Tasking in OpenMP

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HiPeRT Lab

Outline

- Expressing parallelism
  - Understanding parallel threads
- Memory Data management
  - Data clauses
- Synchronization
  - Barriers, locks, critical sections
- Work partitioning
  - Loops, sections, single work, tasks…
- Execution devices
  - Target

A history of OpenMP

- 1997
  - OpenMP for Fortran 1.0
- 1998
  - OpenMP for C/C++ 1.0
- 2000
  - OpenMP for Fortran 2.0
- 2002
  - OpenMP for C/C++ 2.5
- 2008
  - OpenMP 3.0
- 2011
  - OpenMP 3.1
- 2014
  - OpenMP 4.5

Thread-centric

Regular, loop-based parallelism

Task-centric

Irregular, parallelism ➔ tasking

Devices

Heterogeneous parallelism, *à la* GP-GPU

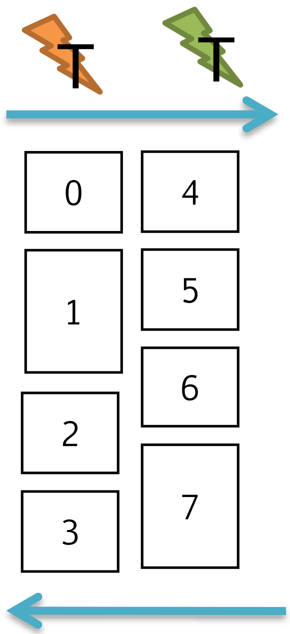
OpenMP programming patterns

- "Traditional" OpenMP has a thread-centric execution model
  - Fork/join
  - Master-slave

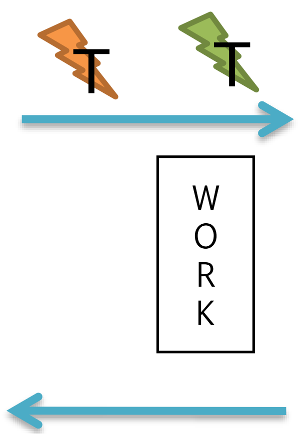
- Create a team of threads…
  - ..then partition the work among them
  - Using work-sharing constructs

OpenMP programming patterns

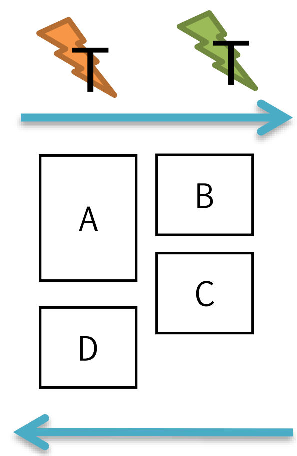
```
#pragma omp for
for (int i=0; i<8; i++)
{
  // ...

}
```




```
#pragma omp single
{
  work();
}
```




```
#pragma omp sections
{
  #pragma omp section
  { A(); }
  #pragma omp section
  { B(); }
  #pragma omp section
  { C(); }
  #pragma omp section
  { D(); }
}
```

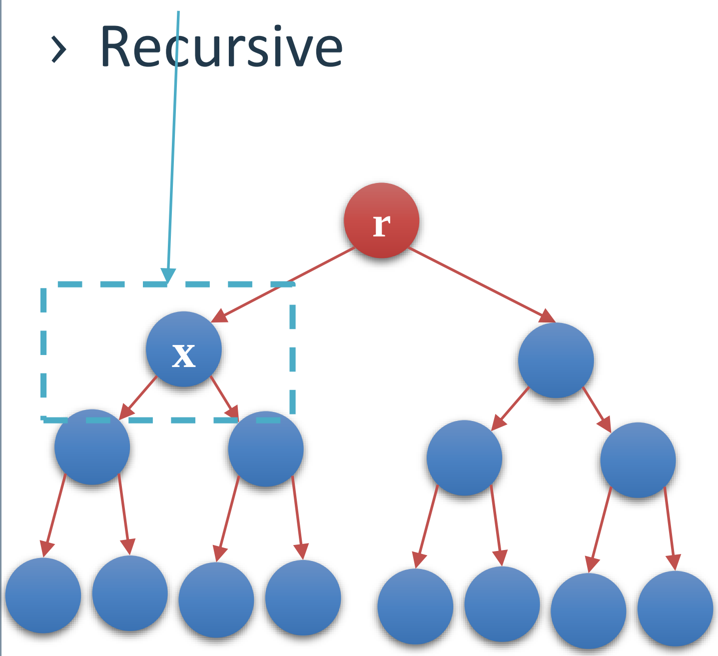


Exercise

Let's code!

