Tasking in OpenMP

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> ) {
    ...
}
```

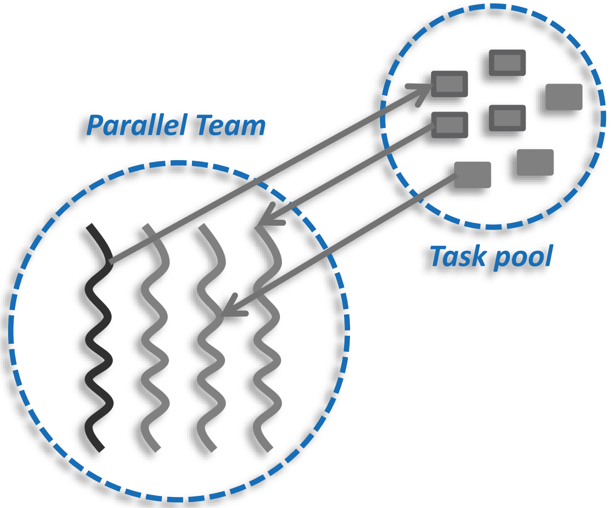
  - → recursive functions

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



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:

Data Environment

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

Miscellaneous

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

Cutoff Strategies

- → if(scalar-expression)
- → mergeable
- → final(scalar-expression)

Synchronization

- → depend(dep-type: list)

Task Scheduling

- → untied
- → priority(priority-value)
- → 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 ☹

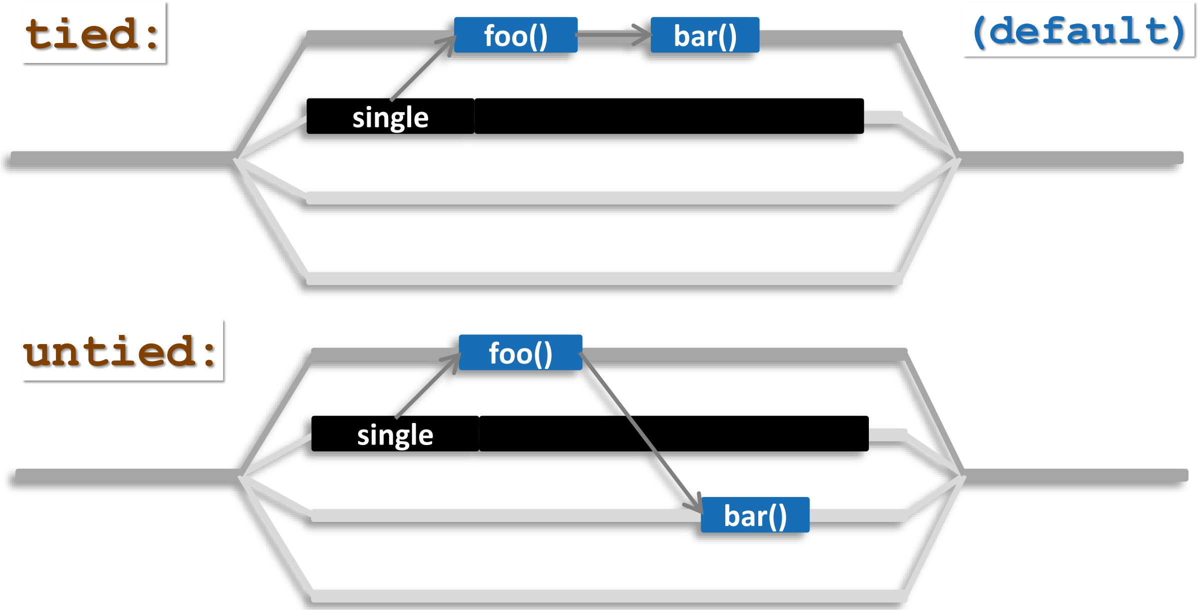
Task scheduling: taskyield directive

- 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 scheduling: programmer’s hints

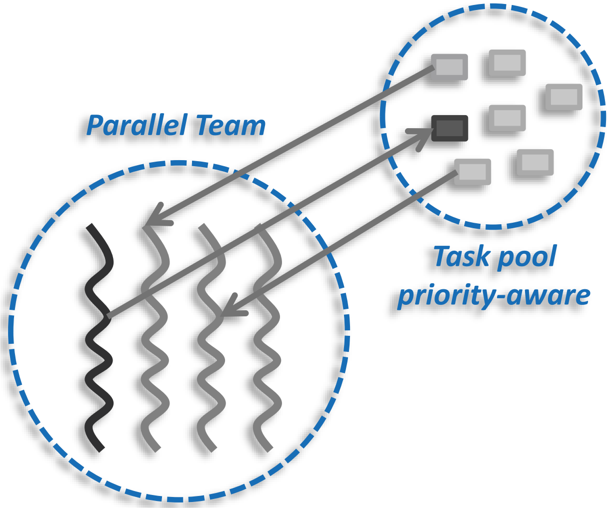
- Programmers may specify a priority value when creating a task

