

# Shared Memory Programming with OpenMP

Parallel Regions



## Parallel region directive

- Code within a parallel region is executed by all threads.
- Syntax:

Fortran: **!\$OMP PARALLEL**

*block*

**!\$OMP END PARALLEL**

C/C++: **#pragma omp parallel**

**{**

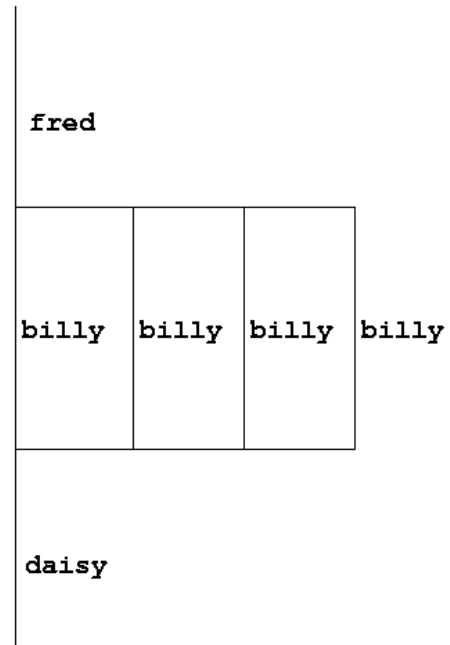
*block*

**}**

## Parallel region directive (cont)

Example:

```
fred();  
#pragma omp parallel  
{  
    billy();  
}  
daisy();
```



## Useful functions

- Often useful to find out number of threads being used.

Fortran:

```
USE OMP_LIB  
INTEGER FUNCTION OMP_GET_NUM_THREADS()
```

C/C++:

```
#include <omp.h>  
  
int omp_get_num_threads(void);
```

- **Important note:** returns 1 if called outside parallel region!

## Useful functions (cont)

- Also useful to find out number of the executing thread.

Fortran:

```
USE OMP_LIB  
INTEGER FUNCTION OMP_GET_THREAD_NUM()
```

C/C++:

```
#include <omp.h>  
int omp_get_thread_num(void)
```

- Takes values between 0 and `OMP_GET_NUM_THREADS () - 1`

# Clauses



- Specify additional information in the parallel region directive through clauses:
- Fortran : `!$OMP PARALLEL [clauses]`
- C/C++: `#pragma omp parallel [clauses]`
- Clauses are comma or space separated.

# Shared and private variables



- Inside a parallel region, variables can be either **shared** (all threads see same copy) or **private** (each thread has its own copy).
- Shared, private and default clauses

Fortran: **SHARED** (*list*)

**PRIVATE** (*list*)

**DEFAULT** (**SHARED** | **PRIVATE** | **NONE**)

C/C++: **shared** (*list*)

**private** (*list*)

**default** (**shared** | **none**)

In C/C++, variables declared inside the scope of the parallel region are private.

## Shared and private (cont.)



- On entry to a parallel region, private variables are uninitialised.
- Variables declared inside the scope of the parallel region are automatically private.
- After the parallel region ends the original variable is unaffected by any changes to private copies.
- In C++ private objects are created using the default constructor
- Not specifying a DEFAULT clause is the same as specifying DEFAULT(SHARED)
  - **Danger!**
  - Always use DEFAULT(NONE)



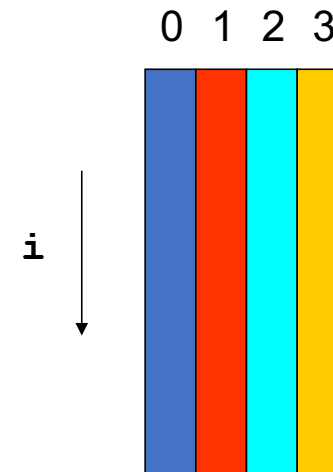
## Shared and private (cont)



Example - each thread initialises its own part of a shared array:

```
int i,myid,n=1000;
float a[4][1000];

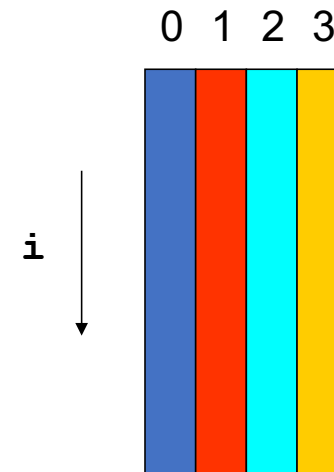
#pragma omp parallel default(none) private(i,myid) shared(a,n)
{
    myid = omp_get_thread_num();
    for (i=0; i<n; i++){
        a[myid][i] = 1.0;
    }
}
```



