Calcul Parallèle avec OpenMP

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OpenMP Overview

OpenMP (Open specifications for MultiProcessing) API for multithreaded applications

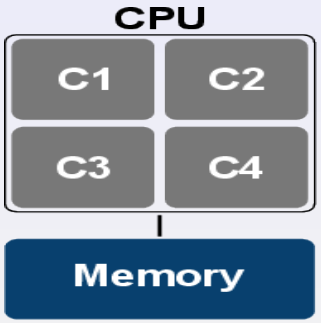
- A set of compiler directives and library routines for parallel application programmers
- Greatly simplifies writing multi-threaded (MT) programs in Fortran, C and C++
- Standardizes lats 20 years of Symmetric Multi-Processing (SMP) practice

Suitable architectures

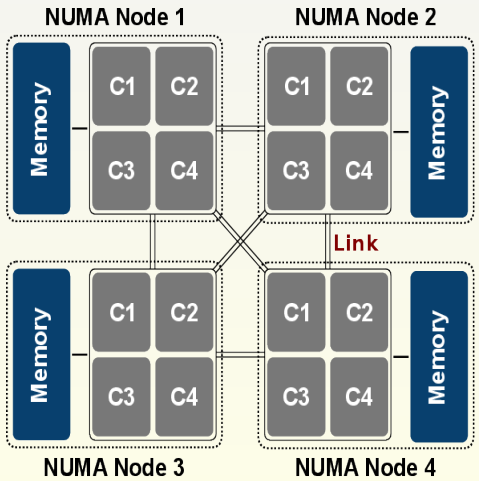
- Multi-threading processors
- Multi-core machines
- Shared-memory machines

Shared memory architecture for SMP

Architecture **UMA** (Uniform Memory Access) : Equal access time



Architecture **NUMA** (Non-Uniform Memory Access) : Different access time



OpenMP Syntax

- OpenMP compiler directives

```
#pragma omp construct[clause[]...]
```

Example : `#pragma omp parallel for`

- Function prototypes and types in the file :

```
#include ‘‘omp.h’’
```

- OpenMP constructs apply to a structured block :
  - a block of one or more statements with one point of entry at the top and one point of exit at the bottom.
  - a structured block can contain an `exit()`

Check if your environment works

hello_omp.c

```
#include <stdio.h>
#include "omp.h"
int main()
{
   int mytid=-1, nb_ths=0;
   #pragma omp parallel
   {
     nb_ths=omp_get_num_threads(); mytid=omp_get_thread_num();
     printf("Hello World from tid %d  %d \n", mytid, nb_ths);
   }
return 0;
}
```

Compile : `gcc -fopenmp hello_omp.c`
Set the number of threads : `export OMP_NUM_THREADS=8`
Run : `./a.out`

Check if your environment works

hello_omp.c 2

```
#include <stdio.h>
#include "omp.h"
int main()
{
   int mytid=-1, nb_ths=0;
   omp_set_num_threads(8);
   #pragma omp parallel
   {
     nb_ths=omp_get_num_threads(); mytid=omp_get_thread_num();
     printf("Hello World from tid %d  %d \n", mytid, nb_ths);
   }
return 0;
}
```

Compile : `gcc -fopenmp hello_omp.c`
Run : `./a.out`

Fixing the number of threadds

Environment variable

```
export OMP_NUM_THREADS=8
```

Runtime library

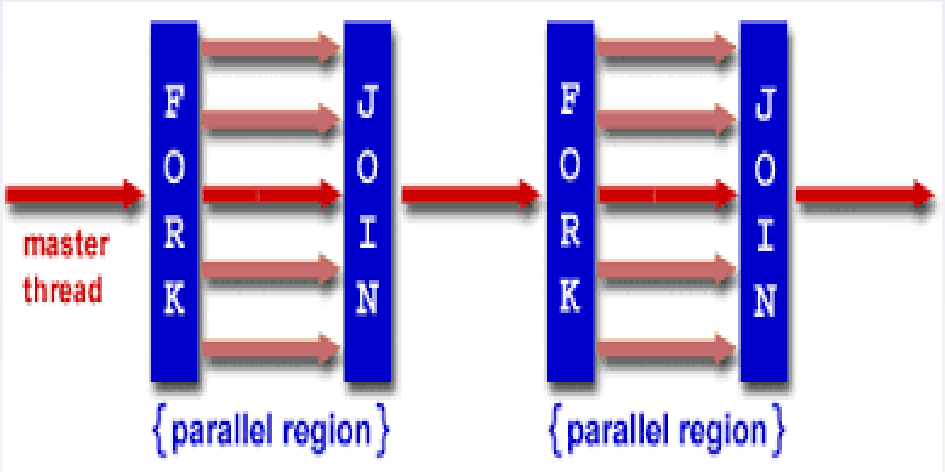
```
omp_set_num_threads(8);
```

Clause of parallel region

```
#pragma omp parallel num_threads(8)
```

Threads interaction

Fork-Join model



OpenMP is a multi-threading, shared address model

- Threads communicate by sharing variables
- Sharing of data causes data conflicts
- Synchronization protects data conflicts
- Synchronization is expensive

Parallel sections

```
#pragma omp parallel sections (+clauses)
{
   #pragma omp section
   {
      block 1
   }
      ...
   #pragma omp section
   {
      block n
   }
} /* synchronization */
```

The blocks defined by `#pragma omp section` are performed in parallel by the threads in the team.