- Traverse a tree
  - Perform the same operation on all elements
  - Download sample code

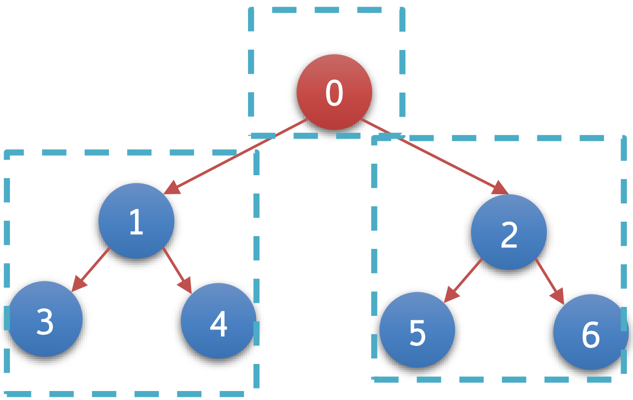
- Recursive



Exercise

Let's code!

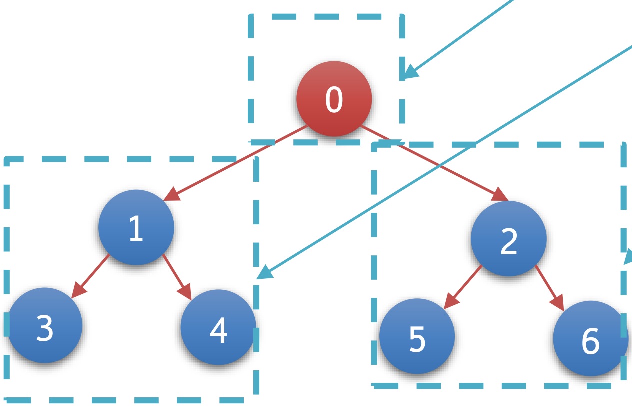
- Now, parallelize it!
  - From the example




```
void traverse_tree(node_t *n)
{
    doYourWork(n);




    if(n->left)
      traverse_tree(n->left);

    if(n->right)
      traverse_tree(n->right);

}


...
traverse_tree(root);
```

Solved: traversing a tree in parallel

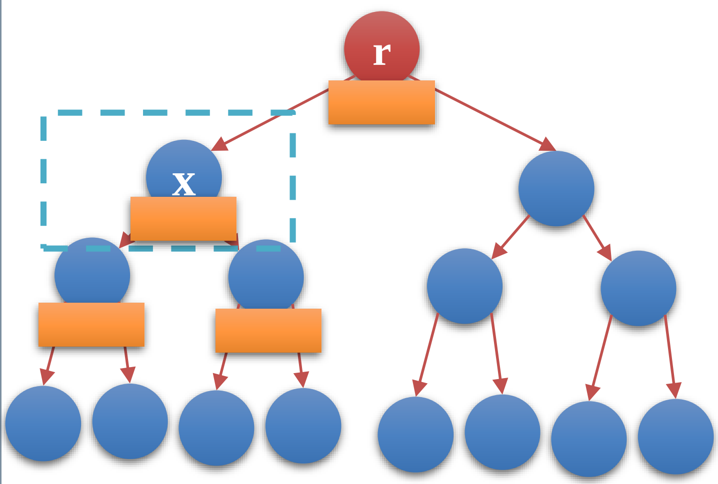
- Recursive
  - Parreg+section for each call
  - Nested parallelism
- Assume the very first time we call `traverse_tree`
  - Root node




```
void traverse_tree(node_t *n)
{
  #pragma omp parallel sections
  {
    #pragma omp section
    doYourWork(n);

    #pragma omp section
    if(n->left)
      traverse_tree(n->left);
    #pragma omp section
    if(n->right)
      traverse_tree(n->right);
  }
}


...
traverse_tree(root);
```

Catches (1)

