

Shared Memory Programming with OpenMP

Work sharing directives



Work sharing directives



- Directives which appear inside a parallel region and indicate how work should be shared out between threads
 - Parallel do/for loops
 - Single directive
 - Master directive

Parallel do loops

- Loops are the most common source of parallelism in most codes. Parallel loop directives are therefore very important!
- A parallel do/for loop divides up the iterations of the loop between threads.
- The loop directive appears inside a parallel region and indicates that the work should be shared out between threads, instead of replicated
- There is a synchronisation point at the end of the loop: all threads must finish their iterations before any thread can proceed

Parallel do/for loops (cont)

Syntax:

Fortran:

```
!$OMP DO [clauses]  
do loop  
[ !$OMP END DO ]
```

C/C++:

```
#pragma omp for [clauses]  
for loop
```

Restrictions in C/C++

- Because the for loop in C is a general while loop, there are restrictions on the form it can take.
- It has to have determinable trip count - it must be of the form:
`for (var = a; var logical-op b; incr-exp)`

where *logical-op* is one of `<`, `<=`, `>`, `>=`

and *incr-exp* is `var = var +/- incr` or semantic equivalents such as `var++`.

Also cannot modify `var` within the loop body.

Parallel loops (example)



Example:

```
!$OMP PARALLEL
!$OMP DO
    do i=1,n
        b(i) = (a(i)-a(i-1))*0.5
    end do
!$OMP END DO
!$OMP END PARALLEL
```

```
#pragma omp parallel
{
    #pragma omp for
    for (int i=0;i<n;i++){
        b[i] = (a[i]*a[i-1])*0.5;
    }
}
```

Parallel DO/FOR directive

- This construct is so common that there is a shorthand form which combines parallel region and DO/FOR directives:

Fortran:

```
!$OMP PARALLEL DO [clauses]  
  do loop  
[ !$OMP END PARALLEL DO ]
```

C/C++:

```
#pragma omp parallel for [clauses]  
  for loop
```

Parallel loops (example)



Example:

```
!$OMP PARALLEL DO
  do i=1,n
    b(i) = (a(i)-a(i-1))*0.5
  end do
!$OMP END PARALLEL DO
```

```
#pragma omp parallel for
for (int i=0;i<n;i++){
  b[i] = (a[i]*a[i-1])*0.5;
}
```


Clauses



- DO/FOR directive can take PRIVATE , FIRSTPRIVATE and REDUCTION clauses which refer to the scope of the loop.
- Note that the parallel loop index variable is PRIVATE by default
 - other loop indices are private by default in Fortran, but not in C.
- PARALLEL DO/FOR directive can take all clauses available for PARALLEL directive.
- **Beware!** PARALLEL DO/FOR is not the same as DO/FOR or the same as PARALLEL

Parallel do/for loops (cont)



- With no additional clauses, the DO/FOR directive will partition the iterations as equally as possible between the threads.
- However, this is implementation dependent, and there is still some ambiguity:
e.g. 7 iterations, 3 threads. Could partition as 3+3+1 or 3+2+2

SCHEDULE clause

- The SCHEDULE clause gives a variety of options for specifying which loops iterations are executed by which thread.

- Syntax:

Fortran: **SCHEDULE** (*kind*[, *chunksize*])

C/C++: **schedule** (*kind*[, *chunksize*])

