OpenMP Tasking Concepts

TACC: Advanced OpenMP

PCSE: class: 4/17/18

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Tasking

Review Worksharing and Limitations

Basic Task Syntax and Operations

Task Synchronization

Running Tasks in Parallel

Data-sharing and firstprivate Default for Tasks

Common Use Cases for Tasks

Task Dependences

Taskloop

Worksharing

- TEAM OF THREADS does work
- LOOP ITERATION PARTITIONING (chunks of independent work)
- DATA ENVIRONMENT is set by parallel region, altered by clauses.
- IMPLIED BARRIER forces threads to wait at end.

```
omp parallel
{

}
```

```
omp parallel
{
   <Worksharing Loops>
}
```

Example - schedule(static,16), threads = 4

```
!$omp parallel do schedule(static,16)
      do i=1,128
       A(i)=B(i)+C(i)
      enddo
```

thread0:
`do i=1,16`
`  A(i)=B(i)+C(i)`
`enddo`
`do i=65,80`
`  A(i)=B(i)+C(i)`
`enddo`
	thread2:
	`do i=33,48`
	`  A(i)=B(i)+C(i)`
	`enddo`
	`do i = 97,112`
	`  A(i)=B(i)+C(i)`
	`enddo`

thread1:
`do i=17,32`
`  A(i)=B(i)+C(i)`
`enddo`
`do i = 81,96`
`  A(i)=B(i)+C(i)`
`enddo`
	thread3:
	`do i=49,64`
	`  A(i)=B(i)+C(i)`
	`enddo`
	`do i = 113,128`
	`  A(i)=B(i)+C(i)`
	`enddo`

Worksharing Limitation

- Worksharing requires ability to know number of work units before execution (loop count).
- Dynamic scheduling of parallel loop work-chunks is limited. Think of work chunks being queued to execute from a single FIFO queue*.
- Ideal for "data parallel", but "task parallel" requires inconvenient construction.

*This can be somewhat limited, but reasonable for monotonically increasing/decreasing work per iteration.

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Learning Objective

-- Tasking --

- Review Worksharing and Limitations
- Basic Task Syntax and Operations
- Task Synchronization
- Running Tasks in Parallel
- Data-sharing and firstprivate Default for Tasks
- Common Use Cases for Tasks
- Task Dependences
- Taskloop

Getting Started with Tasking

Easy to begin using, for a novice

Uncomplicated syntax and coding for many cases

Task clauses provide enough flexibility to be efficient (in programming syntax and execution) for more complicated use cases.

Is it easy? – that depends.
It is somewhat like worksharing—
There are simple and complex cases.

What is Tasking for?

Irregular Computing:

- While loop, execute independent iterations in parallel
- Follow pointers in list until a NULL pointer is reached,
  performing independent work for each pointer position.
  - Note: the pointer chase is inherently serial but if work at each pointer position is independent, then work can be executed in parallel.
- Follow nodes in tree graph & perform independent work at nodes
- Ordered executions that have task (work) with dependences

Generating a task

We first go over generating tasks in a serial region – computationally impractical.

But…it is a practical base for developing concepts.

Hold on– we'll get to executing tasks concurrently in a parallel region!

Generating a task

task is a directive, with clauses (not shown)

- A task is "deferrable". It can be executed immediately or later.
- Deferred tasks are queued.

Tasks in a serial region.

Tasks do independent work.