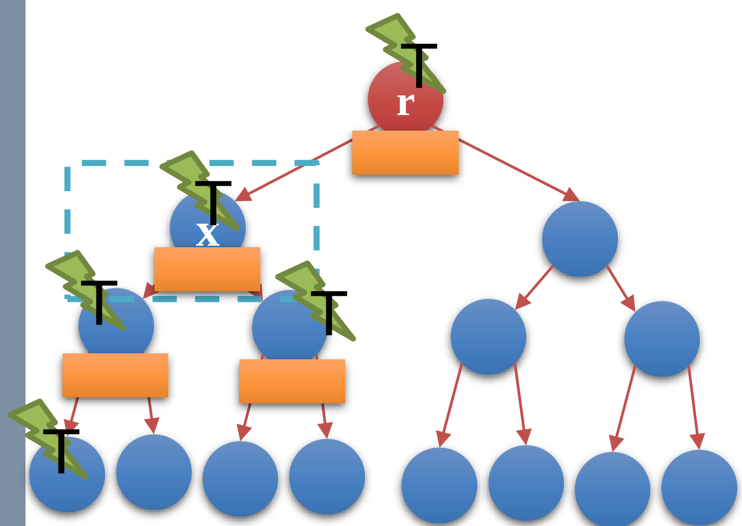
- Cannot nest worksharing constructs without an intervening parreg
  - And its barrier…
  - Costly




```
void traverse_tree(node_t *n)
{
  doYourWork(n);

  #pragma omp parallel sections
  {
    #pragma omp section
    if(n->left)
      traverse_tree(n->left);
    #pragma omp section
    if(n->right)
      traverse_tree(n->right);
  } // Barrier
} // Parrg barrier


...
traverse_tree(root);
```

Catches (2)

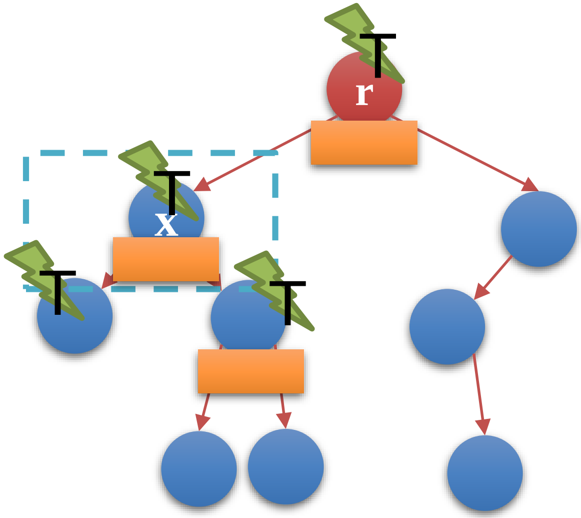
- #threads grows exponentially
  - Harder to manage




```
void traverse_tree(node_t *n)
{
  doYourWork(n);

  #pragma omp parallel sections
  {
    #pragma omp section
    if(n->left)
      traverse_tree(n->left);
    #pragma omp section
    if(n->right)
      traverse_tree(n->right);
  } // Barrier
} // Parrg barrier


...
traverse_tree(root);
```

Catches (3)

- Code is not easy to understand
- Even harder to modify
  - What if I add a third child node?




```
void traverse_tree(node_t *n)
{
  doYourWork(n);

  #pragma omp parallel sections
  {
    #pragma omp section
    if(n->left)
      traverse_tree(n->left);
    #pragma omp section
    if(n->right)
      traverse_tree(n->right);
  } // Barrier
} // Parrg barrier


...
traverse_tree(root);
```

Limitations of "traditional" WS

Cannot nest worksharing constructs without an intervening parreg

- Parreg are traditionally costly
  - A lot of operations to create a team of threads
  - Barrier…

Parreg	Static loops prologue	Dyn loops start
30k cycles	10-150 cycles	5-6k cycles

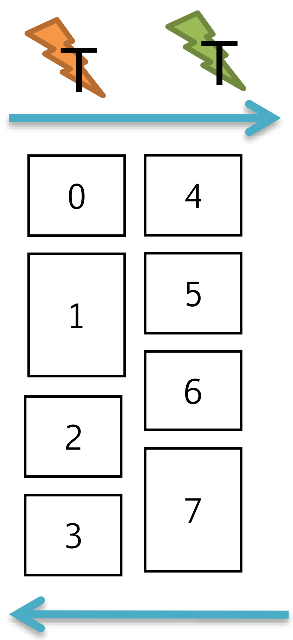
- The number of threads explodes and it's harder to manage
  - Parreg => create new threads

