

# Lecture 10

## Programming Shared Memory IV

Controlling Thread, OpenMP (Open Multi-Processing)

Ceng471 *Parallel Computing* at December 30, 2010

Controlling Thread  
Attributes and  
Synchronization

Attributes Objects for  
Threads

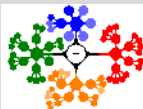
Composite  
Synchronization  
Constructs

Tips for Designing  
Asynchronous  
Programs

OpenMP: a Standard  
for Directive Based  
Parallel Programming

The OpenMP Programming  
Model

Dr. Cem Özdoğan  
Computer Engineering Department  
Çankaya University



## 1 Controlling Thread Attributes and Synchronization

Attributes Objects for Threads

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Attributes and  
Synchronization

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## 2 Composite Synchronization Constructs

Composite  
Synchronization  
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## 3 Tips for Designing Asynchronous Programs

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## 4 OpenMP: a Standard for Directive Based Parallel Programming

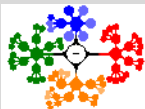
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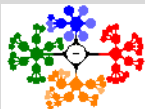
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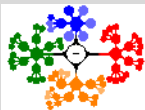
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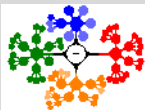
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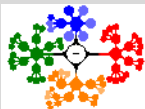
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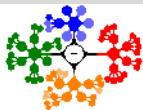
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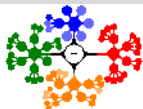
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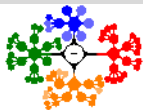
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- **Pthreads** allows the user to change the priority of the thread.



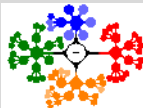
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- When creating a thread or a synchronization variable, we can specify the attributes object that determines the properties of the entity.
- Pthreads allows the user to change the priority of the thread.
- Subsequent changes to attributes objects do not change the properties of entities created using the attributes object prior to the change.



# Controlling Thread and Synchronization Attributes II

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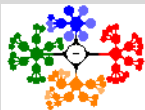
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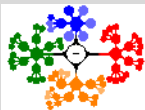
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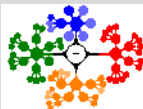


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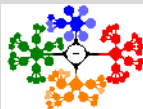
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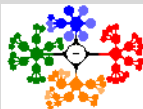
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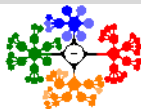
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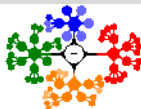
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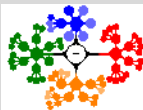
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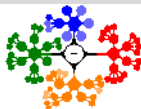
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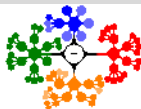
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- To create an attributes object with the desired properties,
  - **we must first create an object with default properties and then modify the object as required.**



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- `pthread_attr_init`;

```
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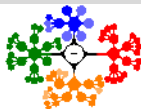


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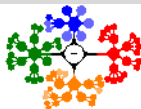


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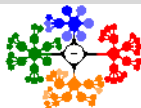


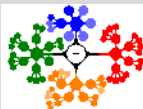
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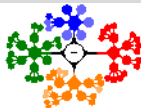
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- The call returns a 0 on successful removal of the attributes object *attr*.

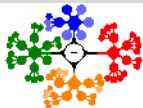
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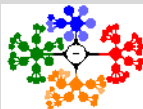
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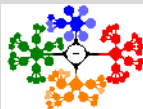
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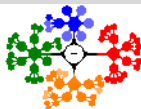
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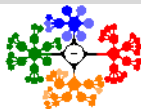
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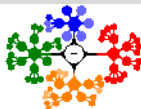
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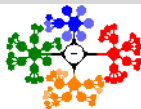
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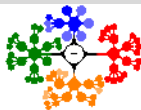
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- **pthread\_attr\_setprio**  $\implies$  to set the priority



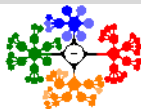
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- **pthread\_attr\_default, pthread\_attr\_init**
- For most parallel programs, default thread properties are generally adequate.



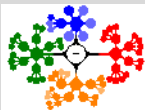
# Composite Synchronization Constructs I

- While the Pthreads API provides a **basic set of synchronization constructs**, often, there is a need for higher level constructs.



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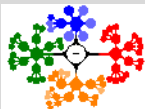
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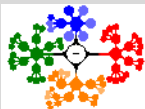
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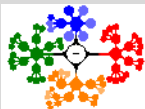
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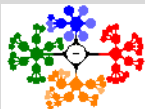
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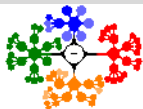
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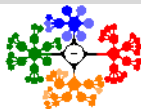
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  - If the *count* is less than the total number of threads, the threads execute a *condition wait*.



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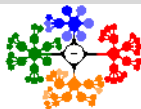
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- Barriers can be implemented using a counter, a mutex and a condition variable.
- A single integer is used to keep track of the number of threads that have reached the barrier.
  - If the *count* is less than the total number of threads, the threads execute a *condition wait*.
  - The last thread entering (and setting the count to the number of threads) wakes up all the threads using a *condition broadcast*.



## Composite Synchronization Constructs II

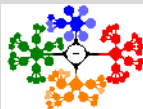
The code for accomplishing this is as follows:

```
1  typedef struct {
2      pthread_mutex_t count_lock;
3      pthread_cond_t ok_to_proceed;
4      int count;
5  } mylib_barrier_t;
6
7  void mylib_init_barrier(mylib_barrier_t *b) {
8      b -> count = 0;
9      pthread_mutex_init(&(b -> count_lock), NULL);
10     pthread_cond_init(&(b -> ok_to_proceed), NULL);
11 }
12
13 void mylib_barrier (mylib_barrier_t *b, int num_threads)
14     pthread_mutex_lock(&(b -> count_lock));
15     b -> count ++;
16     if (b -> count == num_threads) {
17         b -> count = 0;
18         pthread_cond_broadcast(&(b -> ok_to_proceed));
19     }
20     else
21         while (pthread_cond_wait(&(b -> ok_to_proceed),
22             &(b -> count_lock)) != 0);
23     pthread_mutex_unlock(&(b -> count_lock));
24 }
```



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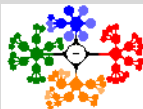
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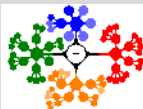


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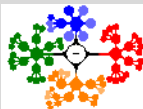
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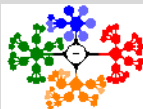
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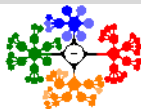
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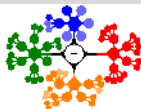
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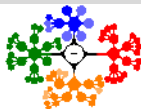
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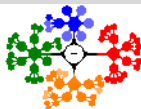
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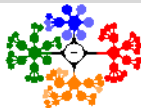
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- Such libraries ( *slightly asynchronous* libraries) are more forgiving of synchronization errors in programs.
- On the other hand, **kernel threads** (threads supported by the kernel) and threads scheduled on multiple processors are less forgiving.
- The programmer must therefore **not make any assumptions** regarding the level of asynchrony in the threads library.



# Tips for Designing Asynchronous Programs II

- The following rules of thumb which help minimize the errors in threaded programs are recommended.



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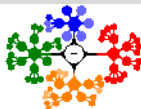
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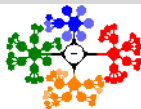
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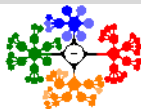
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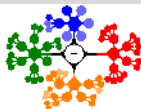
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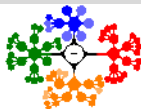
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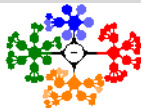
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- Once you create a thread, it is possible that the newly created thread actually runs to completion before the creating thread gets scheduled again.





# Tips for Designing Asynchronous Programs III

- When there is a producer-consumer relation between two threads for certain data items,



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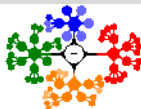
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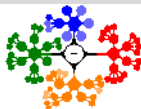
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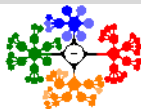
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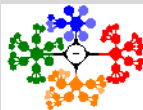
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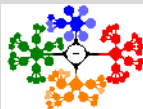
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- This can improve program performance significantly.
- **While these simple tips provide guidelines for writing error-free threaded programs, extreme caution must be taken to avoid race conditions and parallel overheads associated with synchronization.**



# OpenMP: a Standard for Directive Based Parallel Programming I

- While standardization and support for these threaded APIs has come a long way,



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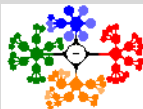
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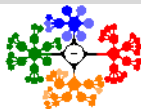
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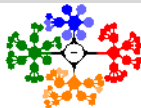
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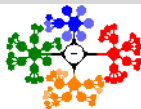
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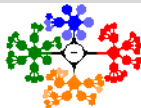
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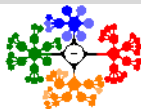
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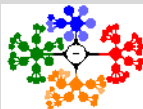
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# The OpenMP Programming Model I

- OpenMP is an API that can be used with FORTRAN, C, and C++ for programming shared address space machines.



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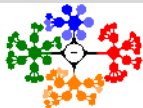
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- OpenMP directives provide support for **concurrency**, **synchronization**, and **data handling** while avoiding the need for explicitly setting up mutexes, condition variables, data scope, and initialization.



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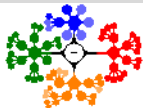
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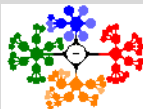
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```
1  #pragma omp directive [clause list]
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# The OpenMP Programming Model I

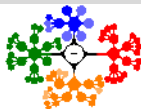
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- OpenMP programs execute serially until they encounter the parallel directive.



# The OpenMP Programming Model I



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- This directive is responsible for **creating a group of threads**.

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# The OpenMP Programming Model II

- The exact number of threads can be specified in the directive, set using an environment variable, or at runtime using OpenMP functions.



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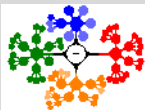
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- The exact number of threads can be specified in the directive, set using an environment variable, or at runtime using OpenMP functions.
- The main thread that encounters the *parallel* directive becomes the *master* of this group of threads with id 0.



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- The exact number of threads can be specified in the directive, set using an environment variable, or at runtime using OpenMP functions.
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- **The *parallel* directive has the following prototype:**