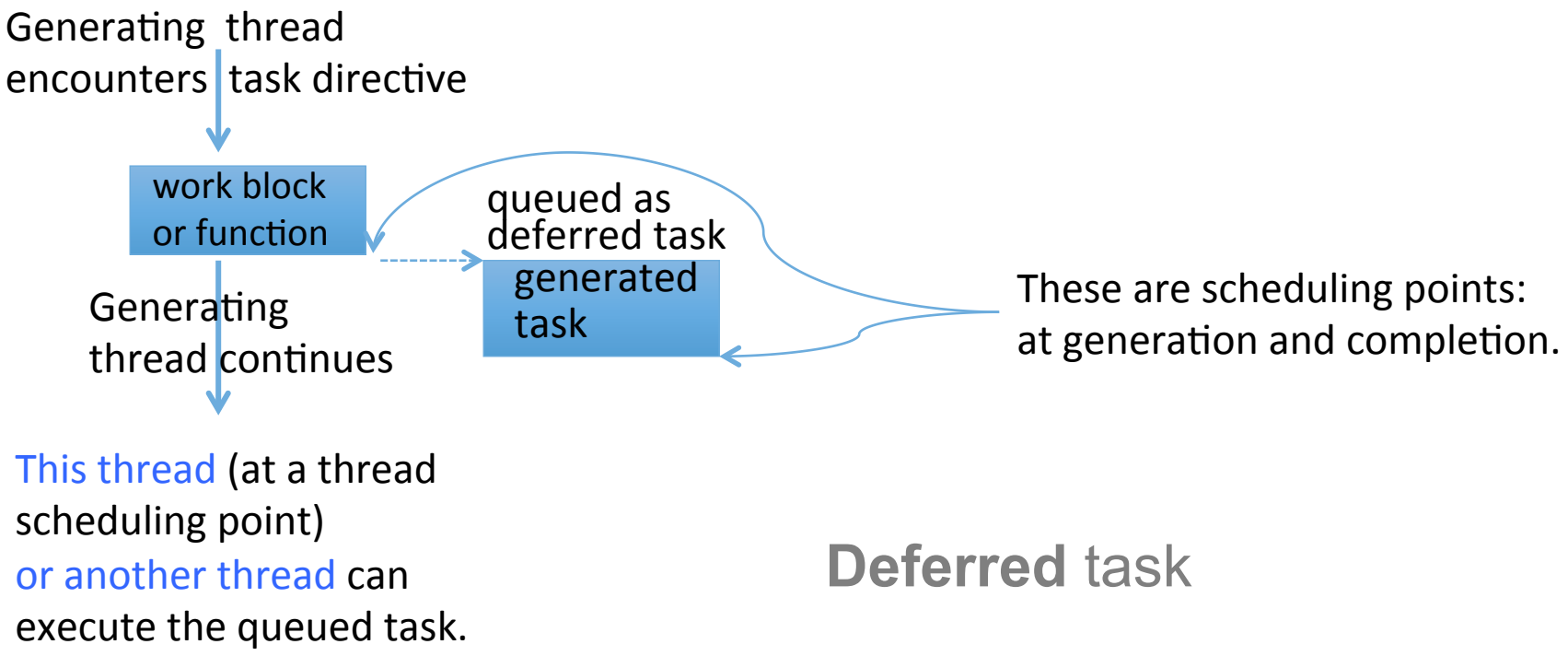
C/C++

```
#pragma omp task
  foo(j);

#pragma omp task
{
  for(i=0;i<n;i++){…};
}
```