```
#pragma omp task priority(pvalue)
{structured-block}
```

→ pvalue: the higher → the best (will be scheduled earlier)

→ once a thread becomes idle, gets one of the highest priority tasks

```
#pragma omp parallel
#pragma omp single
{
  for ( i = 0; i < SIZE; i++) {
    #pragma omp task priority(1)
    { code_A; }
  }
  #pragma omp task priority(100)
  { code_B; }
  ...
}
```



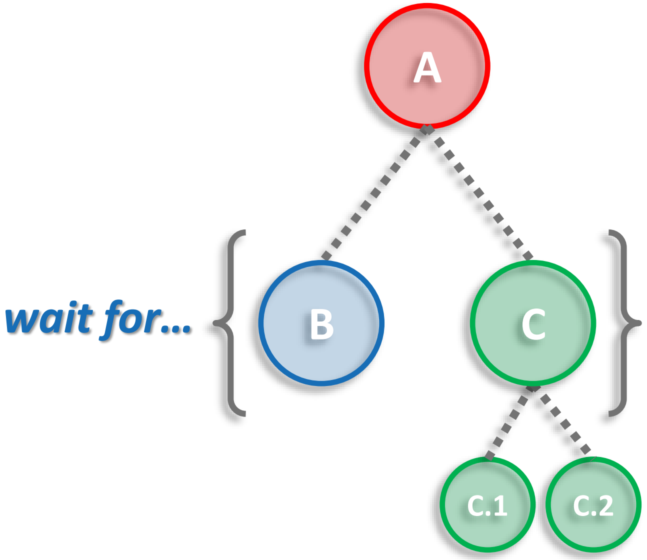
Task synchronization: taskwait directive

- 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
```



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

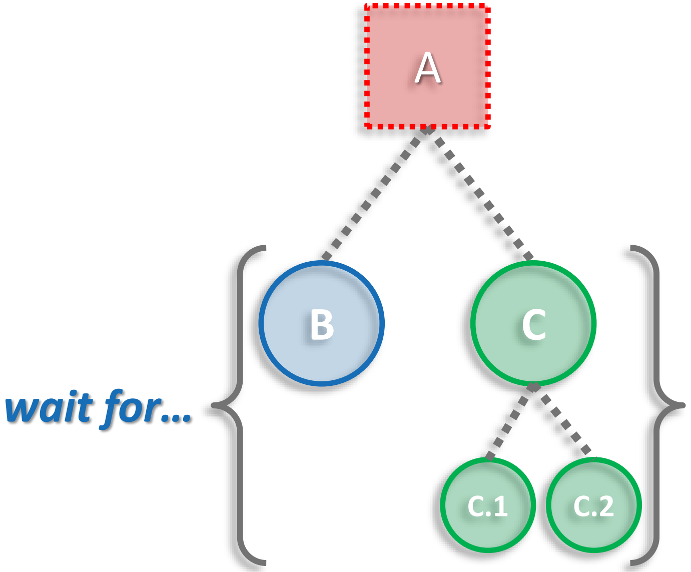
- The taskgroup construct (deep task synchronization)
  - → attached to a structured block; completion of all descendants of the current task; TSP at the end

```
#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
}
```



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)…

5

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

4

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

1

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

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

2

```
int *p;

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

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

3

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

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

Implicit data-sharing attributes (in-practice)

- Implicit data-sharing rules for the task region
  - → the **shared** attribute is lexically inherited
  - → in any other case the variable is **firstprivate**

```
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 (can 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]

```
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]
```