Limitations of "traditional" WS

It is cumbersome to create parallelism dynamically

- In loops, sections
  - Work is statically determined!
  - Before entering the construct
  - Even in dynamic loops
- "if <condition>, then create work"

```
#pragma omp for
for (int i=0; i<8; i++)
{
  // ...

}
```

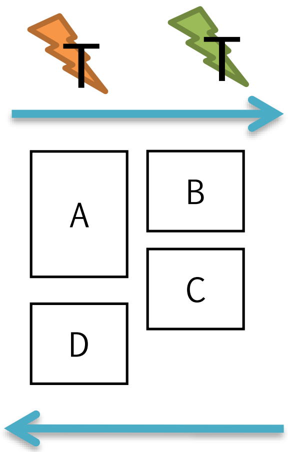


Limitations of "traditional" WS

Poor semantics for irregular workload

- Sections-based parallelism that is anyway cumbersome to write
  - OpenMP was born for loop-based parallelism
- Code not scalable
  - Even a small modifications causes you to re-think the strategy

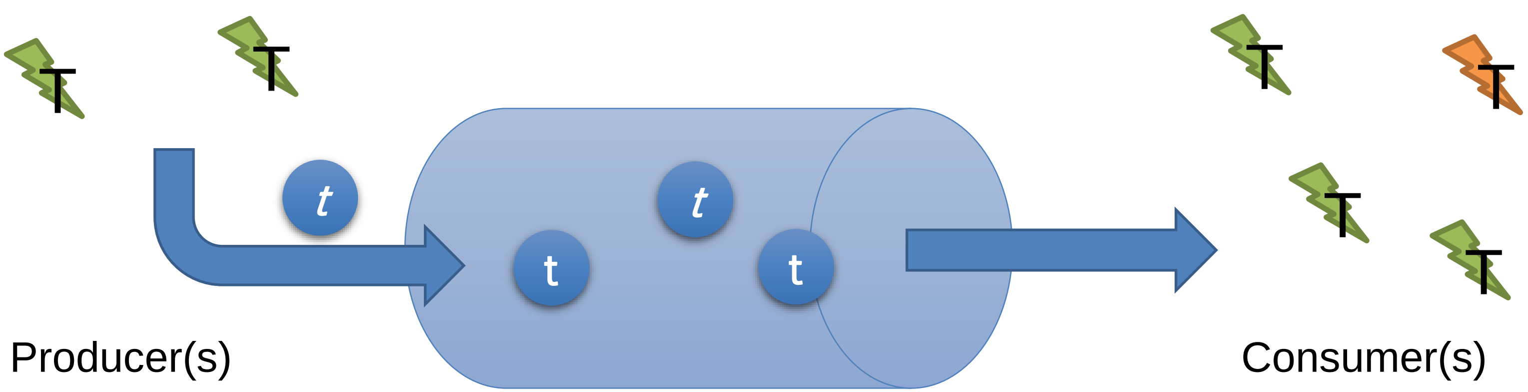
```
#pragma omp sections
{
  #pragma omp section
  { A(); }
  #pragma omp section
  { B(); }
  #pragma omp section
  { C(); }
  #pragma omp section
  { D(); }
}
```



A different parallel paradigm

A work-oriented paradigm for partitioning workloads

- Implements a producer-consumer paradigm
  - As opposite to OpenmP thread-centric model
- Introduce the task pool
  - Where units of work (OpenMP tasks)
  - are pushed by threads
  - and pulled and executed by threads
- E.g., implemented as a fifo queue (aka task queue)



The `task` directive

```
#pragma omp task [clause [[,] clause]...] new-line
  structured-block
```

Where clauses can be:

```
if([ task : ]scalar-expression)
final(scalar-expression)
untied
default(shared | none)
mergeable
private(list)
firstprivate(list)
shared(list)
depend(dependence-type : list)
priority(priority-value)
```

- We will see only data sharing clauses
  - Same as parallel but…DEFAULT IS NOT SHARED!!!!

