OpenMP Tutorial

Para saber se OpenMP está instlado no Ubuntu 14.04:

```
dpkg --get-selections | grep openmp
```

```
dpkg --get-selections | grep mpi
```

https://computing.llnl.gov/tutorials/openMP/

C / C++ - General Code Structure

```
#include <omp.h>

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
             .
  Other OpenMP directives
             .
  Run-time Library calls
             .
  All threads join master thread and disband

  }

% Resume serial code
      .
      .
      .

}
```

GNU C/C++	4.4.7	OpenMP 3.0
OpenMP 4.0 Support: according to vendor documentation, beginning with the following compiler versions, OpenMP 4.0		

is supported: - GNU: 4.9 for C/C++		

Compiler / Platform	Compiler	Flag
GNU	gcc	-fopenmp

C / C++ Directives Format

Format:

#pragma omp	directive-name	[clause, ...]	newline
Required for all OpenMP C/C++ directives.	A valid OpenMP directive. Must appear after the pragma and before any clauses.	Optional. Clauses can be in any order, and repeated as necessary unless otherwise restricted.	Required. Precedes the structured block which is enclosed by this directive.

Example:

```
#pragma omp parallel default(shared) private(beta,pi)
```

C/C++

```
#pragma omp parallel [clause ...]  newline
                     if (scalar_expression)
                     private (list)
                     shared (list)
                     default (shared | none)
                     firstprivate (list)
                     reduction (operator: list)
                     copyin (list)
                     num_threads (integer-expression)


% structured_block
```

Notes:

- 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.

- Starting from the beginning of this parallel region, the code is duplicated and all threads will execute that code.

- There is an implied barrier at the end of a parallel section. Only the master thread continues execution past this point.

- If any thread terminates within a parallel region, all threads in the team will terminate, and the work done up until that point is undefined.

How Many Threads?

- The number of threads in a parallel region is determined by the following factors, in order of precedence:
  1. Evaluation of the **`IF`** clause
  2. Setting of the **`NUM_THREADS`** clause
  3. Use of the **`omp_set_num_threads()`** library function
  4. Setting of the **OMP_NUM_THREADS** environment variable
  5. Implementation default - usually the number of CPUs on a node, though it could be dynamic (see next bullet).

- Threads are numbered from 0 (master thread) to N-1

C / C++ - Parallel Region Example

```
#include <omp.h>

main ()  {

int nthreads, tid;

/* Fork a team of threads with each thread having a private tid
variable */
#pragma omp parallel private(tid)
  {

  /* Obtain and print thread id */
  tid = omp_get_thread_num();
  printf("Hello World from thread = %d\n", tid);

  /* Only master thread does this */
  if (tid == 0)
    {
    nthreads = omp_get_num_threads();
    printf("Number of threads = %d\n", nthreads);
    }
  }  /* All threads join master thread and terminate */

}
```

OpenMP Exercise 1

Getting Started

Overview:

- **Login to the workshop cluster using your workshop username and OTP token**
- **Copy the exercise files to your home directory**
- **Familiarize yourself with LC's OpenMP environment**
- **Write a simple "Hello World" OpenMP program**
- **Successfully compile your program**
- **Successfully run your program**
- **Modify the number of threads used to run your program**

GO TO THE EXERCISE HERE

https://computing.llnl.gov/tutorials/openMP/exercise.html

OpenMP Exercise

https://computing.llnl.gov/tutorials/openMP/exercise.html

Exercise 1

1. **Login to the workshop machine**

Workshops differ in how this is done. The instructor will go over this beforehand.

