# Introduction to OpenMP

Mobeen Ludin

# Login Access

**Username: gateway**
**Password:  sleddog**
**Hostname:  proto.cs.earlham.edu**
**On Mac/Linux:** `$ ssh gateway@proto.cs.earlham.edu`

**User Names:   ncsi1-60**
**Passwords:    sleddog**
**Hostname:     hopper**
**On proto:** `$ ssh ncsi##@cluster.earlham.edu`

**Once you are on hopper, you need to ssh into Al-salam cluster:**

```
$ ssh Al-salam
```

**OpenMP Tutorial Files:**

```
$ cp –r ~mmludin08/xsede14 .
```

## What we learned so far about OpenMP?

- A standard Application Programming Interface (API) for writing shared memory parallel applications in C, C++, and Fortran

- Where to find more information, examples, exercises:
  - OpenMP Web-page: http://www.openmp.org
  - Lawrence Livermore NL: https://computing.llnl.gov/tutorials/openMP/

# Components of OpenMP

**Directives:**
- Parallel region
- work sharing constructs
- Tasking
- Synchronization
- Data-sharing attributes

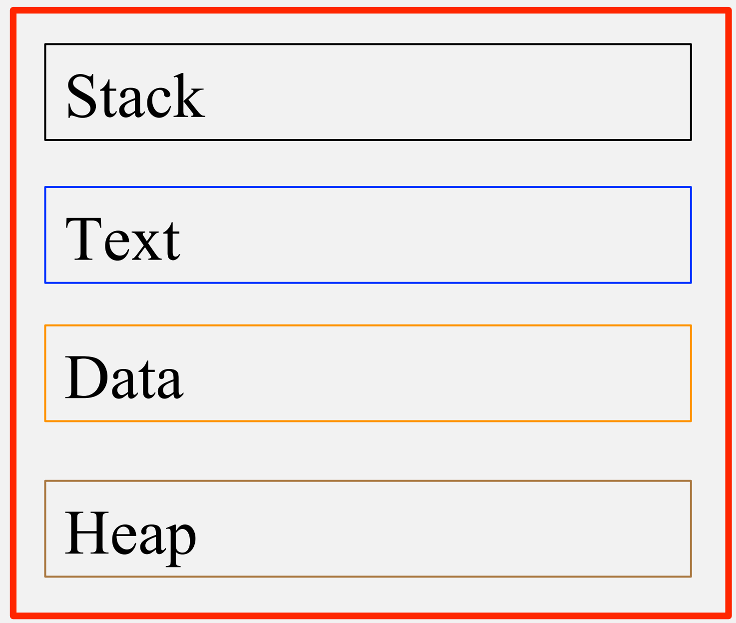
**Library Routines:**
- Number of threads
- Threads ID
- Dynamic thread adjustment
- Nested Parallelism
- Schedule
- Active Levels
- Thread limit
- Nesting level
- Ancestor thread
- Team Size
- Wallclock timer
- Locking

**Environment Variables:**
- Number of threads
- Scheduling type
- Dynamic thread adjustment
- Nested parallelism
- Stacksize
- Idle thread
- Active levels
- Thread limit