Parallel loop

```
#pragma omp parallel  shared(x,y,z)
{
   #pragma omp for private(i)
   for (i=0; i<DIM; i++)
       z[i] = x[i]*y[i];
}
```

Equivalent combined version

```
#pragma omp parallel for shared(x,y,z) private(i)
for (i=0; i<DIM; i++)
    z[i] = x[i]*y[i];
```

Programming example $C = A + B$ serial

```
#include <stdio.h>
#include <stdlib.h>
#define N 4096

int main ()
{
  double A[N][N], B[N][N], C[N][N];
  int i,j;

   for (i = 0; i < N; i++)  /* Initialization */
         for (j = 0; j < N; j++){
              A[i][j] = i*N+j; B[i][j] = i+j;
         }

   for (i = 0; i < N; i++) /* Computing */
         for (j = 0; j < N; j++){
               C[i][j] = A[i][j] + B[i][j];
         }

   return 0;
}
```

Programming example $C = A + B$ parallel

```
#include <stdio.h>
#include <stdlib.h>
#include "omp.h"
#define N 4096

int main ()
{
   double A[N][N], B[N][N], C[N][N];
   int i,j;

   #pragma omp parallel for shared(A,B) private(i,j)
   for (i = 0; i < N; i++)  /* Initialization */
         for (j = 0; j < N; j++){
              A[i][j] = i*N+j; B[i][j] = i+j;
         }

   #pragma omp parallel for shared(A,B,C) private(i,j)
   for (i = 0; i < N; i++) /* Computing */
         for (j = 0; j < N; j++){
               C[i][j] = A[i][j] + B[i][j];
         }
   return 0;
}
```

OpenMP Programming summary

Programming

- Incrementally parallelization
- Multi-task/worksharing
- Variable management (shared/private, initial/final values, etc)
- Threads synchronization

Issues

- Reliability of results
- Deadlocks

`omp parallel` clauses

Clause	Do
`num_threads(nt)`	the number of threads to use
`private(list)`	declare private variable to each thread
`shared(list)`	variables shared by the threads in the team
`firstprivate(list)`	`private` + pre-initialization
`lastprivate(list)`	`private` + the final value of variable is the last one in the last iteration
`reduction(operator:list)`	Peform a reduction on all scalar variables in `list` using the specified `operator`

`omp for` clauses

Clause	Do
`private(list)`	declare private variables to each thread
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`reduction(operator:list)`	Peform a reduction on all scalar variables in `list` using the specified `operator`
`schedule(type)`	Specify how iterations are divided (`static, dynamic, guided`)
`nowait`	avoid the implicit barrier at the end of the `for`-lo

Dot product $x^\top y = \sum x_i y_i$

```
#include <math.h>
#include <stdio.h>
#include <stdlib.h>
#include "omp.h"
int main(){
   int  i,n=10000;
   double   u[n], v[n], s,sx, ts, te;

    for (i=0; i<n; i++){
       u[i] = 1.0/3.0; v[i] = 1.0/3.0;
     }
    sx = (double) n/9.0;

   s = 0.0; /* put "#pragma omp single"  before in parallel region */
   ts = omp_get_wtime();
   #pragma omp parallel for schedule(static) reduction(+:s)
   for (i=0; i<n; i++) s += u[i]*v[i];
   te = omp_get_wtime()-ts;

   printf("s-sx=%15.8e  elapsed time = %f \n",s-sx,te);
   return 0;
}
```

Jacobi's method

Solve

$$Ax = b$$

by the Jacobi iteration :

$$\begin{aligned} x_i^{(k+1)} &= \frac{1}{a_{ii}} \left(b_i - \sum_{j=1}^{i-1} a_{ij} x_j^{(k)} - \sum_{j=i+1} a_{ij} x_j^{(k)} \right), \\ &= \frac{1}{a_{ii}} \left(b_i + a_{ii} x_i^{(k)} - \sum_{j=1}^{n} a_{ij} x_j^{(k)} \right) \end{aligned}$$

Convergence if

$$\| Ax^{(k)} - b \| < \varepsilon \| b \|$$

THANK YOU FOR YOUR ATTENTION