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 for loops
  - Single directive
  - Master directive

Parallel for loops

- Loops are the most common source of parallelism in most codes. Parallel loop directives are therefore very important!

- A parallel 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:

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)

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

Parallel for directive

- This construct is so common that there is a shorthand form which combines parallel region and worksharing loop directives:

C/C++:

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

Parallel loops (example)

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

Clauses

- **`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

- **`parallel for`** directive can take all clauses available for **`parallel`** directive.

- Beware! **`parallel for`** is not the same as **`for`** or the same as **`parallel`**

Parallel for loops (cont)

- With no additional clauses, the `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:

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.

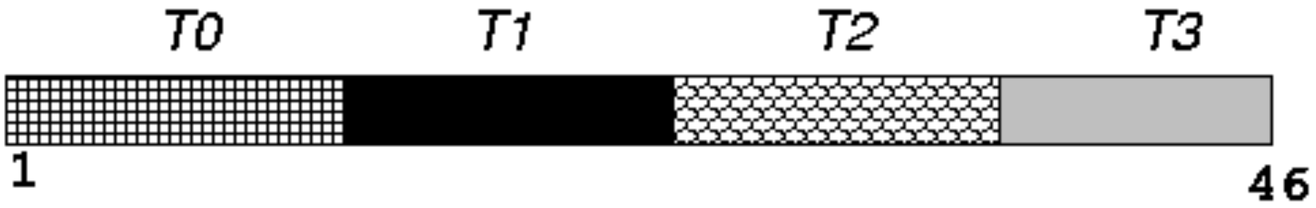
- e.g. **`#pragma omp for schedule(dynamic,4)`**

static schedule

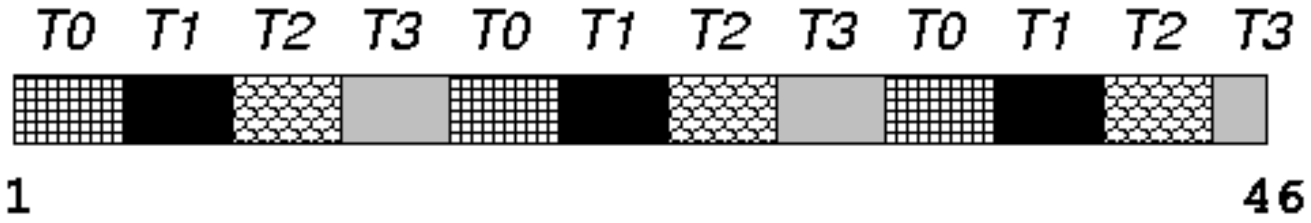
- With no *chunksize* specified, the iteration space is divided into (approximately) equal chunks, and one chunk is assigned to each thread in order (**block** schedule).

- 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



`schedule(static)`



`schedule(static,4)`

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.

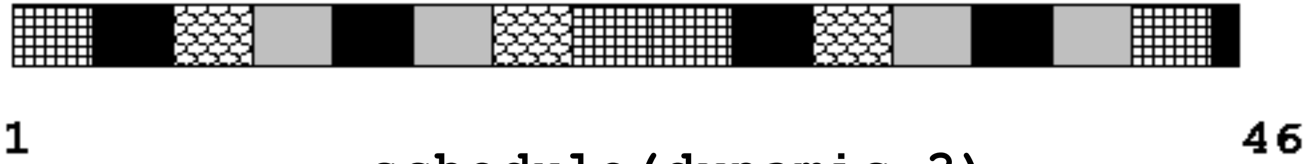
- i.e. as a thread finish a chunk, it is assigned the next chunk in the list.

- When no *chunksize* is specified, it defaults to 1.