# Difference between a process and a thread

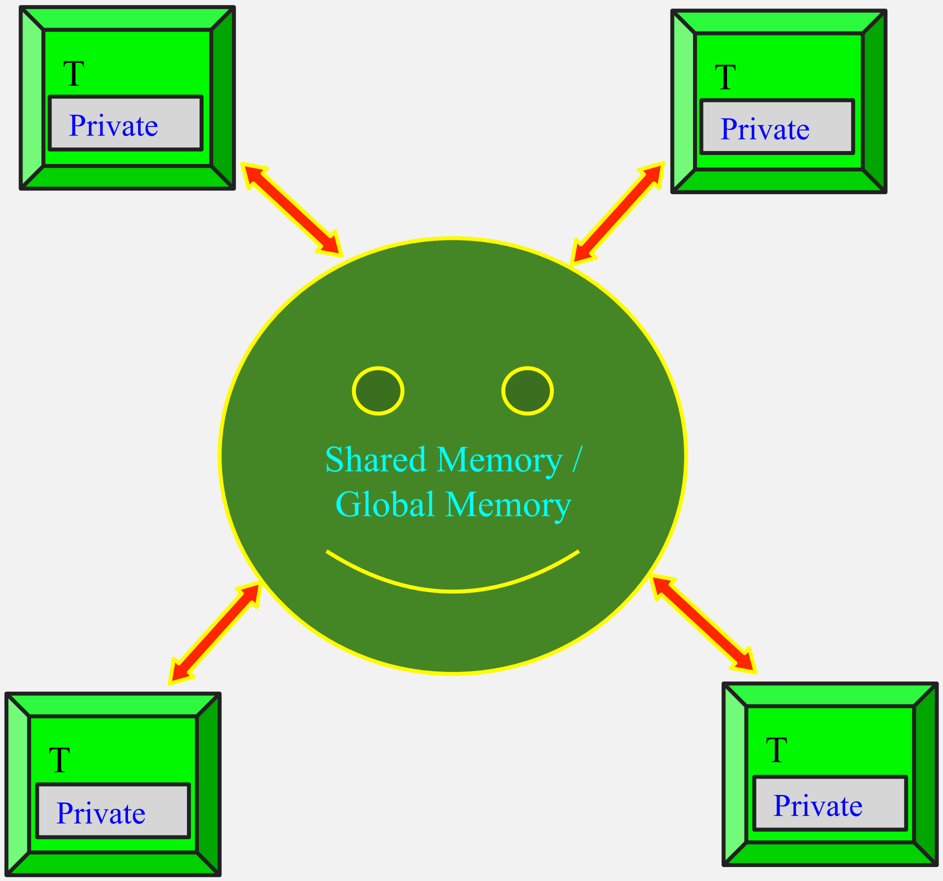
Process and Thread are two unit of executions that are not the same in the sense of executing environment.

- ❖ Compiled program requites CPU to execute its instructions
- ❖ Requires its own memory space for storing its execution environment
  - ➢ Text segment: Storing program code
  - ➢ Heap: Storing global data
  - ➢ Stack: Storing local data



