Introduction to OpenMP

Tasks

Nick Maclaren

nmm1@cam.ac.uk

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OpenMP Tasks

In OpenMP 3.0 with a slightly different model
A form of explicit but virtual threading
Mapped in a complex way to OpenMP threads

- This course will not cover the details of that

Useful for unstructured or irregular problems

Can be hierarchical (i.e. tasks within tasks)
Called descendent tasks, child tasks or subtasks

Their Major Gotcha

The structured block and aliasing rules apply

- And all in the context of a tree structure

Need iron–clad disciplined coding to avoid problems

⇒ This is seriously tricky to get right

In C/C++, watch out for implicit sharing
E.g. in class methods and some library functions

- This course will cover only their simplest use

Essentially just as dynamic, nestable sections

Untied Tasks

This is when tasks can change thread dynamically

- Not covered, because feature is solid with gotchas

E.g.: critical is unsafe in untied tasks
An even fouler gotcha is mentioned in next lecture

Basic Syntax

Fortran:

```
!$OMP TASK [ clauses ]
< structured block >
!$OMP END TASK
```

C/C++:

```
#pragma omp task [ clauses ]
< structured block >
```

Clause syntax is rather like parallel
I.e. default, private, shared and firstprivate

Data Environment (1)

This is very poorly specified and solid with gotchas

- If task construct is lexically within parallel
Default is usually inherited, which is what is wanted

- Otherwise, default is generally firstprivate
No problem when reading the values in task construct
But it will generally copy the whole variable

- May need to specify shared for efficiency
E.g. when tasks use separate array sections
Still mustn't update same element in parallel tasks

Behaviour (1)

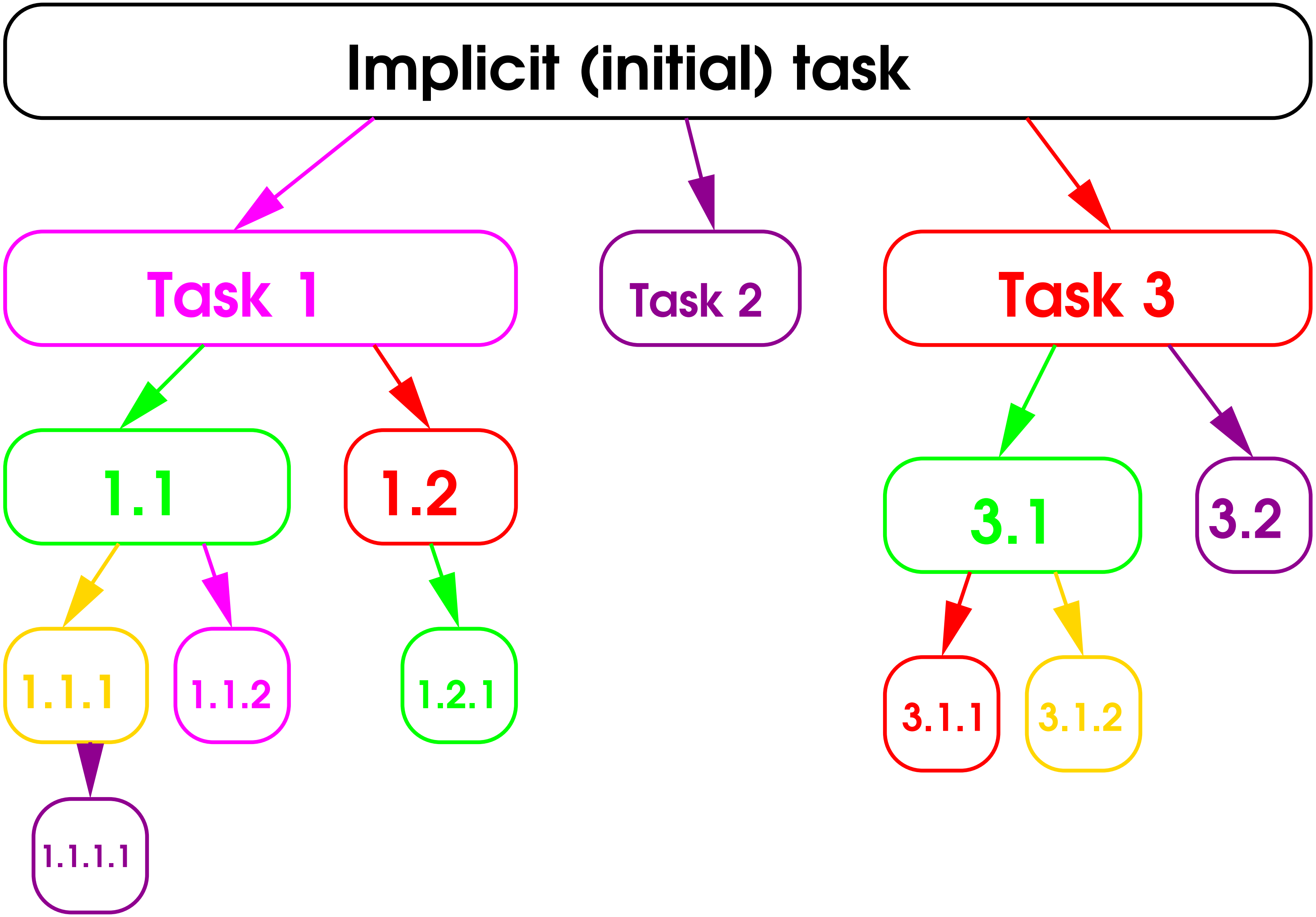
Tasks can create descendants to form a task tree
Just use task within the structured block

