

Threaded Programming

Lecture 4: 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
```

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**

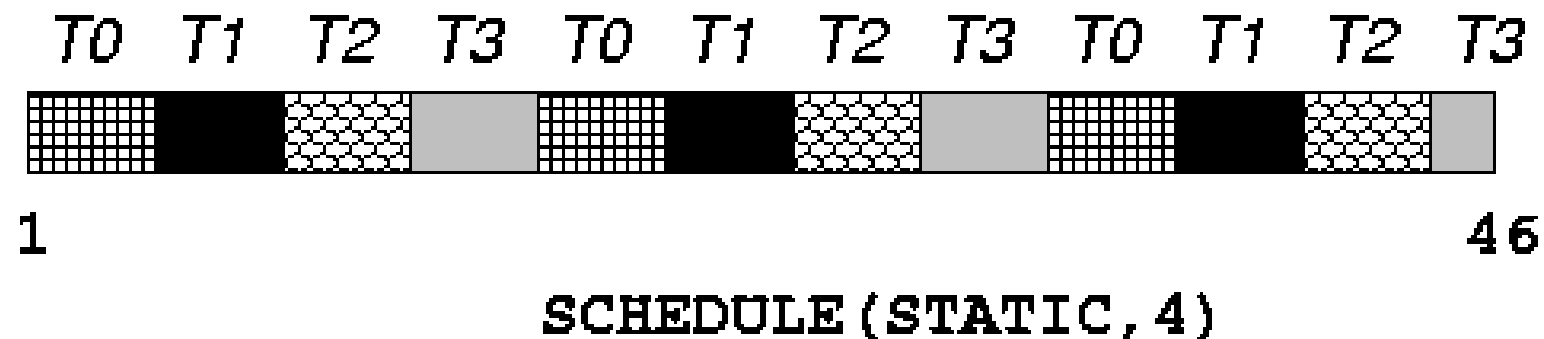
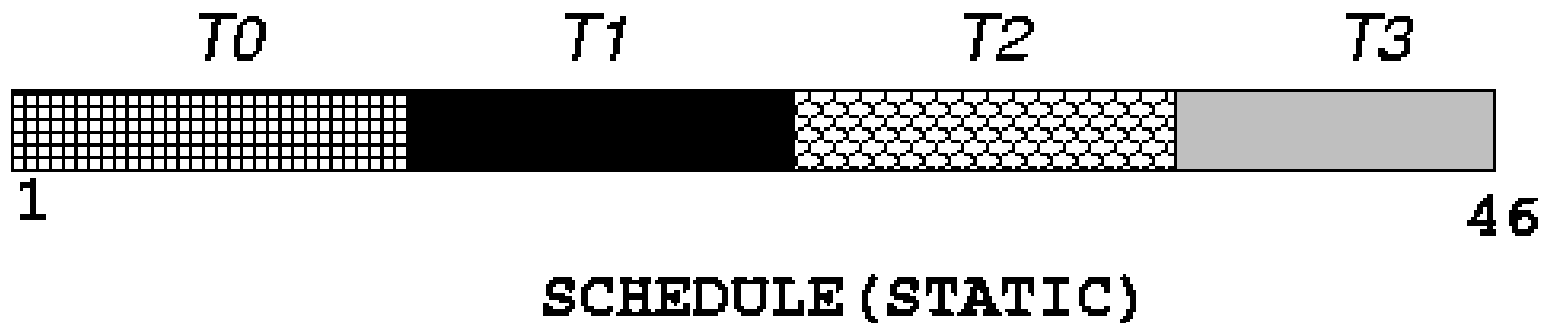
and *chunksize* is an integer expression with positive value.

- 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



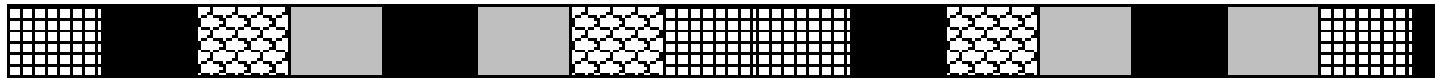
DYNAMIC schedule

- 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



1 **SCHEDULE (DYNAMIC, 3)** 46



1 **SCHEDULE (GUIDED, 3)** 46

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.

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 may be useful if the loop is executed many times over

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++:

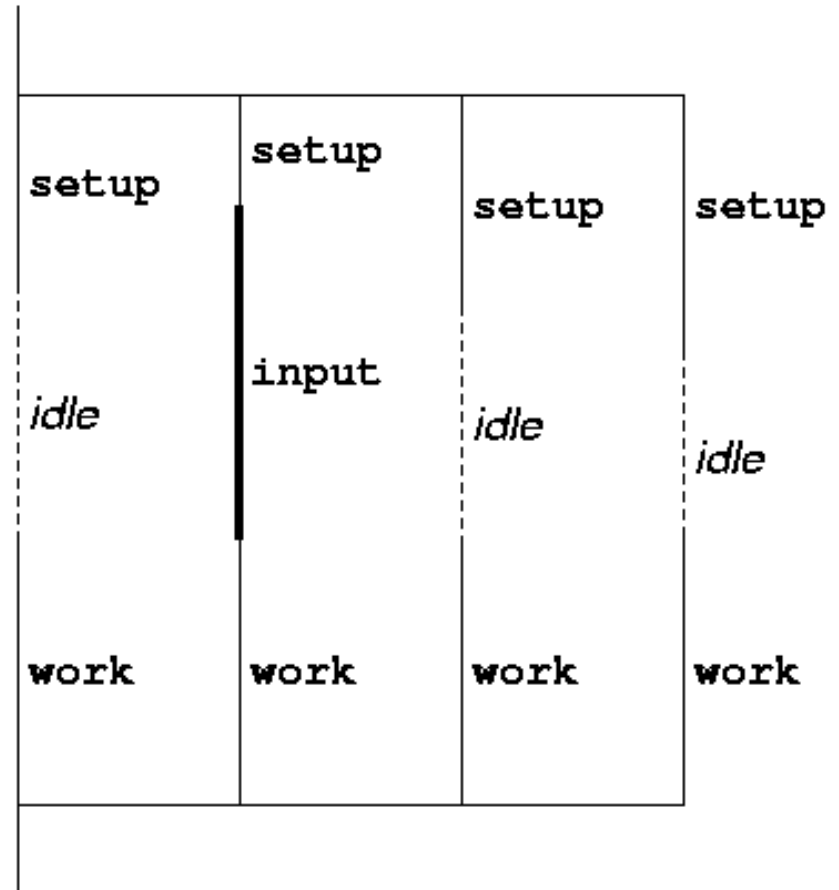
```
#pragma omp single [clauses]
```

```
    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.

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.

Reusing this material



This work is licensed under a Creative Commons Attribution-NonCommercial-ShareAlike 4.0 International License.

http://creativecommons.org/licenses/by-nc-sa/4.0/deed.en_US

This means you are free to copy and redistribute the material and adapt and build on the material under the following terms: You must give appropriate credit, provide a link to the license and indicate if changes were made. If you adapt or build on the material you must distribute your work under the same license as the original.

Note that this presentation contains images owned by others. Please seek their permission before reusing these images.