```
1  #pragma omp parallel [clause list]
2  /* structured block */
3
```

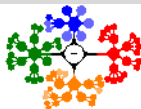


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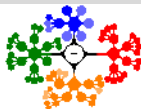


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- Each thread created by this directive executes the structured block specified by the parallel directive.
- It is easy to understand the concurrency model of OpenMP when viewed in the context of the corresponding Pthreads translation.

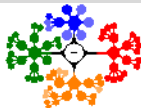


## The OpenMP Programming Model II

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- It is easy to understand the concurrency model of OpenMP when viewed in the context of the corresponding Pthreads translation.
- In Figure 1, one possible translation of an OpenMP program to a Pthreads program is shown.



# The OpenMP Programming Model III



```
int a, b;
main() {
  [ // serial segment
  #pragma omp parallel num_threads (8) private (a) shared (b)
  { [ // parallel segment
  ]
  [ // rest of serial segment
  }
}
```

Sample OpenMP program

```
int a, b;
main() {
  [ // serial segment
  Code inserted by the OpenMP compiler [
  for (i = 0; i < 8; i++)
  pthread_create (....., internal_thread_fn_name, ...);
  for (i = 0; i < 8; i++)
  pthread_join (.....);
  [ // rest of serial segment
  ]
  void *internal_thread_fn_name (void *packaged_argument) {
  int a;
  [ // parallel segment
  ]
}
```

Corresponding Pthreads translation

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**Figure:** A sample OpenMP program along with its Pthreads translation that might be performed by an OpenMP compiler.

# The OpenMP Programming Model IV

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



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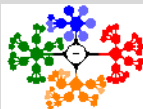
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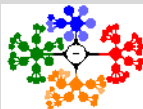
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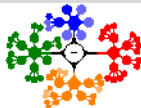
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## The OpenMP Programming Model IV

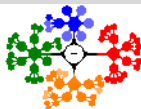
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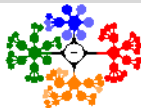
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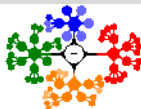
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  - The clause *firstprivate (variable list)* is similar to the *private* clause, except the values of variables on entering the threads are initialized to corresponding values before the parallel directive.



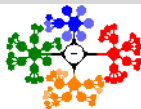
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  - The clause *firstprivate (variable list)* is similar to the private clause, except the values of variables on entering the threads are initialized to corresponding values before the parallel directive.
  - The clause *shared (variable list)* indicates that all variables in the list are shared across all the threads,
  - i.e., there is only one copy. Special care must be taken while handling these variables by threads to ensure serializability.



# The OpenMP Programming Model V

```
#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
All threads join master thread and disband
}
Resume serial code
}
*****
#include <omp.h>
int a,b,num_threads;
int main()
{
printf("I am in sequential part.\n");
#pragma omp parallel num_threads (8) private (a) shared (b)
{
num_threads=omp_get_num_threads();
printf("I am openMP parallelized part and thread %d \n",
omp_get_thread_num());
}
}
}
```



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# The OpenMP Programming Model VI

Using the parallel directive;