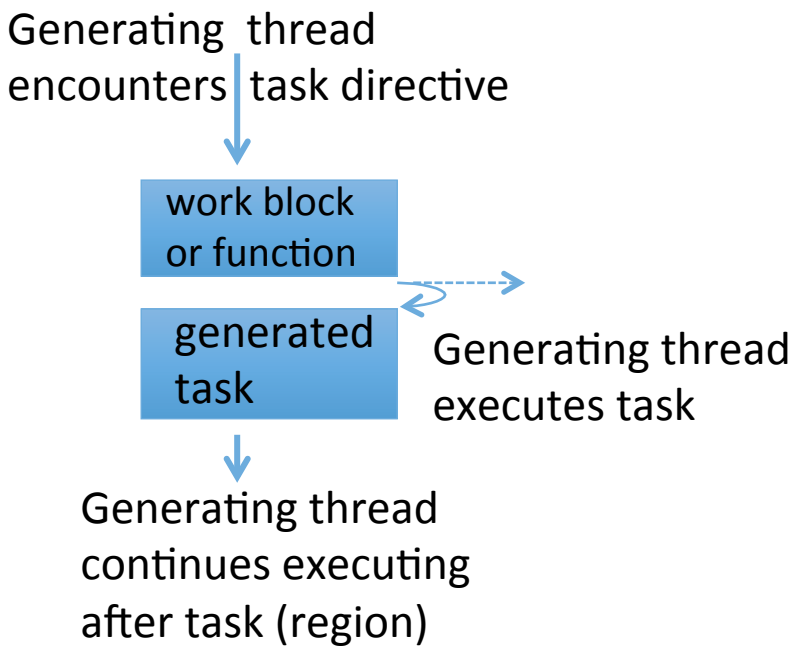
F90

```
!$omp task
   foo(j)
!$omp end task

!$omp task
   do i = 1,n; … ;enddo
!$omp end task
```

Deferred Task



Immediate Task



Immediate task

What is a Task

- It is work generated by a task construct– yeah, yeah we know that now!
  IT IS an explicit task.
- Threads of a parallel region, executing the replicated work-- these are also tasks, with the distinctive name: implicit tasks.

TASK will only mean Explicit Task unless otherwise stated.

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Synchronizing tasks (sibling tasks)

If a task is deferred, use the taskwait construct to wait for completion at some point in the code.

C/C++

```
#pragma omp task
{ foo(j); }


#pragma omp task
{ for(i=0;i<n;i++){…}; }

#pragma omp taskwait
```

F90

```
!$omp task
   call foo(j)
!$omp end task

!$omp task
   do i = 1,n; … ;enddo
!$omp end task
!$omp taskwait
```

Synchronizing tasks (nested tasks)

A taskgroup construct waits for all sibling and their descendants.

Nested Tasks

C/C++

```
#pragma taskgroup
{
  #pragma omp task
    foo(j);


  #pragma omp task
  { for(i=0;i<n;i++)
    #pragma omp task
      foo(i);
   }
}
```

F90

```
!omp taskgroup
  !$omp task
     call foo(j)
  !$omp end task

  !$omp task
     do i = 1,n
     !$omp task
        call foo(i);
     !$omp end task
     enddo
  !$omp end task
!$omp end taskgroup
```

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Generating Concurrent Tasks—in a parallel region

First, create a team of threads, to work on tasks.

Use a single thread to generate tasks.

C/C++

```
#pragma omp parallel num_threads(4)
{
  #pragma omp single
  {
    //generate multiple tasks

  }
}
```

F90

```
!$omp parallel num_threads(4)

  !$omp single

    !generate multiple tasks

  !omp end single
!$omp end parallel
```

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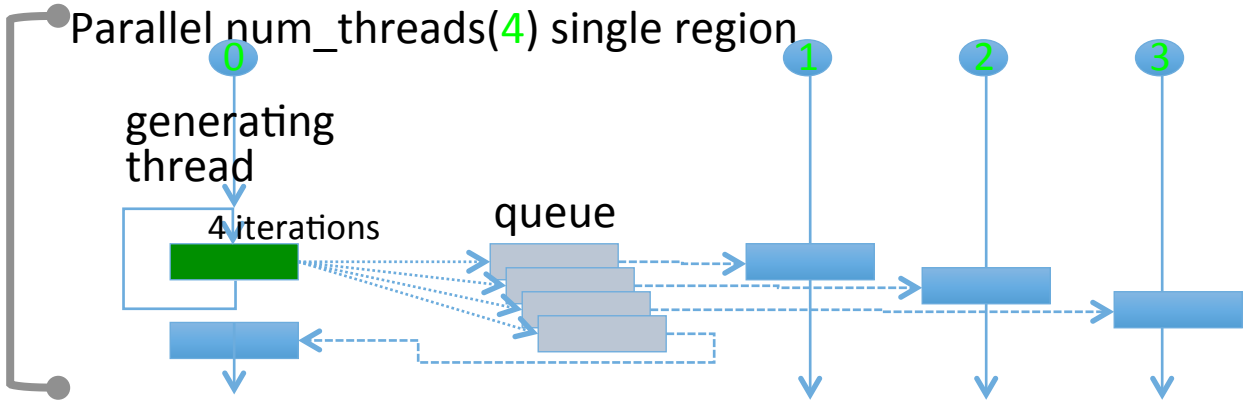
Generate multiple tasks: with loop (while/do/for) or recursion

