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- The OPENMP library contained in both Gnu and Intel compilers allows these operations to be performed.
Outline

- OPENMP: definition
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Definition of the computing world
Outline

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- Compiling and running an OPENMP program, environment variables
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- Conclusion and references.
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- Programming with OPENMP can be simple. It consists in inserting directives into an existing sequential program. In general, you do not destroy the original code! This means that the program can still operate sequentially or by using calculation units associated with a memory single center.
- Since computing sites are made up of one or more computers and networked, the ideal is to combine OPENMP and MPI, but it’s more complicated for development.
Computing world: definition

Memory

Network

Unit

Code
#include <iostream>
#include <omp.h>
using namespace std;
int main()
{
    #pragma omp parallel
    {
        cout << "Hello, world!" << endl;
    }
    cout << "Ciao, mondo!" << endl;
}
the `#pragma omp parallel` and the following braces indicate that the code of this block must be parallelized.

To compile this program with gcc:
```bash
gcc hello.c -fopenmp -o hello
```

To compile this program with intel:
```bash
icc hello.c -openmp -o hello
```

To build and run with codeblocks. To ensure the openmp functionality, open “Compiler and debugger settings”, put “-fopenmp” in “other options”, and “-lgomp -pthread” in “Other linker options”.

If you run this program, it chooses the number of units available. To fix the number of units, the environment variable in the terminal window must be set before launching the program
```bash
export OMP_NUM_THREADS = 20
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Compiling and running a program OPENMP, environment variables

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- Thus the Hello, World print will appear as many times as calculation (virtual) units have been solicited.
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To fix the number of units, the environment variable in the terminal window must be set before launching the program:
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The number of units is virtual, and does not necessarily correspond to the physical number of cores. However, for a simulation code, the number of units number should not be less than or equal to the number of cores. Indeed, in many cases, the running time cannot decrease if you exceed this limit (to subtleties with multitreading).
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The time associated with this process is in the order of $0.1 \mu s$. Again very much faster than clock time of the processor.
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The compiler will split the loop into different parts executed on virtual units. Once executed, the program destroys the threads.

Additional instructions can be added to the previous statement that specify which variables are common to all threads and those that are internal. By default, the compiler is supposed to guess, but nothing prevents you from guiding it to make the right choices.

For a loop with a loop index called `i`, we can write

```c
#pragma omp parallel for default (shared), private (i)
```

By changing the `OMP_NUM_THREADS` statement, you can change the default number of threads used.
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One can look at what happens with the unix instruction `top` in another terminal window that the percentage is greater than 100 %. This illustrates the fact that the program mobilizes multiple computing units at runtime.

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For a loop with a loop index called `i`, we can write `# pragma omp parallel for default (shared), private (i)`.

By changing the OMP `_NUM_THREADS` statement, you can change the default number of threads used.
```cpp
#include <iostream>
#include <cmath>
#include <vector>
#include <omp.h>

using namespace std;

double essai(double x)
{
    return (5.0 + 10.0 * x + x * x * exp(x) * log(x + 0.1) + sqrt(fabs(x)));
}

int main()
{
    const int NITER = 200000000;
    vector<double> a(NITER);
    #pragma omp parallel for default(shared)
    for (int j = 0; j < NITER; j++)
    {
        a[j] = essai(j * 0.01);
    }
    exit(0);
}
```
There are several internal functions that allow to have information about parallel processes and / or modifies inside of the program how the parallelization is carried out.

- `omp_get_num_threads()` gives the number of threads,
- `omp_get_thread_num()` gives the thread label,
- `omp_get_wtime()` gives the time in decimal value.
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Among these functions, let’s mention `omp_get_num_threads()` which gives the number of threads, `omp_get_thread_num()` which gives the thread label and `omp_get_wtime` which gives the time in decimal value.
... int main()
{
    const int NITER = 200000000;
    vector<double> a(NITER);
    double deb, end;
    #pragma omp parallel
    if (omp_get_thread_num() == 0) { deb = omp_get_wtime(); }
    #pragma omp parallel for default(shared)
    for (int j = 0; j < NITER; j++) {
        a[j] = essai(j * 0.01);}
    if (omp_get_thread_num() == 0) { end = omp_get_wtime();
        cout << "omp_elapsed_time= " << (end - deb) << " s" << endl;}
    exit(0);
}
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Reduction

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- The statement is added as argument of a pragma like reduction (operator: list).
- In addition to the usual operations, you can also search for the largest or smallest item in a list.
```cpp
#include <iostream>
#include <iomanip>
#include <cmath>
#include <ctime>
#include <vector>
#include <omp.h>

