Programming OpenMP

Tasking Model

Christian Terboven

Tasking Overview

What is a task in OpenMP?

- Tasks are work units whose execution
  - → may be deferred or…
  - → … can be executed immediately
- Tasks are composed of
  - → **code** to execute, a **data** environment (initialized at creation time), internal **control** variables (ICVs)
- Tasks are created…

  … when reaching a parallel region → implicit tasks are created (per thread)

  … when encountering a task construct → explicit task is created

  … when encountering a taskloop construct → explicit tasks per chunk are created

  … when encountering a target construct → target task is created

Tasking execution model

- Supports unstructured parallelism

  → unbounded loops

  ```
  while ( <expr> ) {
      ...
  }
  ```

  → recursive functions

  ```
  void myfunc( <args> )
  {
      ...; myfunc( <newargs> ); ...;
  }
  ```
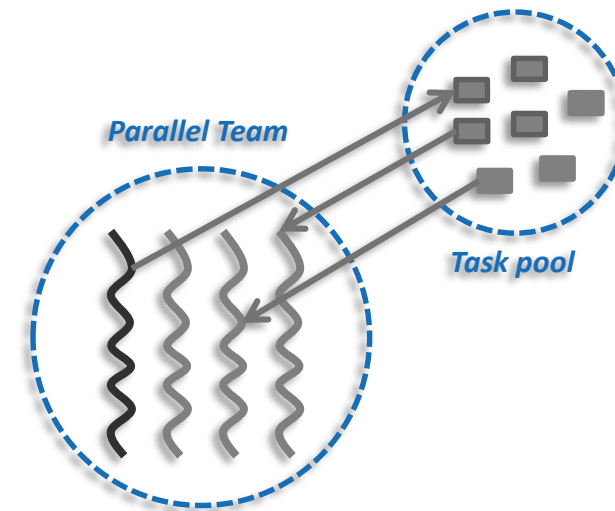
- Several scenarios are possible:

  → single creator, multiple creators, nested tasks (tasks & WS)

- All threads in the team are candidates to execute tasks

- Example (unstructured parallelism)

  ```
  #pragma omp parallel
  #pragma omp master
  while (elem != NULL) {
      #pragma omp task
          compute(elem);
      elem = elem->next;
  }
  ```

Parallel Team

Task pool

The task construct

- Deferring (or not) a unit of work (executable for any member of the team)

```
#pragma omp task [clause[[,] clause]...]
{structured-block}
```

```
!$omp task [clause[[,] clause]...]
…structured-block…
!$omp end task
```

- Where clause is one of:

→ private(list)	
→ firstprivate(list)	
→ shared(list)	**Data Environment**
→ default(shared | none)	
→ in_reduction(r-id: list)	

→ allocate([allocator:] list)	**Miscellaneous**
→ detach(event-handler)	

→ if(scalar-expression)	
→ mergeable	**Cutoff Strategies**
→ final(scalar-expression)	

→ depend(dep-type: list)	**Synchronization**

→ untied	
→ priority(priority-value)	**Task Scheduling**
→ affinity(list)	

Task scheduling: tied vs untied tasks

- Tasks are tied by default (when no untied clause present)

  - → tied tasks are executed always by the same thread (not necessarily creator)

  - → tied tasks may run into performance problems

- Programmers may specify tasks to be untied (relax scheduling)

```
#pragma omp task untied
{structured-block}
```

  - → can potentially switch to any thread (of the team)

  - → bad mix with thread based features: thread-id, threadprivate, critical regions...

  - → gives the runtime more flexibility to schedule tasks

 - → but most of OpenMP implementations doesn't "honor" untied ☹

Task scheduling: taskyield directive

■ Task scheduling points (and the taskyield directive)

→ tasks can be suspended/resumed at TSPs → some additional constraints to avoid deadlock problems

→ implicit scheduling points (creation, synchronization, ...)

→ explicit scheduling point: the taskyield directive

```
#pragma omp taskyield
```