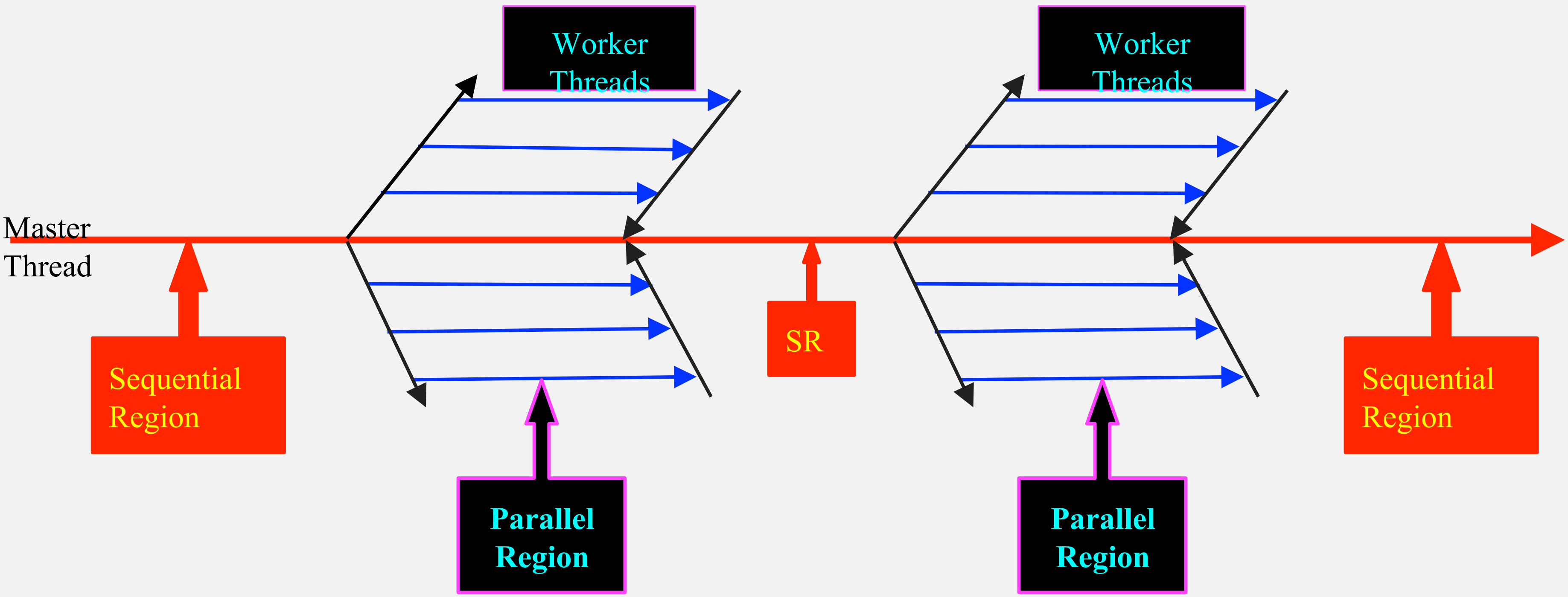
# OpenMP memory model

- All thread have access to the same **globally shared memory**
- Data can be **shared** or **private**
- Shared data is accessible by all threads
- Private data can only be accessed by the thread that owns it
- Data transfer is **transparent** to the programmer
- **Synchronization** takes place, but its mostly implicit

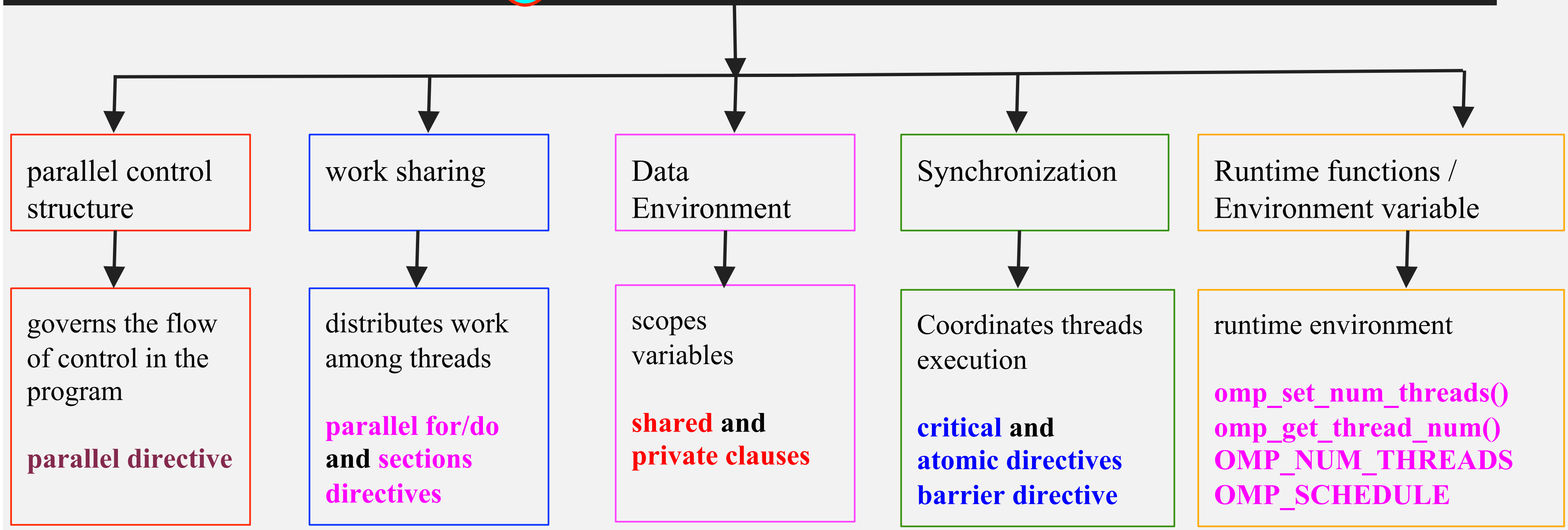


# OpenMP execution model

- **Fork-Join Parallelism:**
  - **Master** thread spawns team of threads as needed
  - Parallelism added incrementally until performance goals are met



# OpenMP Core Elements




- The above categorized constructs are the core elements of OpenMP.
- All the categories and their elements are the same in C/C++ and Fortran

# OpenMP programming model

- **Directives:** OpenMP directives in C/C++ are based on the **`#pragma`** compiler directives. The directive itself consist of directive name followed by a clause
  - **`#pragma omp directive_name [clause list]`**
  - Example: **`#pragma omp parallel`**
    - OpenMP programs execute serially until they encounter the **parallel** directive.
    - This directive is responsible for creating group of threads.
    - The exact number of thread can be specified using **environment variable** or at **runtime using OpenMP functions,** or **clause**.
    - The main thread that encounters the **`parallel`** directive becomes the **master** thread of this group of threads and is assigned the **thread id 0**