Tasks in parallel region

Threads of Team will dequeue & execute tasks

Shared variables of parallel region are also shared by tasks

Tasks obey explicit and implicit barriers, also taskwait & taskgroup



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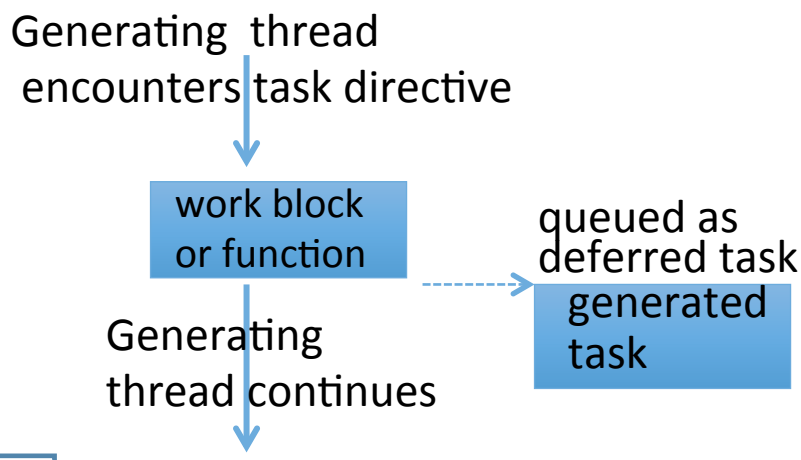
Tasks: Basic Data-sharing Attributes

- If the task generating construct is in a parallel region any shared variables remain shared.
- for/do index variables of a worksharing loop are private (see spec.)
- private variables in an enclosing construct are firstprivate for the task.

The Point: The index passed to a task needs to be first private.

Deferred Task



Basic Concept:
The argument value at generation time is needed– not later when it is run.

```
#pragma omp task firstprivate(j)
  foo(j);

j++;
```

```
!$omp task  firstprivate(j)
   foo(j)
!$omp end task

j = j+1
```

In a parallel region j is shared, and hence needs to be declared firstprivate.

Scheduling Optimization

For a small number of threads and tasks, and a large diversity in task work—an imbalance will occur. Even with moderate diversity and large thread and task counts, an imbalance my be present. The priority clause can alleviate this problem. (Larger # = higher priority.)

```
for (i=0;i<N; i++) {
        #pragma omp task priority(i+1)
        compute_array(array[i], N);
}
```

```
do i=1,N
    !$omp task priority(i)
    call compute_array(matrix(:, i), N)
    !$omp end task
enddo
```

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While loop

- firstprivate clause is necessary, since *cntr* is shared and value must be captured for work.

```
   int cntr = 100;
#pragma omp parallel
#pragma omp single

while(cntr>0){

 #pragma omp task firstprivate(cntr)
 printf("cntr=%d\n",cntr);

  cntr--;
}
```

```
 integer cntr = 100
!$omp parallel
!$omp single

do while(cntr>0)

  !$omp task firstprivate(cntr)
   print*,"cntr= ",cntr
  !$omp end task

  cntr = cntr - 1
enddo
!$omp end single
!$omp end parallel
```

Exploiting tasks within while loop

The generating loop is executed SERIALLY, but concurrently with the dequeued tasks.