2. **Copy the example files**

    1. In your home directory, create a subdirectory for the example codes and then `cd` to it.

    2.
    ```
    mkdir openMP
    cd  openMP
    ```

    3. Then, copy the C version of the parallel OpenMP exercise files to your openMP subdirectory:

C:	**`cp  /usr/global/docs/training/blaise/openMP/C/* ~/openMP`**

https://computing.llnl.gov/tutorials/openMP/exercise.html

EXAMPLE 1 - hello world

```
/*********************************************************************
* FILE: omp_hello.c        Hello world
* DESCRIPTION:
*   OpenMP Example - Hello World - C/C++ Version
*   In this simple example, the master thread forks a parallel region.
*   All threads in the team obtain their unique thread number and
print it.
*   The master thread only prints the total number of threads.  Two
OpenMP
*   library routines are used to obtain the number of threads and each
*   thread's number.
* AUTHOR: Blaise Barney  5/99
* LAST REVISED: 04/06/05
**********************************************************************
********/
#include <omp.h>
#include <stdio.h>
#include <stdlib.h>

int main (int argc, char *argv[])
{
int nthreads, tid;

/* Fork a team of threads giving them their own copies of variables */
#pragma omp parallel private(nthreads, tid)
  {

  /* Obtain thread number */
  tid = omp_get_thread_num();
  printf("Hello World from thread = %d\n", tid);
```

```
  /* Only master thread does this */
  if (tid == 0)
    {
    nthreads = omp_get_num_threads();
    printf("Number of threads = %d\n", nthreads);
    }

  }  /* All threads join master thread and disband */

}
```

Using your choice of compiler (see above section 4), compile your hello world OpenMP program. This may take several attempts if there are any code errors. For example:

```
gcc -fopenmp omp_hello.c -o hello
```

1. When you get a clean compile, proceed.
2. Run your **`hello`** executable and notice its output.
    - Is it what you expected? As a comparison, you can compile and run the provided **`omp_hello.c`** example program.
3. How many threads were created? By default, the GNU compilers will create 1 thread for each core.
4. Notes:
    - For the remainder of this exercise, you can use the compiler command of your choice unless indicated otherwise.
    - Compilers will differ in which warnings they issue, but all can be ignored for this exercise. Errors are different, of course.

EXAMPLE 2 – workShare1

```
/**********************************************************************
* FILE: omp_workshare1.c            Loop work-sharing
* DESCRIPTION:
*   OpenMP Example - Loop Work-sharing - C/C++ Version
*   In this example, the iterations of a loop are scheduled
dynamically
*   across the team of threads.  A thread will perform CHUNK
iterations
*   at a time before being scheduled for the next CHUNK of work.
* AUTHOR: Blaise Barney  5/99
* LAST REVISED: 04/06/05
**********************************************************************
********/
#include <omp.h>
#include <stdio.h>
```

```
#include <stdlib.h>
#define CHUNKSIZE   10
#define N       100

int main (int argc, char *argv[])
{
int nthreads, tid, i, chunk;
float a[N], b[N], c[N];

/* Some initializations */
for (i=0; i < N; i++)
  a[i] = b[i] = i * 1.0;
chunk = CHUNKSIZE;

#pragma omp parallel shared(a,b,c,nthreads,chunk) private(i,tid)
{
  tid = omp_get_thread_num();
  if (tid == 0)
    {
    nthreads = omp_get_num_threads();
    printf("Number of threads = %d\n", nthreads);
    }
  printf("Thread %d starting...\n",tid);

#pragma omp for schedule(dynamic,chunk)
  for (i=0; i<N; i++)
    {
    c[i] = a[i] + b[i];
    printf("Thread %d: c[%d]= %f\n",tid,i,c[i]);
    }

}  /* end of parallel section */

}
```

EXAMPLE 3 - workShare2

```
/*********************************************************************
* FILE: omp_workshare2.c
* DESCRIPTION:
*   OpenMP Example - Sections Work-sharing - C Version
*   In this example, the OpenMP SECTION directive is used to assign
*   different array operations to each thread that executes a SECTION.
* AUTHOR: Blaise Barney  5/99
* LAST REVISED: 07/16/07
**********************************************************************
/
#include <omp.h>
#include <stdio.h>
#include <stdlib.h>
#define N     50

int main (int argc, char *argv[])
{
int i, nthreads, tid;
float a[N], b[N], c[N], d[N];

/* Some initializations */
for (i=0; i<N; i++) {
  a[i] = i * 1.5;
  b[i] = i + 22.35;
  c[i] = d[i] = 0.0;
  }

#pragma omp parallel shared(a,b,c,d,nthreads) private(i,tid)
{
  tid = omp_get_thread_num();
  if (tid == 0)
    {
    nthreads = omp_get_num_threads();
    printf("Number of threads = %d\n", nthreads);
    }
  printf("Thread %d starting...\n",tid);

  #pragma omp sections nowait
    {
    #pragma omp section
      {
      printf("Thread %d doing section 1\n",tid);
      for (i=0; i<N; i++)
        {
        c[i] = a[i] + b[i];
        printf("Thread %d: c[%d]= %f\n",tid,i,c[i]);
        }
      }

    #pragma omp section
      {
      printf("Thread %d doing section 2\n",tid);
      for (i=0; i<N; i++)
        {
        d[i] = a[i] * b[i];
        printf("Thread %d: d[%d]= %f\n",tid,i,d[i]);
        }
      }

    }  /* end of sections */

    printf("Thread %d done.\n",tid);

  }  /* end of parallel section */

}
```