## Directive format:

- **C/C++ directives are case sensitive, Fortran is case insensitive**
- **C/C++ Syntax:**
  - `#pragma omp directive [clause [clause] ...]`
  - **Brake lines: use **

- **Fortran Syntax:**
  - `sentinel directive [clause [[,] clause]...]`
  - The **sentinel** is one of the following:
    - `!$OMP or C$OMP or *$OMP` **(fixed format)**
    - `!$OMP` **(free format)**
  - **Brake lines: use the language syntax (&)**

## Parallel directive example:

```
#include <stdio.h>
#include <omp.h>
int main(){
#pragma omp parallel
     printf("Hello from thread %d, of nthreads %d: \n",
 omp_get_thread_num(), omp_get_num_threads());
}
```

**Compile: $** `gcc -fopenmp omp_hello_world_omp.c –o omp_helloworld`

**Run: $** `export OMP_NUM_THREADS=4 && ./omp_hello_world`

**Output:**

Hello from thread 3, of nthreads 4:
Hello from thread 2, of nthreads 4:
Hello from thread 0, of nthreads 4:
Hello from thread 1, of nthreads 4:

## What are OpenMP Clauses for?

- The **clause [list]** is used to specify **conditional parallelization**, **number of threads**, **and data handling**

  - **Conditional parallelization:** The clause `if(scalar expression)` determines whether the parallel construct results in creation of threads. **Only one if clause can be used with a parallel directive.**

  - **Degree of concurrency:** The **clause** `num_threads(integer expression)` specifies the number of threads that are created **by the parallel directive**.

# The “if()” clause and “num_threads() clause example:

```
int i; double area = 0.0;
 // Serial segment of the code is here
#pragma omp parallel if (n > 100) num_threads(16)
{ // Start of parallel region
 for (i=0; i<n; i++)
      x[i] += y[i];
} // End of parallel region
```

- This program will only execute in parallel when if expression evaluates to true. Otherwise it will just run in serial
- Overhead of fork/join is high
- If a loop is small, you don't want to parallelize.
- 12 threads each gets 1 block, but last four threads gets each 2 blocks
  - doing more work than some other threads. (make the blocks smaller for equal work load)

# Specifying concurrent tasks in OpenMP

The parallel directive can be used in conjunction with other directives to specify concurrency across iterations and tasks.

OpenMP provides two directives (**for and sections**) to specify concurrent iterations

**The for directive:**

```
#pragma omp parallel for
{
 for(i=1; i<n; i++)
     b[i]=(a[i]+a[i-1])/2.0
}
```

Assigning Iterations to Threads

# Parallel loop in C/C++ and Fortran:

**// C/C++ OpenMP code:**

```
void example(int n, float *a,
 float *b)
{
 int i;
#pragma omp parallel for
 for(i=1; i<n; i++)
      b[i]=(a[i]+a[i-1])/2.0
}
```

**!Fortran OpenMP code:**

```
SUBROUTINE EXAMPLE(N, A, B)
        INTEGER I, N
    REAL B(N), A(N)
!$OMP PARALLEL DO
        DO I=2,N
           B(I) = (A(I) + A(I-1))/2.0
        ENDDO
!$OMP END PARALLEL DO
        END SUBROUTINE EXAMPLE
```

# Assigning iterations to threads: using schedule clause

- The schedule clause of the for directive deals with the assignment of the iterations to the threads. Syntax: `schedule(scheduling_class [, parameter])`
  - `schedule(static [, chunk-size ])`
    - Distribute the work evenly or in chunk size units specified
    - Pre-determined and predictable amount of work between each iterations
    - compile time
  - `schedule(dynamic [, chunk-size ])`
    - Distribute the work on available threads in chunk size specified
    - When no idea how long each iterations will take.
    - most work is done runtime
  - `schedule(guided [, chunk-size ])`
    - Variation of dynamic starting from large chunks sizes and exponentially going down to chunk size
  - `schedule(auto)`
    - Compiler do whatever the heck you thinks is best to get some performance
    - supported only in the newer version of OpenMP
  - `schedule( runtime )`
    - the environment variable `OMP_SCHEDULE` which is one of the static, dynamic, guided or an appropriate pair like:
      - `export OMP_SCHEDULE=”static,500”`

