An introduction to

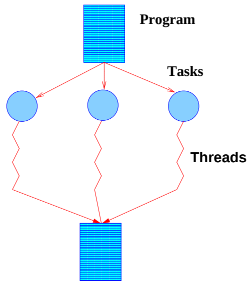
The openMP programming environment

- **Introduction : the openMP model**
- **Basic syntax**
- **A few examples**
- **See also the following site for many resources:**

  http://openmp.org

Threads and the openMP model

➤ openMP implements the Fork-Join model



➤ Makes it easy to parallelize loops or parallel sections of codes

Note: *A thread is a stream of instructions that can be executed in parallel.*

Pros: Arguably the simplest approach to parallel programming.

Cons: Limited to SMPs [Shared memory computers]

The openMP approach

➤ Use C (or C++, Fortran, ...) and add directives / pragmas to:

* Indicate parallel loops,

* Parallel regions of code, ..

* .. and more

➤ Plus a few library routines [e.g., `OMP_GET_THREAD_NUM()`]

➤ Intrinsically designed for Shared Memory SMP machines.

➤ Portable – supported by all High Performance computer vendors: http://openmp.org

➤ ... and implemented in GNU compilers (gcc,..).

➤ Directives/ pragmas:

In C: *#pragma omp ... directives*

In Fortran: *!$OMP ... directives*

```
#pragma omp parallel
{
 ...
//  structured block
 ...
}
```

```
int i;
#pragma omp parallel for
for (i=0; i<n; i++)  {
y[i] += x[i];
...
}
```

➤ These notes will illustrate only a few directives

See http://openmp.org/ for additional details:

- Reference guide for a quick overview
- Specifications [a pdf file] for details

Basic functions

```
omp_get_thread_num()  - get thread number
omp_set_num_threads(nthreads) - set # of threads
omp_get_num_threads() - get number of threads used
```

Example:

```
#include <omp.h>
int omp_get_thread_num();
int main(){
  # pragma omp parallel
  {
    printf("Thread number : %d\n",
    omp_get_thread_num());
  }
}
```


1. Compile with *gcc -o test.ex -fopenmp test.c*
2. Set number of threads with environment variable:

setenv OMP_NUM_THREADS 4

3. Run

```
./test.ex
Thread number: 0
Thread number: 3
Thread number: 2
Thread number: 1
```


Hello World in openMP: pragma parallel

✍1 Compile and run this other version of the previous example

```
#include <stdio.h>
#include <stdlib.h>
int main () {
  int i;
  int omp_get_thread_num();
  printf("Entering parallel threads: \n");
  #pragma omp parallel
  {
  i = omp_get_thread_num();
  printf(" -->> Hello from thread :  %d  \n",i);
 }
  printf(" <<-- Out of threads \n");
}
```


Hello World in openMP: pragma parallel for

```
#include <stdio.h>
#include <stdlib.h>
int main () {
  int i, p;
  int omp_get_thread_num();
  printf(" Entering parallel threads: \n");
#pragma omp parallel for
  for (i=0;i<12; i++) {
  p = omp_get_thread_num();
  printf(" -->> Hello from thread :  %d  \n",p);
 }
 printf(" <<-- Out of threads \n");
}
```

✍2 compile and run:

```
gcc -fopenmp omp_hello.c
```

➤ Can set the number of threads from environment variable...

```
setenv OMP_NUM_THREADS 4
```

➤ ... or in the code with the command

omp_set_num_threads(nthreads)

➤ This freezes the number of threads [takes precedence over environment variable OMP_NUM_THREADS]

✍3 What is the difference between the two examples?

Scoping of variables

➤ Variables can be shared among threads as in

```
#pragma omp parallel shared(var1, var2, ...)
```

➤ Beware of racing between variables.. [no guaranteed order of modifications]

✍4 What can happen if several threads write to the same shared variable? See situation in following example.