where *kind* is one of

STATIC, **DYNAMIC**, **GUIDED**, **AUTO** or **RUNTIME**

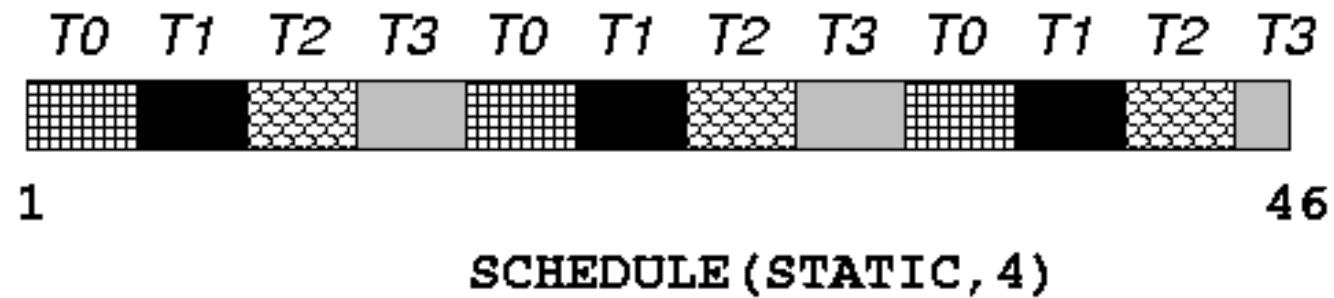
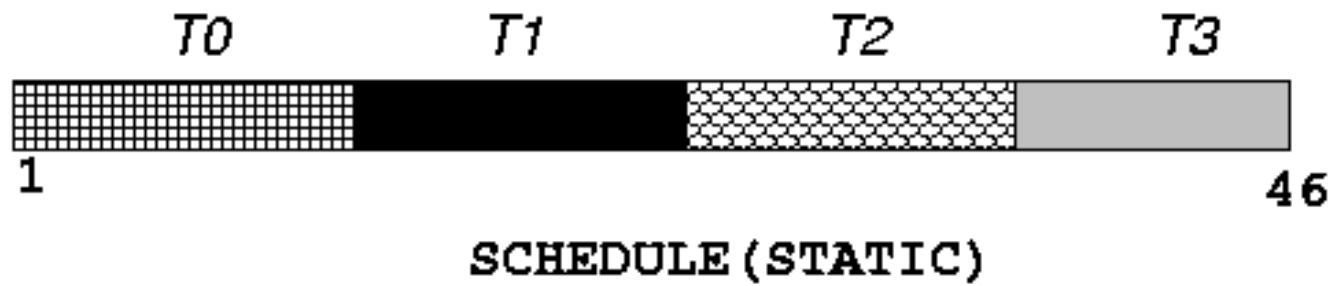
and *chunksize* is an integer expression with positive value.

- e.g. **!\$OMP DO SCHEDULE(DYNAMIC, 4)**

STATIC schedule

- With no *chunksize* specified, the iteration space is divided into (approximately) equal chunks, and one chunk is assigned to each thread in order (**block** schedule).
- If *chunksize* is specified, the iteration space is divided into chunks, each of *chunksize* iterations, and the chunks are assigned cyclically to each thread in order (**block cyclic** schedule)

STATIC schedule



DYNAMIC schedule

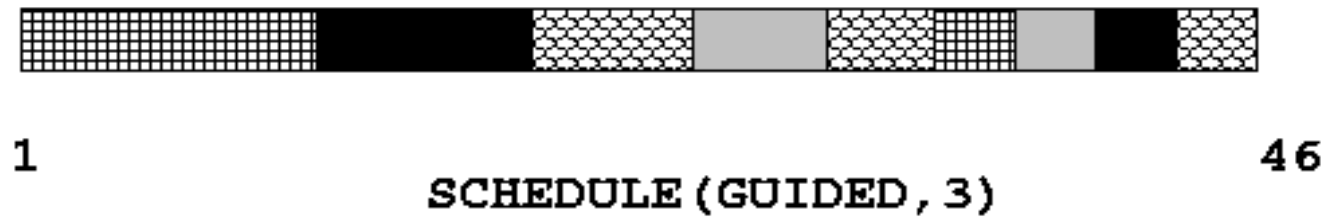


- DYNAMIC schedule divides the iteration space up into chunks of size *chunksize*, and assigns them to threads on a first-come-first-served basis.
- i.e. as a thread finish a chunk, it is assigned the next chunk in the list.
- When no *chunksize* is specified, it defaults to 1.

GUIDED schedule

- GUIDED schedule is similar to DYNAMIC, but the chunks start off large and get smaller exponentially.
- The size of the next chunk is proportional to the number of remaining iterations divided by the number of threads.
- The *chunksize* specifies the minimum size of the chunks.
- When no *chunksize* is specified it defaults to 1.

DYNAMIC and GUIDED schedules



AUTO schedule

- Lets the runtime have full freedom to choose its own assignment of iterations to threads
- If the parallel loop is executed many times, the runtime can evolve a good schedule which has good load balance and low overheads.