# How OpenMP threads interact with each other?

- **OpenMP** is a multi-threading, shared address model
  - Threads **communicate** by sharing variables
- Unintended sharing of data causes **race condition**
  - **Race condition:** when the program's outcome changes as the threads are scheduled differently
- To control race condition:
  - Use **synchronization** to protect data conflicts
- Synchronization is expensive so:
  - Change how data is accessed to minimize the need for synchronization

# Race Condition Exercise

```
#include <stdlib.h>
#include <stdio.h>
#include <omp.h>   // For OpenMP
int main(int argc, char **argv) {
    int i, j, tID;
   printf("There is something wrong with this example FIX IT\n”);
#pragma omp parallel private(i, j)
 {
   for(i = 0; i < 1000; i++)
     for(j = 0; j < 1000; j++)
       tID = omp_get_thread_num();
   printf("Thread %d : My value of tid (thread id) is %d \n",
 omp_get_thread_num(), tID);
 }
   printf("\n Did you figure out what is wrong? \n");
  printf("\nHint: do a # comparison\n”);
}
```

## OpenMP clauses (cont.): Data handling/sharing

- In an OpenMP program data need to be **labeled**
- There are two ways one could label data in OpenMP
  - **Shared:** There is only one instance of the data
    - All the threads can read and write the date simultaneously, unless **protected** through a specific OpenMP construct
    - All changes made are available to all threads
      - But not necessarily immediately, unless inforced
  - **Private:** Each thread has its own copy of the data
    - No other threads can have **`R/W`** access to this data
    - Changes only **visible** to the thread that owns the data

## private and shared clauses

- **`shared ( list )`**
  - Data is accessible by all the threads in the team
  - All threads access the same address space

- **`private ( list )`**
  - No changes associated with the original object
  - All references are to the local object
  - Values are undefined on entry and exit

## Variable Initialization

- `firstprivate(list)`

All variables in the list are initialized with the value the original object had before entering the parallel construct

- `lastprivate(list)`

The thread that executes the sequentially last iteration or section updates the value of the objects in the list

# Initialization example:

```
#include <stdio.h>
#include <omp.h>
int main (void)
{
    int i = 10;
#pragma omp parallel firstprivate(i)
    {
        printf("thread %d: i = %d \n",
  omp_get_thread_num(), i);
        i = 1000 +
  omp_get_thread_num();
    }
    printf("i = %d \n", i);
    return 0;
}
```

**Runtime Experiment:**

**Compile:** `$ gcc -fopenmp firstprivate.c -o firstprivate`

**Output:** `$ export OMP_NUM_THREADS=4 && ./firstprivate`

```
thread 0: i = 0
thread 1: i = -1
thread 3: i = 0
thread 2: i = 0
i = 10
```

Output when `i` is used as private:

`private(i)`

---

```
thread 1: i = 10
thread 3: i = 10
thread 0: i = 10
thread 2: i = 10
i = 10
```

Output when `i` is initialized as firstprivate:

`firstprivate(i)`

## reduction(operator:list) clause

Reduction clause performs a reduction on the variables appear in its list.

**Syntax:**

```
reduction ( [operator | intrinsic] ) : list )
```

- ➢ Reduction variable(s) must be shared variables
- ➢A reduction is defined as:

```
reduction ( operator : list )
```

# A simple OpenMP example

```
#include <stdlib.h>
#include <stdio.h>
#include <omp.h>   // For OpenMP
#define NUM_THREADS 2
static long num_steps = 100000;
double step;
void main (){
 int i;
 double x, pi, sum = 0.0;
 step = 1.0/(double) num_steps;
 omp_set_num_threads (NUM_THREADS);
 #pragma omp parallel for reduction(+:sum) private(x)
 for (i=1;i<= num_steps; i++){
       x = (i-0.5)*step;
       sum = sum + 4.0/(1.0+x*x);
  }
 pi = step * sum;
 printf(" pi is %f \n",pi);
}
```

# Sources:


http://www.cs.uiuc.edu/homes/snir/PPP/
https://computing.llnl.gov/tutorials/openMP/
MIT Course:
http://ocw.mit.edu/courses/earth-atmospheric-and-planetary-sciences/12-950-parallel-programming-for-multicore-machines-using-openmp-and-mpi-january-iap-2010/
http://openmp.org/mp-documents/Intro_To_OpenMP_Mattson.pdf
http://openmp.org/wp/
https://www.cac.cornell.edu/VW/OpenMP/threads.aspx
https://source.ggy.bris.ac.uk/wiki/OpenMP