`**
    - Mutual exclusion for atomic variable updates
    - Only for simple memory updates
      - x *binop*= *expr*; x++; ++x; x--; --x
  - Explicit use of locks

OpenMP Mutual Exclusion

- **`omp critical`**

```
int dot_product(int* u, int* v, int n) {
  int r = 0;
  #pragma omp parallel
  {
    int private_r = 0;
    #pragma omp for
    for (int i = 0; i < n; i++)
      private_r += u[i] * v[i];
    #pragma omp critical
    r += private_r;
  }
  return r;
}
```

OpenMP Mutual Exclusion

- **`omp atomic`**

```
int dot_product(int* u, int* v, int n) {
  int r = 0;
  #pragma omp parallel
  {
    int private_r = 0;
    #pragma omp for
    for (int i = 0; i < n; i++)
      private_r += u[i] * v[i];
    #pragma omp atomic
    r += private_r;
  }
  return r;
}
```

OpenMP Mutual Exclusion

- Locks

```
int dot_product(int* u, int* v, int n) {
  int r = 0;
  omp_lock_t lock;
  omp_init_lock(&lock); // initialize lock
  #pragma omp parallel
  {
    int private_r = 0;
    #pragma omp for
    for (int i = 0; i < n; i++)
      private_r += u[i] * v[i];
    omp_set_lock(&lock); // acquire lock
    r += private_r;
    omp_unset_lock(&lock); // release lock
  }
  omp_destroy_lock(&lock); // destroy lock
  return r;
}
```

OpenMP other synchronization

- **`omp master`**
  - Executed only be master thread
  - Ignored by others; no synchronization
- **`omp single`**
  - Executed by a single thread
  - Implicit barrier for all threads
    - Except **`nowait`** clause is used
- **`omp barrier`**
  - Explicit barrier

OpenMP `schedule` clause

- `schedule(static[,chunk])`
  - Each thread has fixed number of iterations
- `schedule(dynamic[,chunk])`
  - Each thread grabs "chunk" iterations off a queue until all iterations have been handled
- `schedule(guided[,chunk])`
  - Threads dynamically grab blocks of iterations
  - The size of the block starts large and shrinks down to size "chunk" as the calculation proceeds.
- `schedule(runtime)`
  - Schedule and chunk size taken from the OMP_SCHEDULE environment variable (or the runtime library).
- `schedule(auto)`
  - Schedule is left up to the runtime to choose (does not have to be any of the above).