Program race.c:

```
#define N_MAX 10000
int main()  {
int i;
double fx, fsum=0.0;
#pragma omp parallel for
 for (i = 1; i <= N_MAX; i++) {
        fx = (double)i ;
        fsum += fx;
 }
 printf("-- sum %f \n", fsum);
}
```


Private variables

Variables can be private – local copies of variables made for each thread – Note: when copies are made they are *not* initialized

```
#pragma omp private(var1, var2, ...)
```

➤ Can set default for scoping of variable by

```
#pragma omp default(DEF)
```

where DEF == one of `private`, `shared`, or `none`.

➤ If no default is set, and there is no explicit clause for scoping, variables are assumed to be `shared`

Example: Dot-Product

```
  omp_set_num_threads(nt);  // nt = # threads
  m = n/nt;     // assumes n divisible by nt (!)
  #pragma omp parallel for private(t, i1, i2, i)
  for (it = 0; it < nt; it++) {
      i1 = it*m;
      i2 = i1+m;
      if (i2 > n) i2 = n;
      t = 0.0;
      for ( i = i1; i <  i2; i++ )
          t +=x[i]*y[i];
      tt[it] = t;
    }
    t = 0.0;
    for (it = 0; it< nt; it++)
      t += tt[it];
```

Critical sections

➤ Solutions to race conditions: `critical` sections which permit a code fragment to be executed by one thread only

```
#pragma omp critical [name]
{
... structured block ...
}
```

➤ Go back to program race.c seen earlier..

Here is how it can be corrected..

a) First declare fx as private..

b) Then summation should be critical. [loss of parallelism]

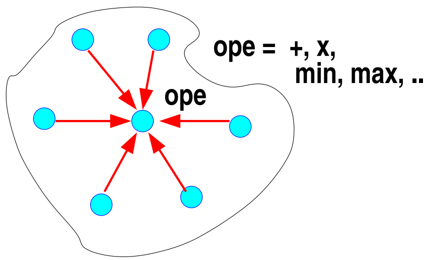
Program race_cor.c:

```
#define N_MAX 10000
int main(){
  int i;
  double fx, fsum;
#pragma omp parallel for private(fx)
  for (i = 1; i <= N_MAX; i++) {
  fx = (double)i ;
#pragma omp critical
  fsum += fx;
}
printf("-- sum %f \n", fsum);
```

➤ Better solution: Reduction operation

Reduction operations

➤ A reduction does a global operation (e.g. a sum) on an array down to one single result. For example $a = \sum_{i=0}^{n-1} x_i$ or $a = \max_{i=0}^{n-1} x_i$, ..



Reduction

Clause syntax: `reduction(<op >: variable)`

Example: Dot product computation seen earlier

```
omp_set_num_threads(nt);
...
t = 0.0;
#pragma omp parallel for reduction(+:t)
for (i = 0; i<n; i++)
    t +=x[i]*y[i];
```

➤ Private copy of t (in clause) is created for each thread.

➤ At the end of reduction, reduction operation $+$ (in clause) is applied to private variable t (in clause) –

➤ Result of this reduction written to 'master' thread (shared variable) t

Sections

➤ Each section executed by one thread
➤ Cannot branch into and out of block of sections

```
#pragma omp sections
{
// section 1
#pragma omp
 {
    block
 }
// section 2
#pragma omp
 {
    block
 }
 ...
}
```


Schedule clauses

➤ Consider the example

```
#pragma omp parallel for
  for (i=0; i<n; i++) {
/*--- cost of function varies
        a lot with i */
        x[i] = some_function(i);
  }
```

Result: poor load balancing. Solution schedule work dynamically.

`schedule (type [,chunk])`

`type` is one of `static, dynamic,guided` or `runtime`

runtime = set by an environment variable

`setenv OMP_SCHEDULE ''type,chunk''` command.

```
#pragma omp parallel for schedule(dynamic)
  for (i=0; i<n; i++) {
/* cost of function varies a lot with i */
      x[i] = some_function(i);
  }
```


A few runtime functions

➤ `omp_get_num_threads ()` returns current number of threads

Note: this is always one in a sequential section.

➤ `omp_set_num_threads (int )` sets number of threads in code

2 other methods for this: environment variable (seen before), and clause [#pragma omp parallel num_threads(3)]

➤ `omp_get_num_procs ()` returns current number of processors available