■ Scheduling [tied/untied] tasks: example

```
#pragma omp parallel
#pragma omp single
{
    #pragma omp task untied
    {
        foo();
        #pragma omp taskyield
        bar()
    }
}
```
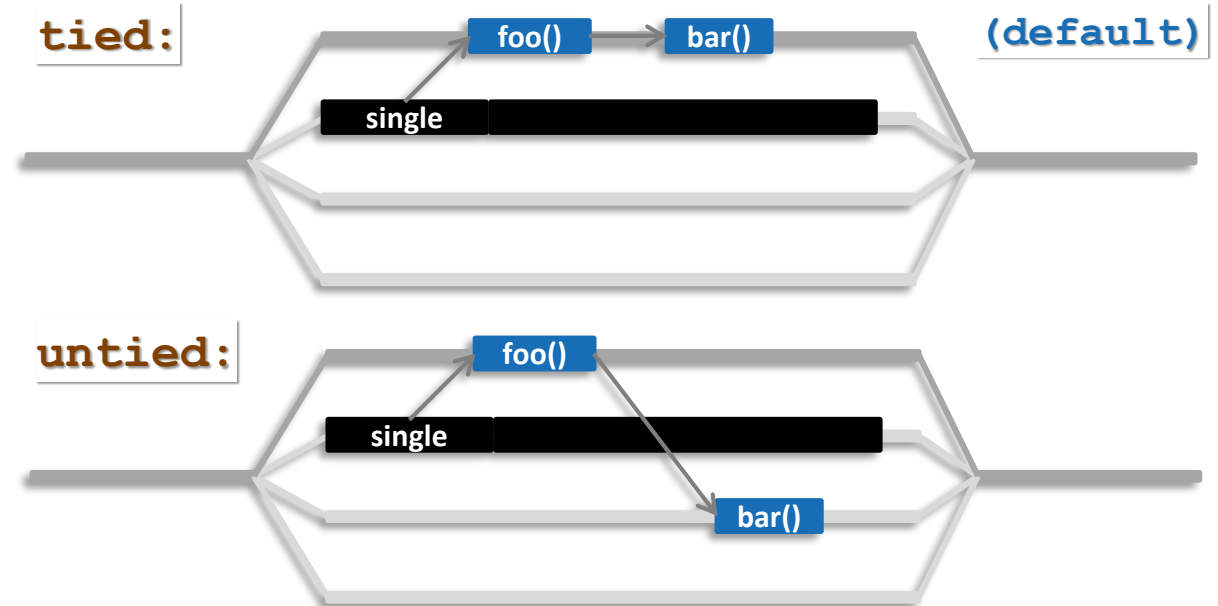
Task synchronization: taskwait directive

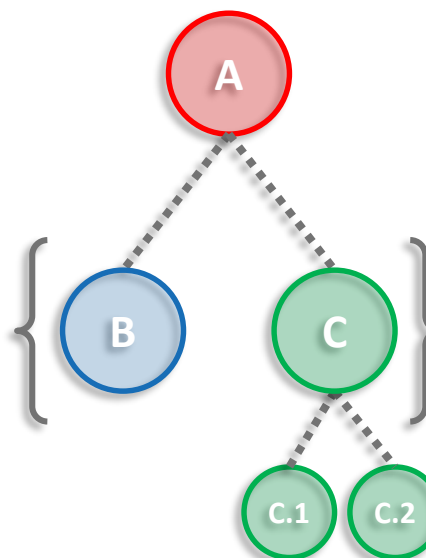- The taskwait directive (shallow task synchronization)

  → It is a stand-alone directive

```
#pragma omp taskwait
```

  → wait on the completion of child tasks of the current task; just direct children, not all descendant tasks;

    includes an implicit task scheduling point (TSP)


```
#pragma omp parallel
#pragma omp single
{
    #pragma omp task                  :A
    {
        #pragma omp task  :B
        { … }
        #pragma omp task  :C
        { … #C.1; #C.2; …}
        #pragma omp taskwait
    }
} // implicit barrier will wait for C.x
```

wait for…

Programming in OpenMP
Christian Terboven & Members of the OpenMP Language Committee

Task synchronization: barrier semantics

■ OpenMP barrier (implicit or explicit)

→ All tasks created by any thread of the current team are guaranteed to be completed at barrier exit

```
#pragma omp barrier
```

→ And all other implicit barriers at parallel, sections, for, single, etc…

Task synchronization: taskgroup construct

- The taskgroup construct (deep task synchronization)

  → attached to a structured block; completion of all descendants of the current task; TSP at the end

```
#pragma omp taskgroup [clause[[,] clause]...]
{structured-block}
```

  → where clause (could only be): reduction(reduction-identifier: list-items)

```
#pragma omp parallel
#pragma omp single
{
    #pragma omp taskgroup          : A
    {
        #pragma omp task           :B
        { … }
        #pragma omp task           :C
        { … #C.1; #C.2; …}

    } // end of taskgroup
}
```