RUNTIME schedule

- Allows the schedule to be set using the environment variable **OMP_SCHEDULE**
 - e.g. **export OMP_SCHEDULE=dynamic,1**
- Convenient for experimenting with schedules and chunksizes without having to recompile.

Choosing a schedule

When to use which schedule?

- STATIC best for load balanced loops - least overhead.
- `STATIC,n` good for loops with mild or smooth load imbalance, but can induce overheads.
- DYNAMIC useful if iterations have widely varying loads, but ruins data locality.
- GUIDED often less expensive than DYNAMIC, but beware of loops where the first iterations are the most expensive!
- AUTO allows compiler-specific options

SINGLE directive



- Indicates that a block of code is to be executed by a single thread only.
- The first thread to reach the SINGLE directive will execute the block
- There is a synchronisation point at the end of the block: all the other threads wait until block has been executed.

SINGLE directive (cont)

Syntax:

Fortran:

```
! $OMP SINGLE [clauses]  
    block  
! $OMP END SINGLE
```

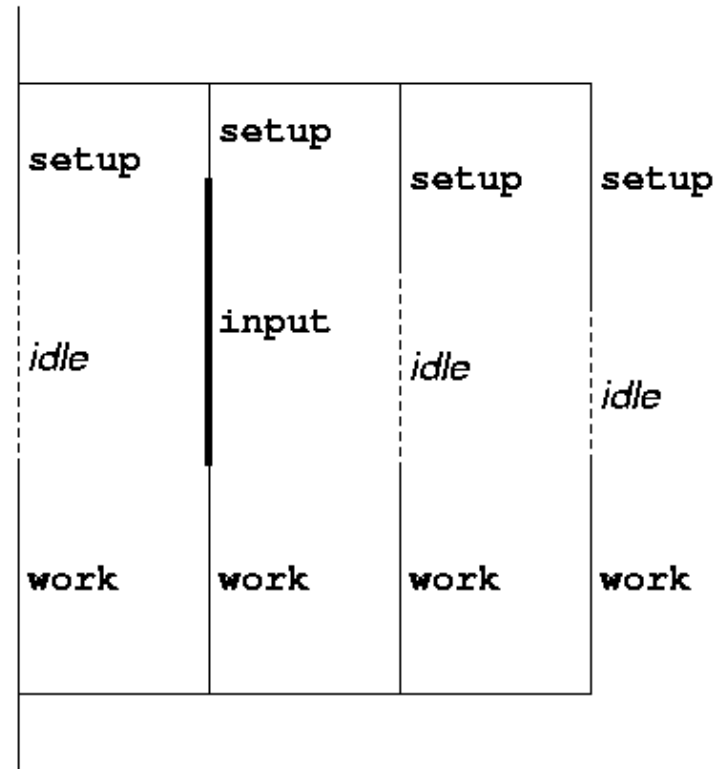
C/C++:

```
#pragma omp single [clauses]  
    structured block
```

SINGLE directive (cont)

Example:

```
#pragma omp parallel
{
    setup(x);
#pragma omp single
    {
        input(y);
    }
    work(x,y);
}
```



SINGLE directive (cont)



- SINGLE directive can take PRIVATE and FIRSTPRIVATE clauses.
- Directive must contain a structured block: cannot branch into or out of it.

NOWAIT clause

- The implicit barrier synchronization at the end of worksharing directive (**do/for** or **single**) can be removed by adding a **nowait** clause.
 - Use with care! Easy to introduce race conditions...

Fortran:

```
!$OMP DO  
    do loop  
!$OMP END DO NOWAIT
```

C/C++:

```
#pragma omp for nowait  
    for loop
```


MASTER directive



- Indicates that a block of code should be executed by the master thread (thread 0) only.
- There is no synchronisation at the end of the block: other threads skip the block and continue executing: N.B. different from SINGLE in this respect.

MASTER directive (cont)

Syntax:

Fortran:

```
! $OMP MASTER  
    block  
! $OMP END MASTER
```

C/C++:

```
#pragma omp master  
    structured block
```

Exercise



- Redo the Mandelbrot example using a worksharing do/for directive.

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