```
1  #pragma omp parallel if (is_parallel == 1) num_threads(8)
2      private (a) shared (b) firstprivate(c)
3  {
4      /* structured block */
5  }
```

- Here, if the value of the variable *is\_parallel* equals one, eight threads are created.



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- Here, if the value of the variable *is\_parallel* equals one, eight threads are created.
- Each of these threads gets private copies of variables *a* and *c*, and shares a single value of variable *b*.



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- Here, if the value of the variable *is\_parallel* equals one, eight threads are created.
- Each of these threads gets private copies of variables a and c, and shares a single value of variable b.
- Furthermore, the value of each copy of c is initialized to the value of c before the parallel directive.



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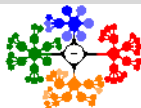


## The OpenMP Programming Model VI

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- Here, if the value of the variable *is\_parallel* equals one, eight threads are created.
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- Furthermore, the value of each copy of c is initialized to the value of c before the parallel directive.
- The clause *default (shared)* implies that, by default, a variable is shared by all the threads.

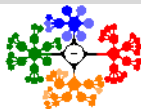


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- The clause *default (none)* implies that the state of each variable used in a thread must be explicitly specified.



## The OpenMP Programming Model VI

Using the parallel directive;

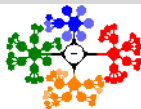
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- Furthermore, the value of each copy of c is initialized to the value of c before the parallel directive.
- The clause *default (shared)* implies that, by default, a variable is shared by all the threads.
- The clause *default (none)* implies that the state of each variable used in a thread must be explicitly specified.
- This is generally recommended, to guard against errors arising from unintentional concurrent access to shared data.



# The OpenMP Programming Model VII

- Just as *firstprivate* specifies how multiple local copies of a variable are initialized inside a thread,



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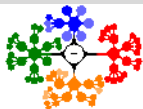
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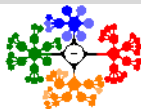
# The OpenMP Programming Model VII

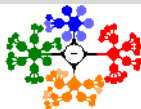
- Just as *firstprivate* specifies how multiple local copies of a variable are initialized inside a thread,
- the reduction clause specifies how multiple local copies of a variable at different threads are combined into a single copy at the master when threads exit.



# The OpenMP Programming Model VII

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- the *reduction* clause specifies how multiple local copies of a variable at different threads are combined into a single copy at the master when threads exit.
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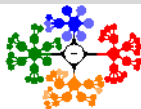
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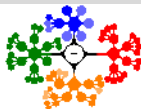
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# The OpenMP Programming Model VII



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- The variables in the list are implicitly specified as being private to threads.
- **The *operator* can be one of**

`+, *, -, &, |, ^, &&, and ||.`

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Using the reduction clause;