wait for…
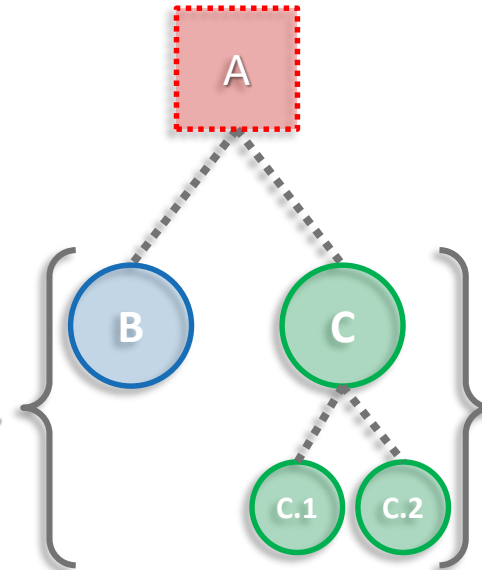
Data Environment

Explicit data-sharing clauses

- Explicit data-sharing clauses (shared, private and firstprivate)

```
#pragma omp task shared(a)
{
  // Scope of a: shared
}
```

```
#pragma omp task private(b)
{
    // Scope of b: private
}
```

```
#pragma omp task firstprivate(c)
{
    // Scope of c: firstprivate
}
```

- If **default** clause present, what the clause says

  → shared: data which is not explicitly included in any other data sharing clause will be **shared**

  → none: compiler will issue an error if the attribute is not explicitly set by the programmer (very useful!!!)

```
#pragma omp task default(shared)
{
 // Scope of all the references, not explicitly
 // included in any other data sharing clause,
 // and with no pre-determined attribute: shared
}
```

```
#pragma omp task default(none)
{
 // Compiler will force to specify the scope for
 // every single variable referenced in the context
}
```

Hint: Use default(none) to be forced to think about every variable if you do not see clearly.

Pre-determined data-sharing attributes

- threadprivate variables are threadprivate **(1)**
- dynamic storage duration objects are shared (malloc, new,…) **(2)**
- static data members are shared **(3)**
- variables declared inside the construct

  → static storage duration variables are shared **(4)**

  → automatic storage duration variables are private **(5)**

- the loop iteration variable(s)…

```
#pragma omp task                    5
{
    int x = MN;
    // Scope of x: private
}
```

```
#pragma omp task                    4
{
    static int y;
    // Scope of y: shared
}
```

```
int A[SIZE];                        1
#pragma omp threadprivate(A)

// ...
#pragma omp task
{
  // A: threadprivate
}
```

```
int *p;                             2

p = malloc(sizeof(float)*SIZE);

#pragma omp task
{
    // *p: shared
}
```

```
void foo(void){                     3
    static int s = MN;
}

#pragma omp task
{
    foo(); // s@foo(): shared
}
```

Implicit data-sharing attributes (in-practice)

OpenMP

■ Implicit data-sharing rules for the task region

→ the **shared** attribute is lexically inherited

→ in any other case the variable is **firstprivate**

```cpp
int a = 1;
void foo() {
    int b = 2, c = 3;
    #pragma omp parallel private(b)
    {
        int d = 4;
        #pragma omp task
        {
            int e = 5;
            // Scope of a:
            // Scope of b:
            // Scope of c:
            // Scope of d:
            // Scope of e:
        }
    }
}
```

→ Pre-determined rules (could not change)

→ Explicit data-sharing clauses (+ default)

→ Implicit data-sharing rules

■ (in-practice) variable values within the task:

→ value of a: 1

→ value of b: x // undefined (undefined in parallel)

→ value of c: 3

→ value of d: 4

→ value of e: 5

Task reductions (using taskgroup)

- **Reduction operation**
  - → perform some forms of recurrence calculations
  - → associative and commutative operators
- **The (taskgroup) scoping reduction clause**

```
#pragma omp taskgroup task_reduction(op: list)
{structured-block}
```

  - → Register a new reduction at [1]
  - → Computes the final result after [3]
- **The (task) in_reduction clause [participating]**

```
#pragma omp task in_reduction(op: list)
{structured-block}
```

  - → Task participates in a reduction operation [2]

```c
int res = 0;
node_t* node = NULL;
...
#pragma omp parallel
{
  #pragma omp single
  {
    #pragma omp taskgroup task_reduction(+: res)
    { // [1]
      while (node) {
        #pragma omp task in_reduction(+: res) \
                      firstprivate(node)
        { // [2]
          res += node->value;
        }
        node = node->next;
      }
    } // [3]
  }
}
```

Task reductions (+ modifiers)

- Reduction modifiers
    - → Former reductions clauses have been extended
    - → task modifier allows to express task reductions
    - → Registering a new task reduction [1]
    - → Implicit tasks participate in the reduction [2]
    - → Compute final result after [4]
- The (task) in_reduction clause [participating]

```
#pragma omp task in_reduction(op: list)
{structured-block}
```

- → Task participates in a reduction operation [3]

```
int res = 0;
node_t* node = NULL;
...
#pragma omp parallel reduction(task,+: res)
{ // [1][2]
  #pragma omp single
  {
    #pragma omp taskgroup
    {
      while (node) {
        #pragma omp task in_reduction(+: res) \
                    firstprivate(node)
        { // [3]
          res += node->value;
        }
        node = node->next;
      }
    }
  }
} // [4]
```

Intel compiler 2021 still not able to compile!
Can be compiled with Clang 11!