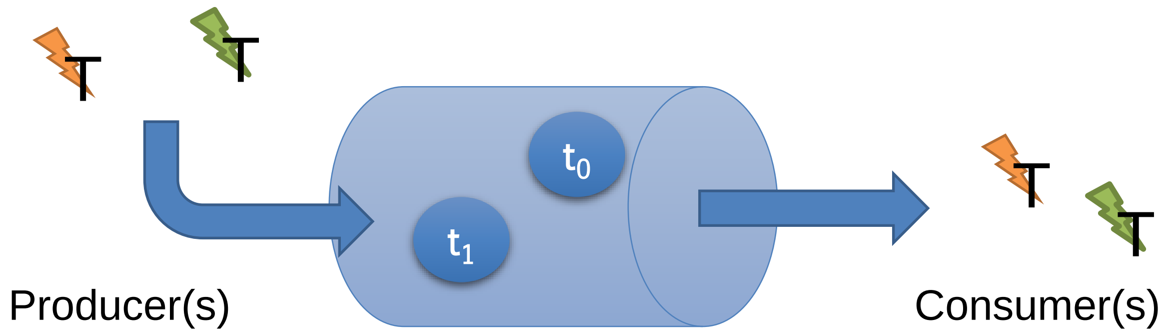
Two sides

- Tasks are **produced**
- Tasks are **consumed**

```
Let's
code!
```

- Try this!
  - t_0 and t_1 are `printf`
  - Also, print who produces

```
/* Create threads */
#pragma omp parallel num_treads(2)
{
  /* Push a task in the q */
  #pragma omp task
  {
    t0();
  }

  /* Push another task in the q */
  #pragma omp task
    t1();

} // Implicit barrier
```



I cheated a bit

- How many producers?
  - So, how many tasks?

```
/* Create threads */
#pragma omp parallel num_treads(2)
{
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  #pragma omp task
  {
    t0();
  }

  /* Push another task in the q */
  #pragma omp task
    t1();

} // Implicit barrier
```

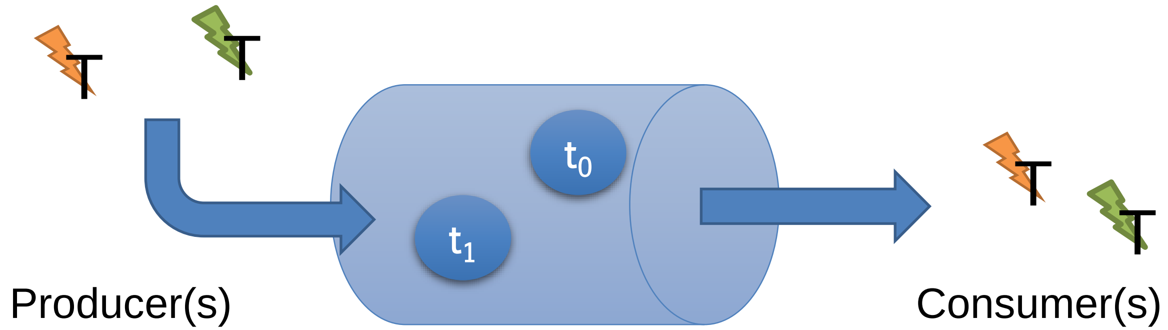

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/* Create threads */
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  {
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    t1();

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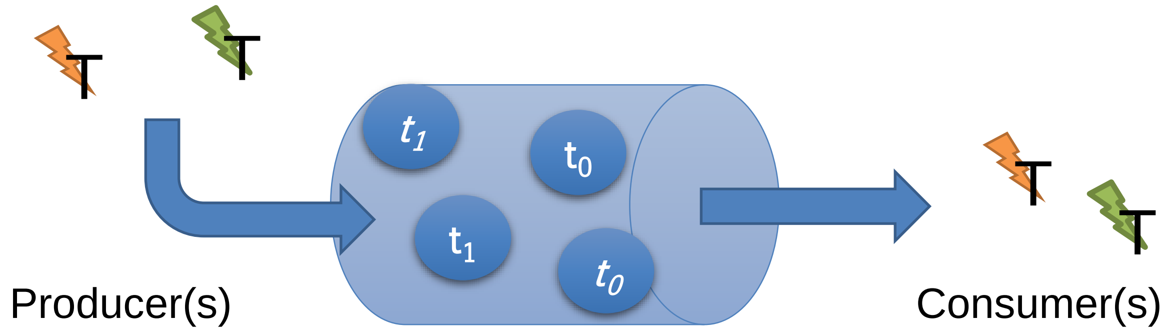
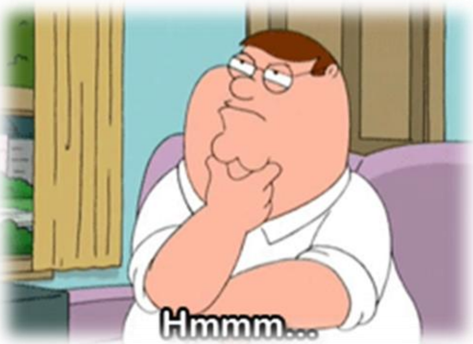


Let's make it simpler

- Work is produced in parallel by threads
- Work is consumed in parallel by threads

- A lot of confusion!
  - Number of tasks grows
  - Hard to control producers

- How to make this simpler?