The descendant may run in parallel to its parent
Or suspend the parent and run synchronously

- Do not write code that assumes either behaviour

Some clauses control this, to a limited extent
Specification is bizarre and ambiguous

Hierarchical Trees



Behaviour (2)

- Avoid starting more tasks than available threads

And that means available in the parallel region

Will work if you use just the facilities taught here
But there are lots of gotchas if you go beyond them

You can control some of that, but horribly complicated
There are some brief references to the features later

- It's safe if you don't use any synchronisation

Except simple uses of critical and atomic (see later)

Data Environment (2)

Child task may need to return result to parent
Parent must share a private variable with the child

- You should use shared and be careful

- The variable must not move or go out of scope

So ensure that you call taskwait before it does

Unclear about C++ containers
Or Fortran pointers and allocatables

- Do not reallocate or change pointers

While shared by parent and any active tasks
Don’t add or remove elements, either!

Shared and Arguments/References

When you use task in a procedure
Can task have an argument that is shared?

- Yes, but always call taskwait before returning

I.e. do so in the same procedure that used task

Literal reading of specification states that is not so
At least for Fortran and C++ reference arguments
OpenMP's specification conflicts with the standards'

- Call taskwait before the name goes out of scope

Same applies to all block–scoped references

Thread-specific Data

Serious problems to do with thread–specific data
Including threadprivate, OpenMP thread ids, errno,
IEEE 754 flags/modes, and even C++ exceptions

The details are far too foul to describe in this course

- Do not trust any of these over a task boundary

- Do not mark any of them shared, even indirectly

E.g. by Fortran and C++ reference arguments

- Don't use both threadprivate and tasks

Waiting for Completion (1)

The taskwait directive is a sort of barrier
Waits for all immediate child tasks to finish

Fortran:

```
!$OMP TASKWAIT
```

C/C++:

```
#pragma omp taskwait
```

Like barrier, mustn't be executed conditionally
No good reason for that restriction, but don't do it

Waiting for Completion (2)

At the end of the structured block, what happens?
Does it wait for all of its child tasks or not?
The specification says nothing useful – assume either

- End each structured block with a taskwait

It does wait at the end of a parallel region
For all tasks and descendants in that parallel region

- Relying on this has its uses but is trickier

E.g. can write a dynamic parallel sections

Barriers and Task Completion

barrier and taskwait are not interchangeable
Neither implies the other, though there are links

- Don't use barrier with active tasks

⇒ And that means implicit barriers, too
That means all worksharing constructs, like DO/for

Using barrier with active tasks is possible
It's tricky and not covered in this course

Other Restrictions (1)

- No reduction operations inside tasks

- Rules for avoiding deadlock were given above

Just follow them with tasks replacing worksharing

Can use task within a worksharing construct

A fairly insane idea, and probably very inefficient

⇒ Except for single, as described below

That (and master) is a trick to get tasks started

Other Restrictions (2)

- Worksharing cannot be used within a task

Though you can use parallel worksharing constructs

⇒ Be warned – this is nested parallelism

Do NOT do this without learning about nesting
Must enable it explicitly, and tuning is tricky

- It is too complicated to cover in this course

- Same applies to many other complications

A Recursion Gotcha

Tasks can create recursion in non–recursive code
Applies to all procedures called from within tasks

Task A is suspended inside such a procedure
Task B is scheduled on the same thread as task A

- Within tasks, make all procedures pure

That's much stronger than recursive, but needs it

Don't change static data or use if it may change
And don't call any procedures that might
And see the next lecture about Program Global State