Programming in OpenMP
Christian Terboven & Members of the OpenMP Language Committee

Tasking illustrated

Fibonacci illustrated

```
 1  int main(int argc,
 2              char* argv[])
 3  {
 4      [...]
 5      #pragma omp parallel
 6      {
 7           #pragma omp single
 8         {
 9             fib(input);
10         }
11      }
12      [...]
13  }
```

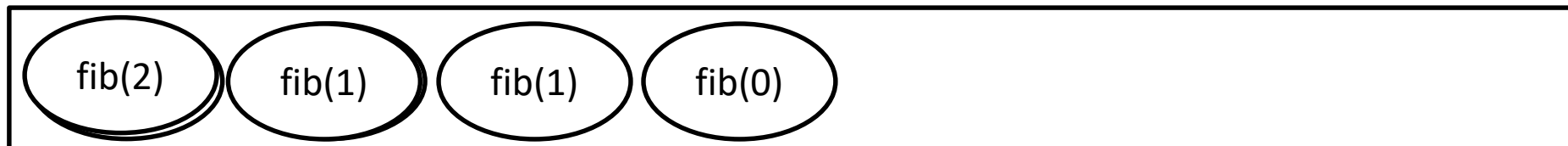```
14 int fib(int n)   {
15   if (n < 2) return n;
16   int x, y;
17   #pragma omp task shared(x)
18   {
19   x = fib(n - 1);
20   }
21   #pragma omp task shared(y)
22   {
23   y = fib(n - 2);
24   }
25   #pragma omp taskwait
26   return x+y;
27 }
```

- Only one Task / Thread enters fib() from main(), it is responsible for creating the two initial work tasks

- Taskwait is required, as otherwise x and y would get lost

- **T1 enters fib(4)**
- **T1 creates tasks for fib(3) and fib(2)**
- **T1 and T2 execute tasks from the queue**
- **T1 and T2 create 4 new tasks**
- **T1 - T4 execute tasks**
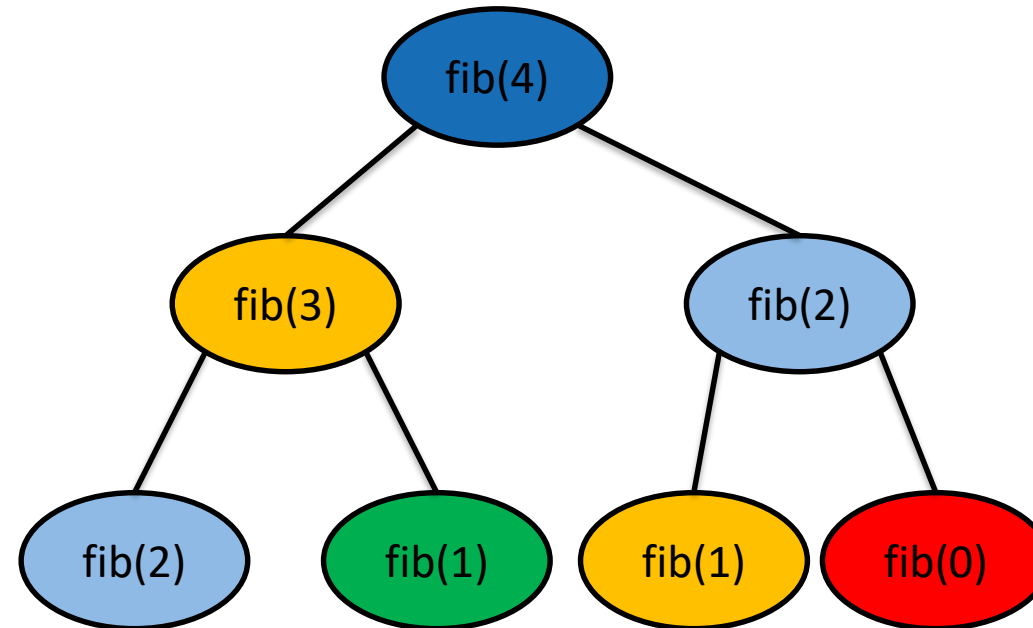


Task Queue

- **T1 enters fib(4)**
- **T1 creates tasks for fib(3) and fib(2)**
- **T1 and T2 execute tasks from the queue**
- **T1 and T2 create 4 new tasks**
- **T1 - T4 execute tasks**
- **…**