- So, the non-tasking loop parts should not be costly.
- Any generated tasks can be picked up directly by other team members.

```
#pragma omp single
while(cntr>0){
  #pragma omp task firstprivate(cntr)
    printf("cntr=%d\n",cntr);

  cntr--;
}
```

Serial – generation

Parallel – Tasking

Serial – incrementer

Pointer Chasing

- ***ptr*** points to a C/C++ structure or F90 defined type

```
   int *ptr;
…//initialize pointer
#pragma omp parallel
#pragma omp single

while(ptr){
  #pragma omp task firstprivate(ptr)
    process(ptr);


  ptr = ptr->next;
}
```

```
 integer,pointer :: ptr
…! initialize pointer
!$omp parallel
!$omp single

do while(associated(ptr))
 !$omp task firstprivate(ptr)
     process(ptr)
 !$omp end task

 ptr = ptr%next
enddo

!$omp end single
!$omp end parallel
```

Using Recursion in C/C++

- Starting point for tree searches.
- Note, the recursion function, not the "process", is directly tasked.

```
#pragma omp parallel
#pragma omp single
    chase(ptr);
…
void chase(node *ptr){

  if(ptr->next){
   #pragma omp task
   chase(ptr->next);
  }
   process(ptr)
}
```

Just another way to build a queue of tasks– but with recursion (bunch of context switching)

Undeferred Tasks with if clause

```
while(ptr){

  usec=ptr->cost*factor;

  #pramga omp task if(usec>0.01) firstprivate(ptr)
  process(ptr)

  ptr = ptr->next;
}
```

If the ***if*** argument is false (exec time (usec) is less than 0.01), task is undeffered.

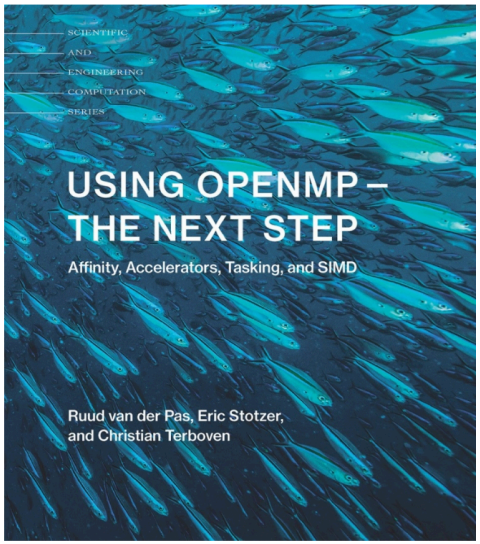
- Generating thread will suspend generation
- Generating thread will execute the task
- Generating thread will resume generation

--The END--

Questions?

References:

OpenMP Programming: The Next Step



More Steps? We can cover Task Dependences, time permitting.

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Depend clause

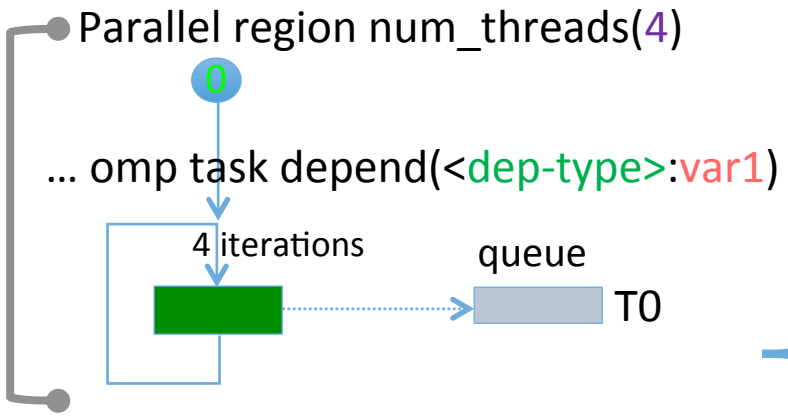
Syntax: … **`task depend(`** *dependence-type* **`:`** *list* **`)`**