## Shared and private (cont)

Using the C language scoping:

```
int n=1000;  
float a[4][1000];  
  
#pragma omp parallel default(none) shared(a,n)  
{  
    int myid = omp_get_thread_num();  
    for (int i=0; i<n; i++){  
        a[myid][i] = 1.0;  
    }  
}
```

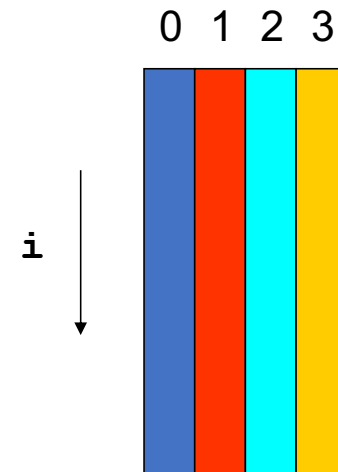


## Shared and private (cont)



Example - each thread initialises its own part of a shared array:

```
INTEGER :: myid,i,n
REAL (KIND = 4) :: a(1000,4)
!$OMP PARALLEL DEFAULT(NONE), PRIVATE(i,myid), SHARED(a,n)
    myid = omp_get_thread_num() + 1
    do i = 1,n
        a(i,myid) = 1.0
    end do
!$OMP END PARALLEL
```



## Multi-line directives

- Fortran: fixed source form

```
!$OMP PARALLEL DEFAULT(NONE) , PRIVATE(I,MYID) ,  
!$OMP& SHARED(A,N)
```

- Fortran: free source form

```
!$OMP PARALLEL DEFAULT(NONE) , PRIVATE(I,MYID) , &  
!$OMP SHARED(A,N)
```

- C/C++:

```
#pragma omp parallel default(none) \  
private(i,myid) shared(a,n)
```

# Initialising private variables



- Private variables are uninitialised at the start of the parallel region.
- If we wish to initialise them, we use the FIRSTPRIVATE clause instead of PRIVATE:

Fortran: **FIRSTPRIVATE** (*list*)

C/C++: **firstprivate** (*list*)

- Private copies are initialised with the value in the original variable at the start of the parallel region
- Note: use cases for this are surprisingly uncommon!
- In C++ the default copy constructor is called to create and initialise the new object

## Initialising private variables (cont)



Example:

```
float b = 23.0;
float c[4][1000];
. . . . .
#pragma omp parallel firstprivate(b), private(i,myid)
{
    myid = omp_get_thread_num();
    for (i=0; i<n; i++){
        b += c[myid][i];
    }
    c[myid][n] = b;
}
```

## Initialising private variables (cont)



Example:

```
b = 23.0
. . . . .
!$omp parallel firstprivate(b) private (myid)

    myid = omp_get_thread_num() + 1
    do i = 1,n-1
        b = b + c(i,myid)
    end do
    c(n,myid) = b

!$omp end parallel
```

## Reductions

- A *reduction* produces a single value from associative operations such as addition, multiplication, max, min, and, or.
- Would like each thread to reduce into a private copy, then reduce all these to give final result.
- Use REDUCTION clause:

Fortran: **REDUCTION** (*op*:*list*)

C/C++: **reduction** (*op*:*list*)

- Can have reduction arrays – reduction is done on each element
  - In C/C++, need to use a special OpenMP syntax for array sections
  - **array[firstelement:numofelements]**



## Reductions (cont.)



Example:

```
int b = 10;
#pragma omp parallel reduction(+:b)
{
    int myid = omp_get_thread_num();
    for (int i=0; i<n; i++){
        b += c[myid][i];
    }
}
a = b;
```