```
1 #pragma omp parallel reduction(+: sum) num_threads(8)
2 {
3  /* compute local sums here */
4  }
5  /* sum here contains sum of all local instances of sums */
```

- In this example, each of the eight threads gets a copy of the variable *sum*.

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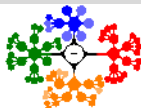
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- When the threads exit, the sum of all of these local copies is stored in the single copy of the variable (at the master thread).

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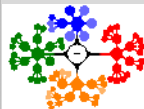
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# The OpenMP Programming Model IX

- **Computing PI** using OpenMP directives (presented a Pthreads program for the same problem).



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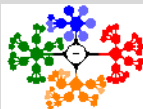
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# The OpenMP Programming Model IX

- **Computing PI** using OpenMP directives (presented a Pthreads program for the same problem).
- The *omp\_get\_num\_threads()* function returns the number of threads in the parallel region



Controlling Thread  
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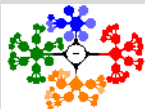
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# The OpenMP Programming Model IX



- **Computing PI** using OpenMP directives (presented a Pthreads program for the same problem).
- The `omp_get_num_threads()` function returns the number of threads in the parallel region
- The `omp_get_thread_num()` function returns the integer id of each thread (recall that the master thread has an id 0).

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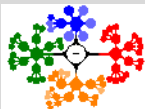
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# The OpenMP Programming Model IX



- **Computing PI** using OpenMP directives (presented a Pthreads program for the same problem).
- The `omp_get_num_threads()` function returns the number of threads in the parallel region
- The `omp_get_thread_num()` function returns the integer id of each thread (recall that the master thread has an id 0).
- **The parallel directive specifies that all variables except `npoints`, the total number of random points in two dimensions across all threads, are local.**

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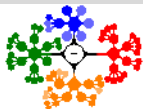
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# The OpenMP Programming Model IX



- **Computing PI** using OpenMP directives (presented a Pthreads program for the same problem).
- The `omp_get_num_threads()` function returns the number of threads in the parallel region
- The `omp_get_thread_num()` function returns the integer id of each thread (recall that the master thread has an id 0).
- The parallel directive specifies that all variables except `npoints`, the total number of random points in two dimensions across all threads, are local.
- Furthermore, the directive specifies that there are eight threads, and the value of sum after all threads complete execution is the sum of local values at each thread.

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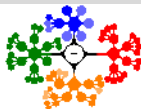
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- **Computing PI** using OpenMP directives (presented a Pthreads program for the same problem).
- The `omp_get_num_threads()` function returns the number of threads in the parallel region
- The `omp_get_thread_num()` function returns the integer id of each thread (recall that the master thread has an id 0).
- The parallel directive specifies that all variables except `npoints`, the total number of random points in two dimensions across all threads, are local.
- Furthermore, the directive specifies that there are eight threads, and the value of sum after all threads complete execution is the sum of local values at each thread.
- A for loop generates the required number of random points (in two dimensions) and determines how many of them are within the prescribed circle of unit diameter.

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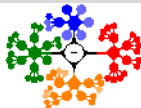
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# The OpenMP Programming Model X



```
1 /* *****
2 An OpenMP version of a threaded program to compute PI.
3 ***** */
4
5 #pragma omp parallel default(private) shared (npoints) \
6     reduction(+: sum) num_threads(8)
7 {
8     num_threads = omp_get_num_threads();
9     sample_points_per_thread = npoints / num_threads;
10    sum = 0;
11    for (i = 0; i < sample_points_per_thread; i++) {
12        rand_no_x = (double) (rand_r(&seed)) / (double) ((2<<14) - 1);
13        rand_no_y = (double) (rand_r(&seed)) / (double) ((2<<14) - 1);
14        if (((rand_no_x - 0.5) * (rand_no_x - 0.5) +
15            (rand_no_y - 0.5) * (rand_no_y - 0.5)) < 0.25)
16            sum ++;
17    }
18 }
```

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Note that this program is much easier to write in terms of specifying creation and termination of threads compared to the corresponding POSIX threaded program.