EXAMPLE

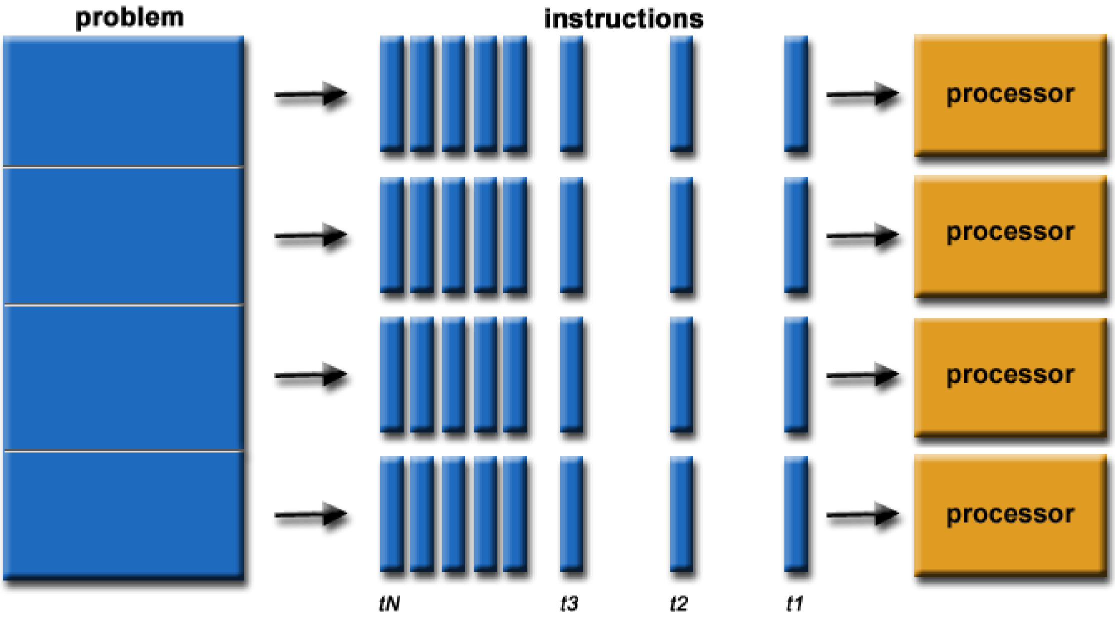
```
/******************************************************************************
* FILE: omp_mm.c              Matrix multiply

* DESCRIPTION:
*   OpenMp Example - Matrix Multiply - C Version
*   Demonstrates a matrix multiply using OpenMP. Threads share row
iterations
*   according to a predefined chunk size.
* AUTHOR: Blaise Barney
* LAST REVISED: 06/28/05
```