Value in original variable is saved

Each thread gets a private copy of **b**, initialised to 0

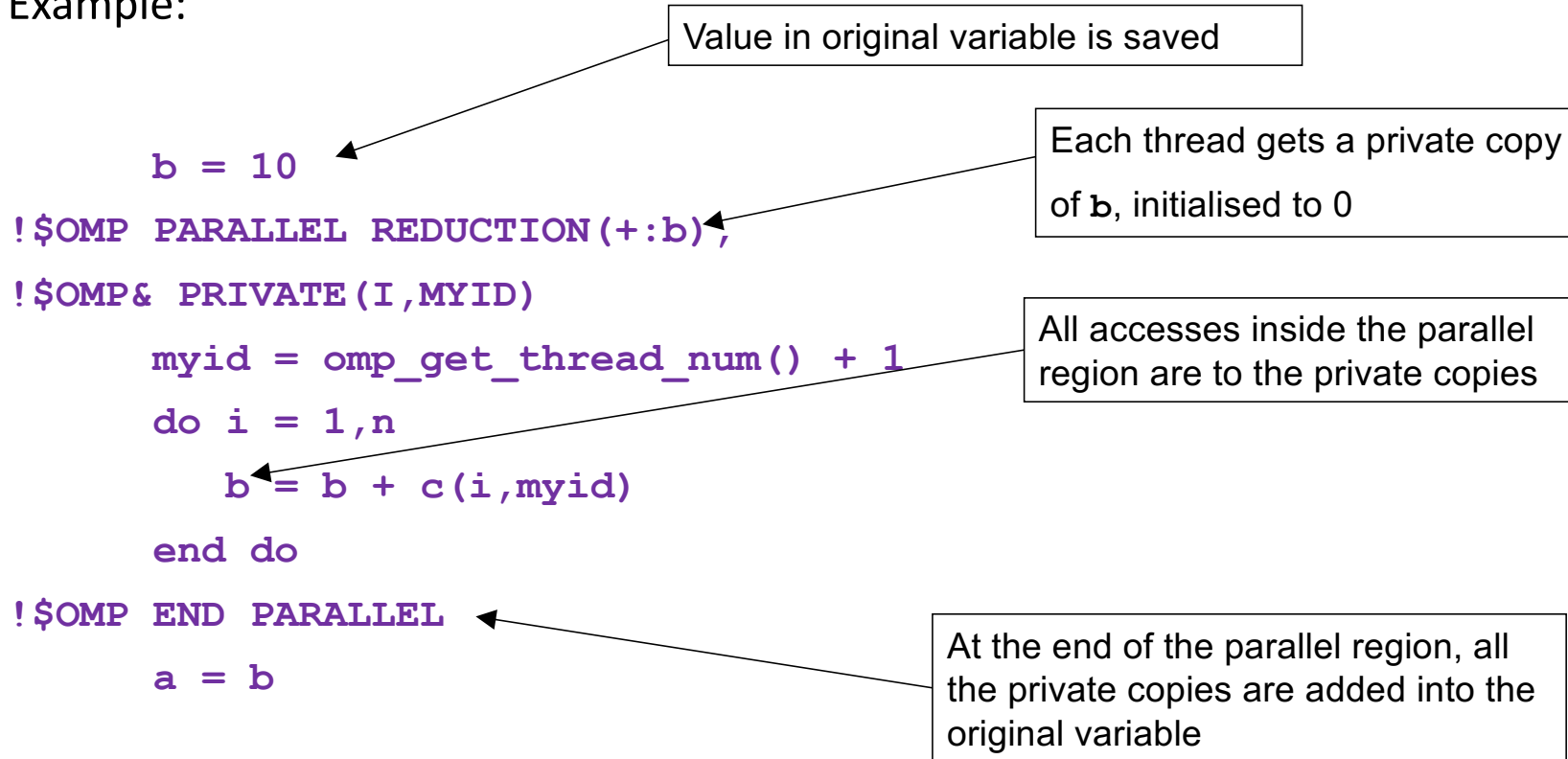
All accesses inside the parallel region are to the private copies

At the end of the parallel region, all the private copies are added into the original variable

## Reductions (cont.)



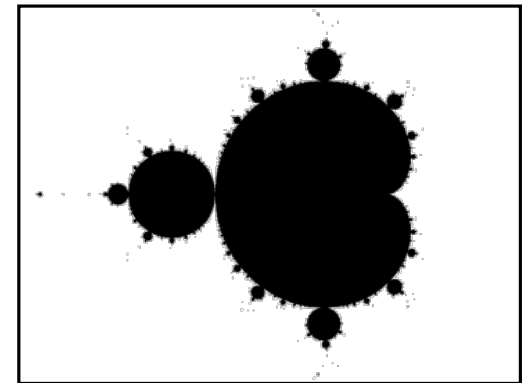
Example:



## Exercise

### Area of the Mandelbrot set

- Aim: introduction to using parallel regions.
- Estimate the area of the Mandelbrot set.
  - Sequential code is provided as a starting point
  - Generates a grid of complex numbers in a box surrounding the set
  - Tests each number to see if it is in the set or not.
  - Ratio of points inside to total number of points gives an estimate of the area.
  - Testing of points is independent - parallelise with a parallel region!



# Reusing this material



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