- Dependences are derived from *dependence-type* and the *list* items of the depend clause.

dependence-type: == what the task needs to do with list item

in	think of as a read
out	think of as a write
inout	think of as a read and then a write
list	item (variable) needing to “Read” or “Write”

Dependences

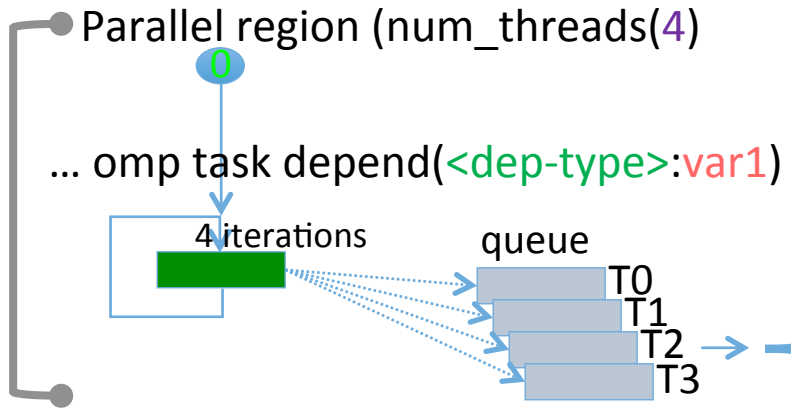


Task 1 execution dependence

When runtime executes T0, it checks previously generated tasks for identical list items (var1).

There are no previous tasks– so this task has NO dependence. EVEN if it has an IN (read) dependence type!

Dependences



Task 3 execution dependence

T3 checks previously generated tasks for identical list times (var1).

If an identical list item exists in previously generated tasks, T3 adheres to the *dependence-type*.

Task depend clause

Flow Control (RaW, Read after Write)

```
    x = 1;
#pragma omp parallel
#pragma omp single
{
   #pragma omp task shared(x) depend(out: x)
      x = 2;
   #pragma omp task shared(x) depend( in: x)
      printf("x = %d\n", x);
}
...
```

T1 is put on queue, sees no previously queued tasks with x identifier→ No dependences.

T2 is put on queue, sees previously queued task with identifier→ Has RaW dependence.

Print value is always 2.

Task depend clause

Anti-dependence (WaR, write after read)

```
   x = 1;
#pragma omp parallel
#pragma omp single
{
   #pragma omp task shared(x) depend( in: x)
      printf("x = %d\n", x);
   #pragma omp task shared(x) depend(out: x)
      x = 2;
}
...
```

T1 is put on queue, sees no previously queued tasks with x identifier→ No dependences.

T2 is put on queue, sees previously queued task with identifier→ has WaR dependence.

Print value is always 1.

Task depend clause

Output Dependence (WaW, Write after Write)

```
    x = 1;
#pragma omp parallel
#pragma omp single
{
   #pragma omp task shared(x) depend(out: x)
      printf("x = %d\n", x);
   #pragma omp task shared(x) depend(out: x)
      x = 2;
}
```

T1 is put on queue, sees no previously queued tasks with x identifier→ No dependences.

T2 is put on queue, sees previously queued task with identifier→ has WaW dependence.

Print value is always 1.

Task depend clause

(RaR, no dependence)

```
    x = 1;
#pragma omp parallel
#pragma omp single
{
   #pragma omp task shared(x) depend(in: x)
      printf("x = %d\n", x);
   #pragma omp task shared(x) depend(in: x)
      x = 2;
}
```

T1 is put on queue, sees no previously queued tasks with x identifier→ No dependences.