Single-producer, multiple consumers

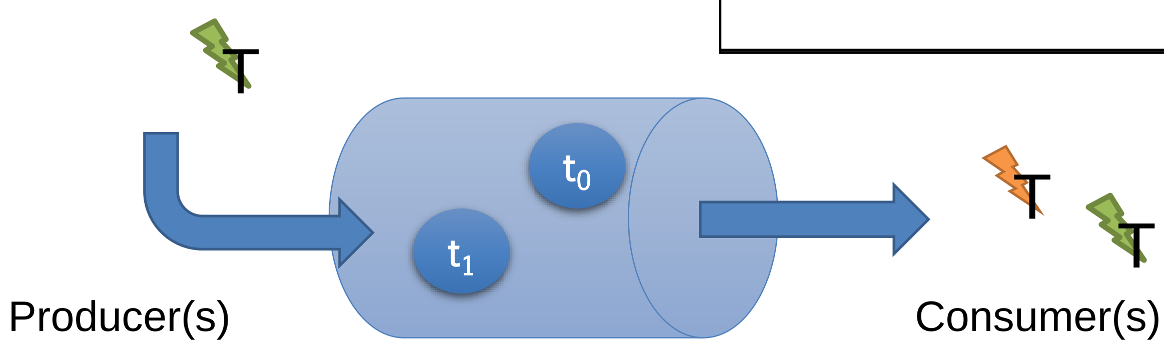
- A paradigm! Typically preferred by programmers
  - Code more understandable
  - Simple
  - More manageable

```
/* Create threads */
#pragma omp parallel num_treads(2)
{
  #pragma omp single
  {
    #pragma omp task
      t0();

    #pragma omp task
      t1();
  }

} // Implicit barrier
```

- How to do this?



The `task` directive

Can be used

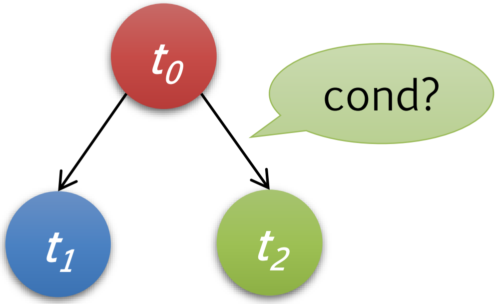
- in a nested manner
  - Before doing work, produce two other tasks
  - Only need one parreg "outside"
- in an irregular manner
  - See `cond` ?
  - Barriers are not involved!
  - Unlike parregs'

```
/* Create threads */
#pragma omp parallel num_treads(2)
{
  #pragma omp single
  {
    /* Push a task in the q */
    #pragma omp task
    {
      /* Push a (children) task in the q */
      #pragma omp task
        t1();

      /* Conditionally push task in the q */
      if(cond)
        #pragma omp task
          t2();

      /* After producing t1 and t2,
       * do some work */
      t0();
    }
  }
} // Implicit barrier
```

The `task` directive



- A task graph
- Edges are "father-son" relationships
- Not timing/precendence!!!

```
/* Create threads */
#pragma omp parallel num_treads(2)
{
  #pragma omp single
  {
    /* Push a task in the q */
    #pragma omp task
    {
      /* Push a (children) task in the q */
      #pragma omp task
        t1();

      /* Conditionally push task in the q */
      if(cond)
        #pragma omp task
          t2();

      /* After producing t1 and t2,
       * do some work */
      t0();
    }
  }
} // Implicit barrier
```

It's a matter of time

- The `task` directive represents the push in the WQ
  - And the pull???
- Not "where" it is in the code
  - But, when!
- In OpenMP tasks, we separate the moment in time
  - when we produce work (push - `#pragma omp task`)
  - when we consume the work (pull - ????)