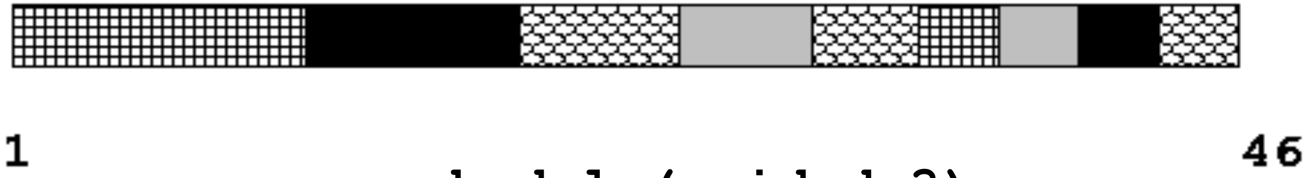
guided schedule

- `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



`schedule(dynamic,3)`



`schedule(guided,3)`

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`** usually best for load balanced loops - least overhead.
- **`static,n`** good for loops with mild or smooth load imbalance, but can induce overheads for small chunksizes.
- **`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:

C/C++:

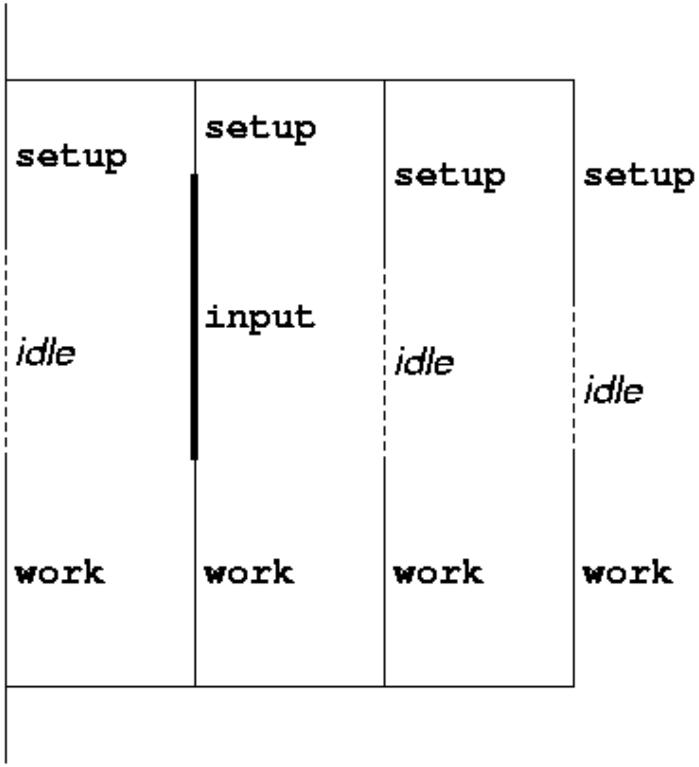
```
#pragma omp single [clauses]
        structured block
```

- Construct must contain a structured block: cannot branch into or out of it.

single directive (cont)

Example:

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



nowait clause

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

C/C++:

```
#pragma omp for nowait
   for loop

#pragma omp single nowait
   structured block
```

master directive

- Indicates that a block of code should be executed by the master thread (thread 0) only.
- Technically this isn’t a worksharing directive(!)
- 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.
- Latest versions of OpenMP have deprecated the name and replaced it with **`masked`**.

master directive (cont)

Syntax:

C/C++:

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

Orphaned directives

- Directives can be present in functions called from inside parallel regions

Example:

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

void fred() {
#pragma omp for
   for (int i=0; i<N; i++) {
      a[i] += 23.5;
   }
}
```

Orphaned directives (cont)

- This is very useful, as it allows a modular programming style….

- But it can also be rather confusing if the call tree is complicated (what happens if **fred** is also called from outside a parallel region? - the worksharing loop is all executed by the master thread)

- There are some extra rules about data scope attributes….

Data scoping rules

When we call a subroutine/function from inside a parallel region:

- Variables passed by reference/address in the argument list inherit their data scope attribute from the calling routine.
- Global variables in C/C++ are shared unless declared `threadprivate`
- `static` local variables in C/C++ are shared.
- All other local variables are private.

Exercise

- Redo the Mandelbrot example using a worksharing `for` directive.

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