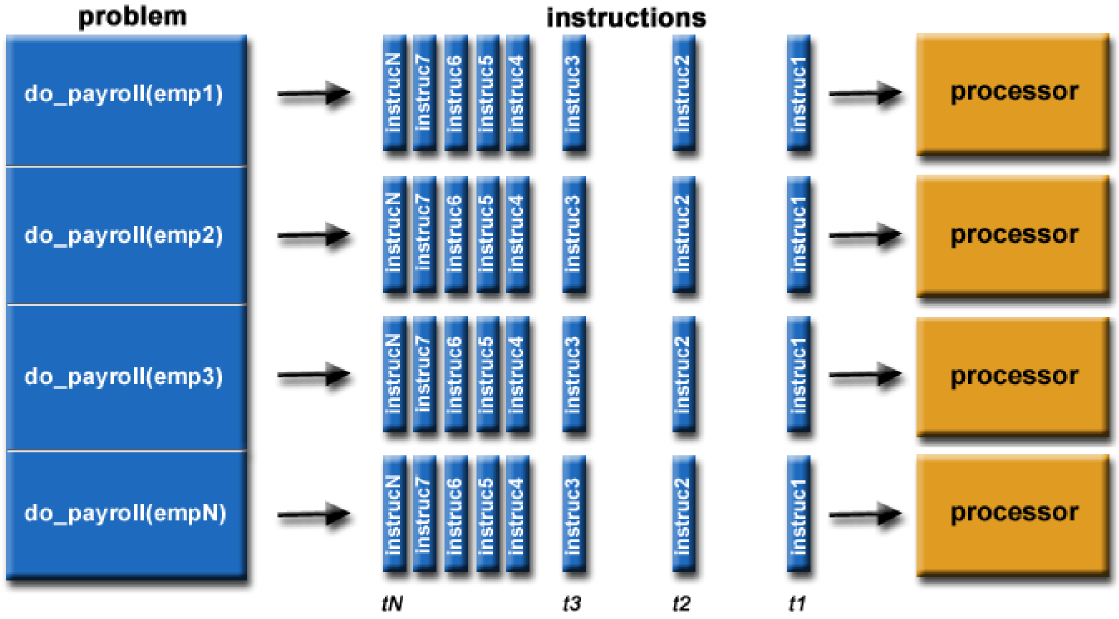
```
**********************************************************************
/
#include <omp.h>
#include <stdio.h>
#include <stdlib.h>

#define NRA 62                  /* number of rows in matrix A */
#define NCA 15                  /* number of columns in matrix A */
#define NCB 7                   /* number of columns in matrix B */

int main (int argc, char *argv[])
{
int     tid, nthreads, i, j, k, chunk;
double  a[NRA][NCA],           /* matrix A to be multiplied */
        b[NCA][NCB],           /* matrix B to be multiplied */
        c[NRA][NCB];           /* result matrix C */

chunk = 10;                    /* set loop iteration chunk size */

/*** Spawn a parallel region explicitly scoping all variables ***/
#pragma omp parallel shared(a,b,c,nthreads,chunk) private(tid,i,j,k)
  {
  tid = omp_get_thread_num();
  if (tid == 0)
    {
    nthreads = omp_get_num_threads();
    printf("Starting matrix multiple example with %d
threads\n",nthreads);
    printf("Initializing matrices...\n");
    }
  /*** Initialize matrices ***/
  #pragma omp for schedule (static, chunk)
  for (i=0; i<NRA; i++)
    for (j=0; j<NCA; j++)
      a[i][j]= i+j;
  #pragma omp for schedule (static, chunk)
  for (i=0; i<NCA; i++)
    for (j=0; j<NCB; j++)
      b[i][j]= i*j;
  #pragma omp for schedule (static, chunk)
  for (i=0; i<NRA; i++)
    for (j=0; j<NCB; j++)
      c[i][j]= 0;

  /*** Do matrix multiply sharing iterations on outer loop ***/
  /*** Display who does which iterations for demonstration purposes
***/
  printf("Thread %d starting matrix multiply...\n",tid);
  #pragma omp for schedule (static, chunk)
  for (i=0; i<NRA; i++)
    {
    printf("Thread=%d did row=%d\n",tid,i);
    for(j=0; j<NCB; j++)
      for (k=0; k<NCA; k++)
        c[i][j] += a[i][k] * b[k][j];
    }
  }   /*** End of parallel region ***/

/*** Print results ***/
printf("******************************************************\n");
printf("Result Matrix:\n");
for (i=0; i<NRA; i++)
  {
  for (j=0; j<NCB; j++)
    printf("%6.2f   ", c[i][j]);
  printf("\n");
  }
printf("******************************************************\n");
printf ("Done.\n");

}
```

https://computing.llnl.gov/tutorials/parallel_comp/

Parallel Computing:

- In the simplest sense, ***parallel computing*** is the simultaneous use of multiple compute resources to solve a computational problem:
  - A problem is broken into discrete parts that can be solved concurrently
  - Each part is further broken down to a series of instructions
  - Instructions from each part execute simultaneously on different processors
  - An overall control/coordination mechanism is employed





- The computational problem should be able to:
  - Be broken apart into discrete pieces of work that can be solved simultaneously;
  - Execute multiple program instructions at any moment in time;
  - Be solved in less time with multiple compute resources than with a single compute resource.
- The compute resources are typically:
  - A single computer with multiple processors/cores
  - An arbitrary number of such computers connected by a network.

OPENMP

C Examples of Parallel Programming with OpenMP

https://people.sc.fsu.edu/~jburkardt/c_src/openmp/openmp.html

OpenMP Exercise

https://computing.llnl.gov/tutorials/openMP/exercise.html

Aprendendo a usar a estrutura OpenMP com GCC

http://www.ibm.com/developerworks/br/aix/library/au-aix-openmp-framework/#list2