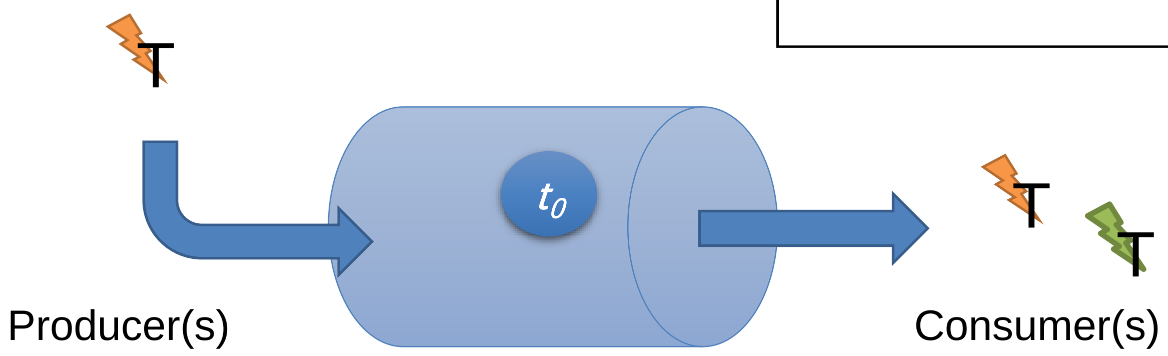
Timing de-coupling

- One thread produces
- All of the thread consume
- ..but, when????

```
/* Create threads */
#pragma omp parallel num_treads(2)
{
  #pragma omp single
  {
    #pragma omp task
      t0();

    #pragma omp task
      t1();
  } // Implicit barrier

} // Implicit barrier
```



Timing de-coupling

- One thread produces
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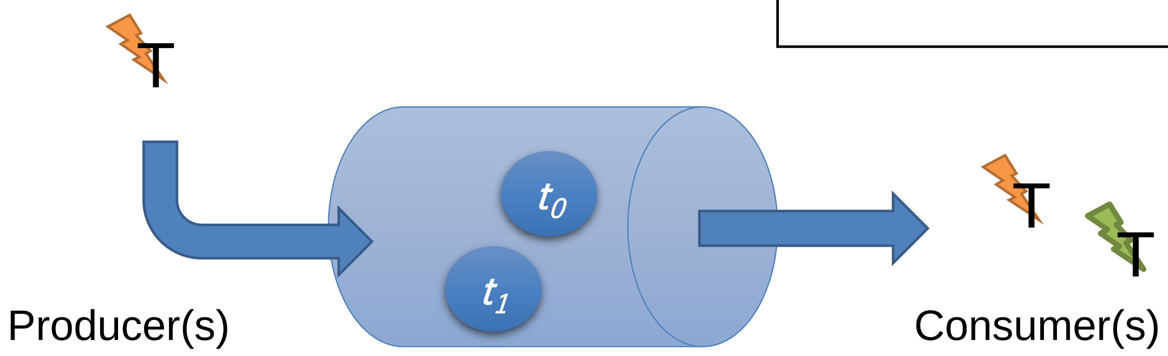
- ..but, when????

```
/* Create threads */
#pragma omp parallel num_treads(2)
{
  #pragma omp single
  {
    #pragma omp task
      t0();

    #pragma omp task
      t1();
  } // Implicit barrier

} // Implicit barrier
```



Task Scheduling Points

› The point when the executing thread can pull a task from the q

OMP specs

a. the point immediately following the generation of an explicit task;
b. after the point of completion of a task region;
c. in a taskyield region;
d. in a taskwait region;
e. at the end of a taskgroup region;
f. in an implicit and explicit barrier region;

```
/* Create threads */
#pragma omp parallel num_treads(2)
{
  #pragma omp single
  {
    #pragma omp task
      t0();

    #pragma omp task
    {
      #pragma omp task
        t2();

      t1();

      /* I just finished a task */      b
    }
    // I just pushed a task        a

  } // Implicit barrier       f

} // Implicit barrier      f
```