using namespace std;

double f(double a) { return (4.0 / (1.0 + a*a)); }

int main() {
    const int ITER = 1000000000;
    double pi, sum = 0.0, h;
    h = 1.0 / (double) ITER;
    double startwtime = 0.0, endwtime;

    #pragma omp parallel
    if (omp_get_thread_num() == 0) { startwtime = omp_get_wtime(); }

    #pragma omp parallel for reduction(+:sum)
    for (int i = 0; i <= ITER; i++) {
        double x = h * (i - 0.5);
        sum += f(x);
    }

    pi = h * sum;
    if (omp_get_thread_num() == 0) {
        endwtime = omp_get_wtime();
        cout << "wall clock time=" << endwtime - startwtime << endl;
        cout << "pi is approximately " << setprecision(15) << pi <<", Error is " << fabs(pi - M_PI) << endl;
    }
    exit(0);
}
```
OpenMP is a shared memory library, so most code variables are visible, by default, by all threads.
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Sometimes, private variables are needed to avoid conflicts in memory and it is necessary to pass values between the sequential part and in the parallel region. Data management is done through data attribute sharing clauses by adding them to the OpenMP instructions.
The different types of clauses are

- **shared**: data within a parallel region is shared, which means visible and accessible by all threads simultaneously. By default, all variables in the sharing region are shared except for the loop counter.

- **private**: the data within a parallel region is specific to each thread, which means that each thread will have a local copy and use it as a temporary variable. A private variable is not initialized and the value is not retained for use outside the parallel region.

- **default**: Allows the programmer to specify that the default value for data in a region

- **none**: The none option imposes on the programmer to declare each variable in the parallel region using the data attribute sharing clauses.
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Synchronisation clauses

The fine surgery of OPENMP programming is done with synchronization guidelines

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- **ordered**: the structured block is executed in the order in which the iterations will be executed in a sequential loop.

- **barrier** Each thread waits for all other threads until the team reaches this instruction. (Very useful!)
#include <iostream>
#include <cmath>
#include <ctime>
#include <vector>
#include <omp.h>

using namespace std;

double essai(double x)
{
    return (5.0+10.0*x+x*x*exp(x)*log(x+0.1)+sqrt(fabs(x)));}

int main()
{
    const int NITER=200000000;
    vector<double> a(NITER);
    double deb,end;
    int b=0;
    #pragma omp parallel
    if(omp_get_thread_num() == 0) { deb=omp_get_wtime();}
    #pragma omp parallel for default(shared)
    for (int j=0;j<NITER;j++){
        a[j] = essai(j/10.0);
        if((j%1000) ==0){
            #pragma omp atomic
            b++;
        }
    }
    if(omp_get_thread_num() == 0) {end=omp_get_wtime();
    cout<<"ompelapsed time="<< (end-deb)<<"s"<<endl;}
    cout<<"valeur_de_b="<<b<<endl;
    exit(0);
}
The OPENMP library has been developed for several languages (Fortran, C, C++).
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Developing an OPENMP program is easier than the one with the MPI library, but the number of cores (sharing the same memory) is generally less than ten, but significantly lower than by using many computers with the MPI library.