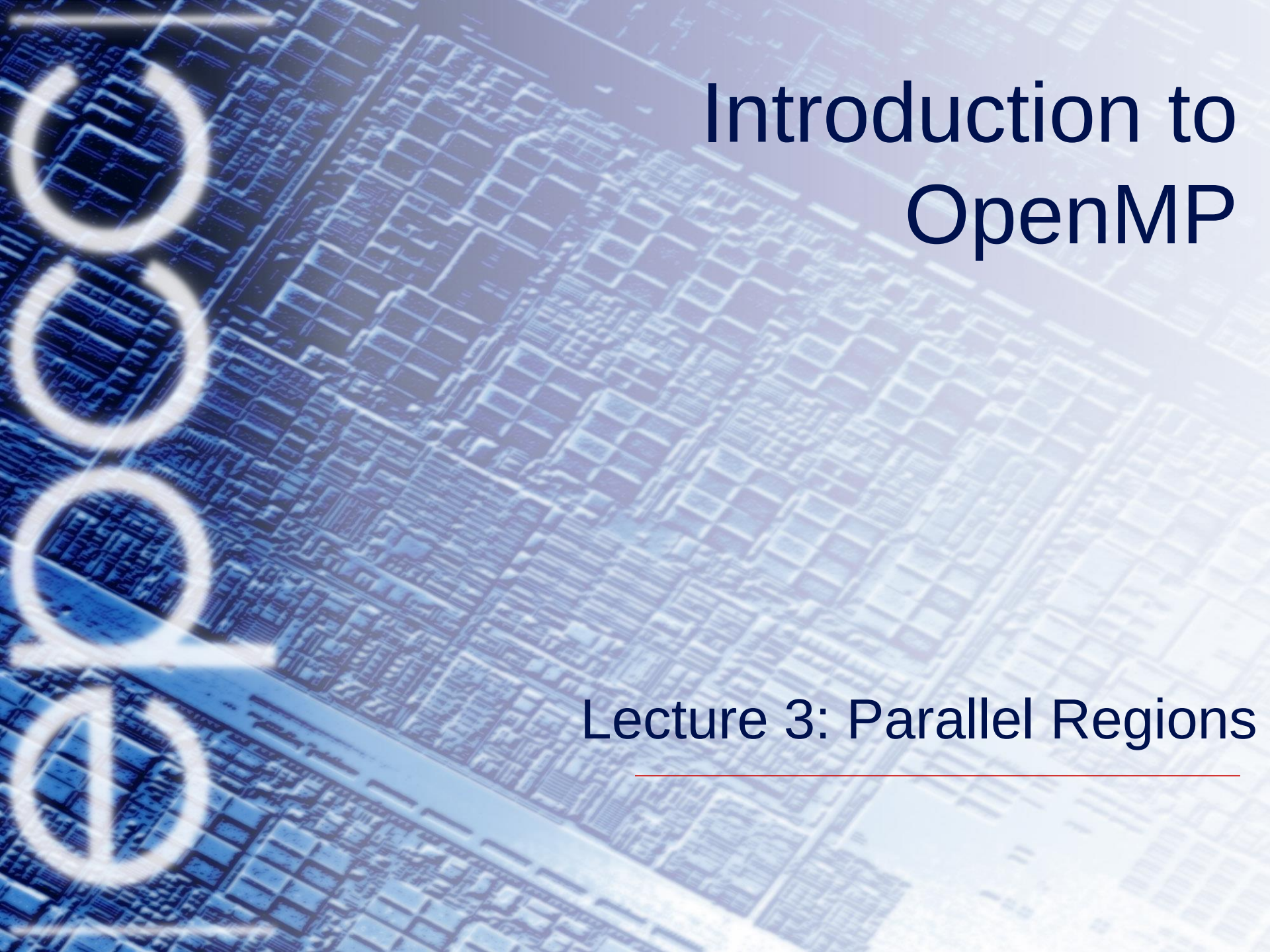


# Introduction to OpenMP

## Lecture 3: Parallel Regions

# Parallel region directive

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

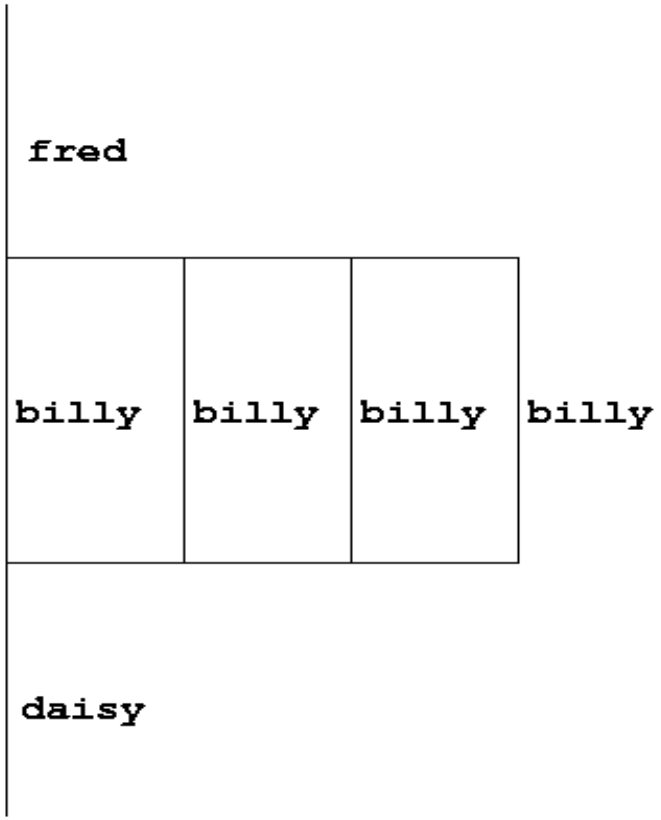
Fortran:
```
!$OMP PARALLEL
        block
!$OMP END PARALLEL
```

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 in Fortran, space separated in C/C++.

# 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*`)`**

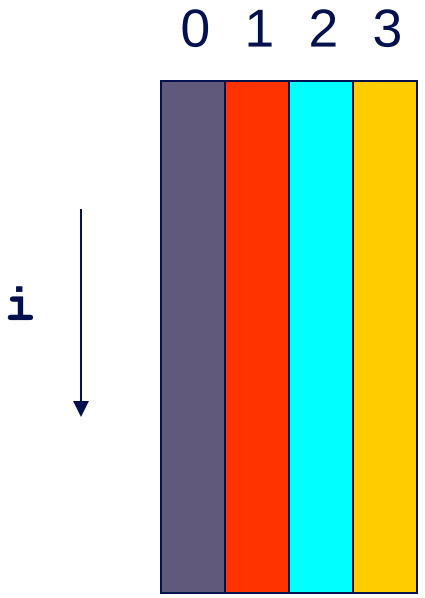
**`private (`***list*`)`**

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

# Shared and private (cont)

Example: each thread initialises its own column of a shared array:

```
!$OMP PARALLEL DEFAULT(NONE),PRIVATE(I,MYID),
!$OMP& 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:

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

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

# Initialising private variables (cont)

Example:

```
      b = 23.0;
      . . . . .
#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;
   }
```

# 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 in Fortran, but not in C/C++

# Reductions (cont.)

Example:

```
      b = 10
!$OMP PARALLEL REDUCTION(+:b),
!$OMP& PRIVATE(I,MYID)
      myid = omp_get_thread_num() + 1
      do i = 1,n
         b = b + c(i,myid)
      end do
!$OMP END PARALLEL
      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

# Exercise

Area of the Mandelbrot set

- Aim: introduction to using parallel regions.
- Estimate the area of the Mandelbrot set by Monte Carlo sampling.
  - Generate a grid of complex numbers in a box surrounding the set
  - Test 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!