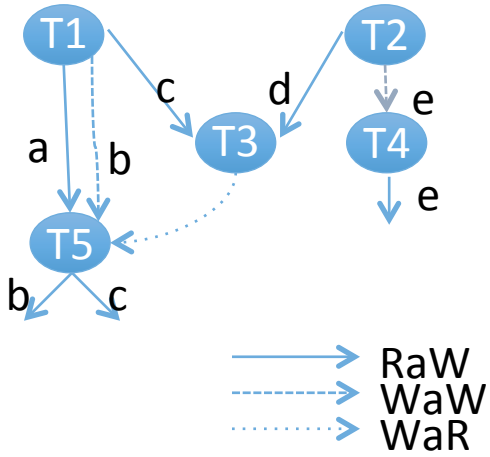
T2 is put on queue, sees previously queued task with x identifier→ has NO ordering (because it is RAR)

Print value is 1 or 2.

Task depend clause

Following a graph

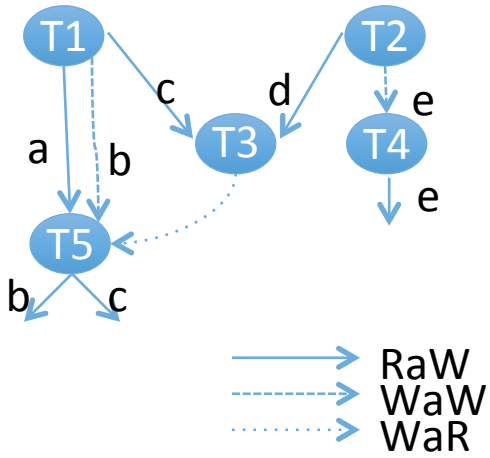
```
  #pragma omp parallel
  #pragma omp single
  {
T1  #pragma omp task depend(out:a,b,c)
      f1(&a, &b, &c);
T2  #pragma omp task depend(out:d,e)
      f2(&d, &e);
T3  #pragma omp task depend(in:c,d)
      f3(c,d);
T4  #pragma omp task depend(out,e)
      f4(&e);
T5  #pragma omp task depend(in:a) depend(out:b,c)
      f5(a,&b,&c)
  }
```



Task Depend Clause

Following non-computed variables-- works, too.

```
 #pragma omp parallel
 #pragma omp single
 {
T1 #pragma omp task depend(out:t1,t2,t3)
     f1(&a, &b, &c);
T2 #pragma omp task depend(out:t4,t5)
     f2(&d, &e);
T3 #pragma omp task depend(in:t3,t4)
     f3(c,d);
T4 #pragma omp task depend(out,t5)
     f4(&e);
T5 #pragma omp task depend(in:t1)depend(out:t2,t3)
     f5(a,&b,&c)
 }
```



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Iterations of loops are executed as tasks (of a taskgroup)

Single generator needed

All team members are not necessary

Implied taskgroup for the construct

Syntax: `...` `omp taskloop` *`[clauses]`*

- some clauses:

grainsize numtasks	or	number of iterations assigned to a task (See spec 4 details.) number of tasks to be executed concurrently (See spec 4 details.)
	default:	--number of tasks & iterations/task implementation defined
untied		tasks need not be continued by initial thread of task
nogroups		don't create a task group
priority		for each task (default 0)

Taskloop

- ptr points to a structure in C/C++, defined type in F90

```
void parallel_work(void) {  // execute by single in parallel
   int i, j;
   #pragma omp taskgroup
   {
     #pragma omp task
     long_running(); // can execute concurrently

     #pragma omp taskloop private(j) grainsize(500) nogroup
     for (i = 0; i < 10000; i++)  //can execute concurrently
       for (j = 0; j < i; j++)
          loop_body(i, j);

   }  // end taskgroup
}
```

Summary

- Tasks are used mainly in irregular computing.
- Tasks are often generated by a single thread.
- Task generation can be recursive.
- Depend clause can prescribe dependence.
- Priority provides hint for execution order.
- First private is default data-sharing attribute, shared variables remain shared.
- Untied generator task can assure generation progress.