Shared Memory Programming with OpenMP

Parallel Regions

archer2

epcc

Parallel region directive

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

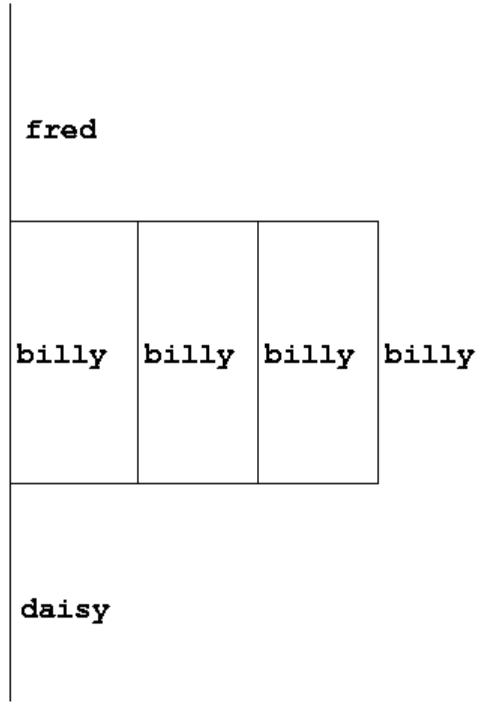
Fortran:
```
!$OMP PARALLEL
        block
!$OMP END PARALLEL
```

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)`

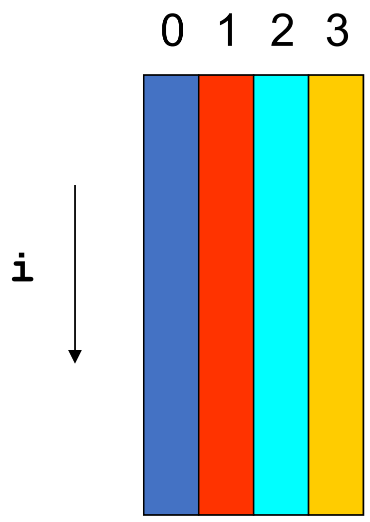
Shared and private (cont.)

- 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:

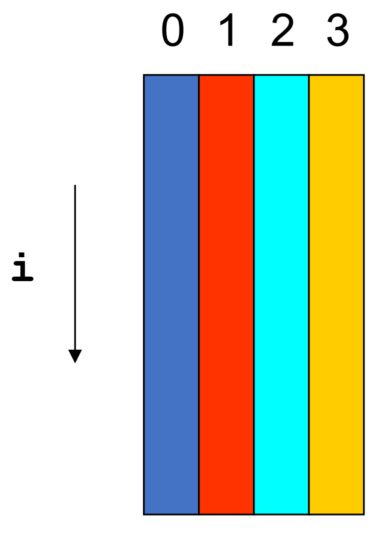
```
int i,myid,n=1000;
float a[4][1000];

#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:

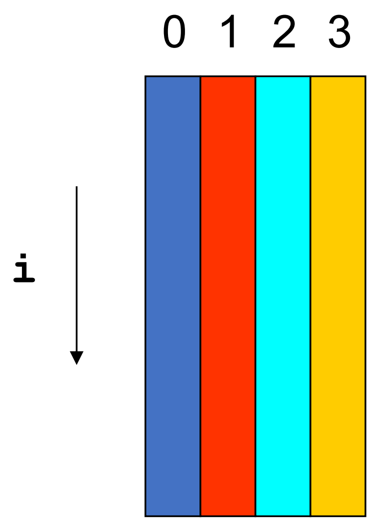
```
int n=1000;
float a[4][1000];

#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:

```
!$OMP PARALLEL DEFAULT(NONE), PRIVATE(I,MYID), SHARED(A,N)
      myid = omp_get_thread_num() + 1
      do i = 1,n
         a(i,myid) = 1.0
      end do
!$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:

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 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

Reductions (cont.)

Example:

Value in original variable is saved

```
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;
```

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:

Value in original variable is saved

```
      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
```

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

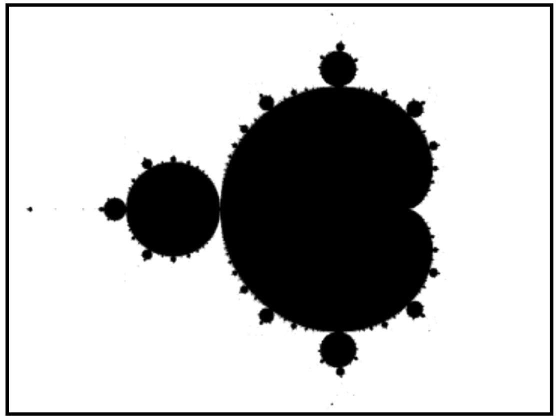
All accesses inside the parallel region are to the private copies

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.
  - 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!



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