Synchronisation Inside Tasks

- Don’t use master and explicit thread id checks

Tasks bound to a single, arbitrary OpenMP thread
You are likely to cause deadlock

single is also almost certainly asking for trouble

critical can be used for task synchronisation etc.
Watch out if you use features not in this course

- Do NOT use tasking within critical
- Do NOT call SMP–capable libraries in it

Using Tasks for Worksharing (1)

One simple use is your own worksharing construct
Then use that just like any other (e.g. DO/for)

Need to embed it in single (or master+barrier)
That thread then starts all the top–level tasks
Waits for all tasks before exiting the single

- Each task waits for all subtasks before exiting
Can omit that if no subtasks but be careful

Using Tasks for Worksharing (2)

Can create tasks in loops, tasks create subtasks etc.
Each task waits for all descendants before exit

- Use taskwait at the end of all tasks

- Make sure that all subtrees are independent

A subtree is a task and all its descendants

This is BY FAR the most common cause of errors
It is terribly easy to think of just one level

Fortran Task Worksharing

```
!$OMP SINGLE [clauses]
DO . . .
    !$OMP TASK [clauses]
        . . .
        !$OMP TASK
            . . .
        !$OMP END TASK
            . . .
        !$OMP TASKWAIT
    !$OMP END TASK
END DO
!$OMP TASKWAIT
!$OMP END SINGLE
```

C/C++ Task Worksharing

```
#pragma single [clauses]
{
        for (. . .) {
                #pragma task [clauses]
                {
                        . . .
                        #pragma task
                        {
                                . . .
                        }
                        . . .
                        #pragma taskwait
                }
        }
        #pragma taskwait
}
```

Fortran Task Parameters (1)

Passing dynamic parameters to the task is tricky
E.g. this will not work, because index is private:

```
!$OMP SINGLE
DO index = 1 , count
    !$OMP TASK FIRSTPRIVATE ( index )
        CALL Fred ( index )
    !$OMP END TASK
END DO
!$OMP TASKWAIT
!$OMP END SINGLE
```

Leaving out the FIRSTPRIVATE doesn’t work, either

Fortran Task Parameters (2)

Need to share index, but best done indirectly

```
!$OMP PARALLEL SHARED ( copy )
!$OMP SINGLE
DO index = 1 , count
        copy = index
        !$OMP TASK FIRSTPRIVATE ( copy )
                CALL Fred ( index )
        !$OMP END TASK
END DO
!$OMP TASKWAIT
!$OMP END SINGLE
!$OMP END PARALLEL
```

- Note that copy is accessed in only one thread

C/C++ Task Parameters (1)

Passing dynamic parameters to the task is tricky
E.g. this will not work, because index is private:

```
#pragma omp single
{
    for ( index = 0 ; index < count ; ++index )
    {
        #pragma omp task firstprivate ( index )
        fred ( index ) ;
    }
    #pragma omp taskwait
}
```

Leaving out the firstprivate doesn't work, either

C/C++ Task Parameters (2)

Need to share index, but best done indirectly

```
#pragma omp parallel shared ( copy )
{
    #pragma omp single
    {
        for ( index = 0 ; index < count ; ++index )
        {
            copy = index ;
            #pragma omp task firstprivate ( copy )
            fred ( index ) ;
        }
        #pragma omp taskwait
    }
}
```

- Note that copy is accessed in only one thread

Task Parameters (3)

⇒ Even the above code is not entirely safe

Unclear when firstprivate is executed
Might be in parallel with next iteration

- Could allocate array and use separate elements
Remember to deallocate after the taskwait
Applies to Fortran, C and C++

Dynamic Sections

Just create a parallel region and do all waiting at end

- All tasks (not just subtrees) must be independent

This is just a dynamic form of parallel sections
A bit more flexible than either that or parallel DO/for

- Can combine these two simple usages

Use this form at top level, and previous for subtasks

Fortran Parallel Task Worksharing

```
!$OMP PARALLEL [clauses]
!$OMP MASTER
    . . .
    !$OMP TASK
        . . .
        !$OMP TASK
            . . .
        !$OMP END TASK
        . . .
    !$OMP END TASK
    . . .
!$OMP MASTER
!$OMP END PARALLEL
```

Use SINGLE if you prefer (possibly with NOWAIT)

C/C++ Parallel Task Worksharing

```
#pragma parallel [clauses]
{
        #pragma master
        {
                . . .
                #pragma task
                {
                        . . .
                        #pragma task
                        {
                                . . .
                        }
                        . . .
                }
                . . .
        }
}
```

Last Word

Beyond these simple usages, there be dragons ...