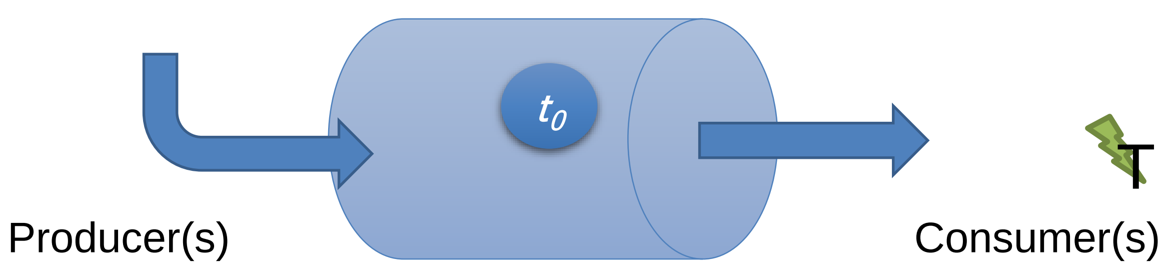
Timing de-coupling

- One thread produces
- All of the thread consume

```
/* Create threads */
#pragma omp parallel num_treads(2)
{
  #pragma omp single
  {
    #pragma omp task
      t0();

    #pragma omp task
      t1();
  } // Implicit barrier

} // Implicit barrier
```



Timing de-coupling

- One thread produces
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```
/* Create threads */
#pragma omp parallel num_treads(2)
{
  #pragma omp single
  {
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      t0();

    #pragma omp task
      t1();
  } // Implicit barrier

} // Implicit barrier
```

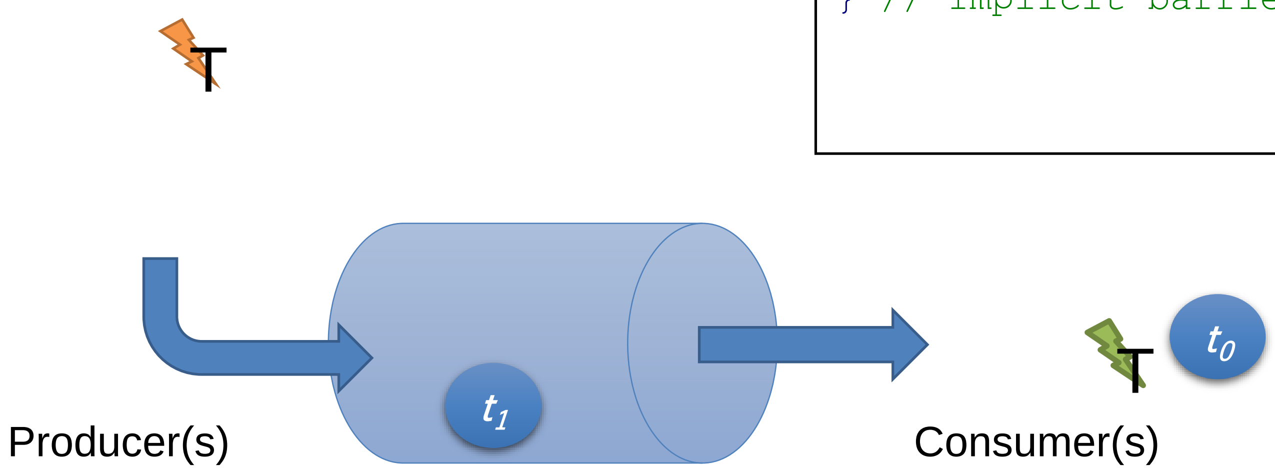

Timing de-coupling

- One thread produces
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```
/* Create threads */
#pragma omp parallel num_treads(2)
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      t0();

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      t1();
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```
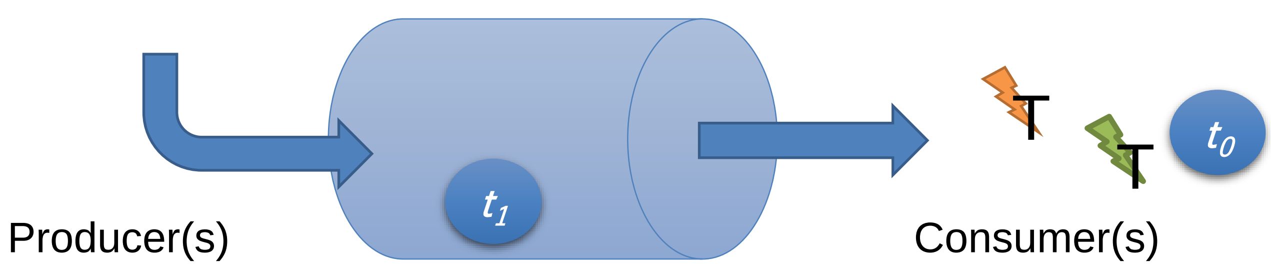
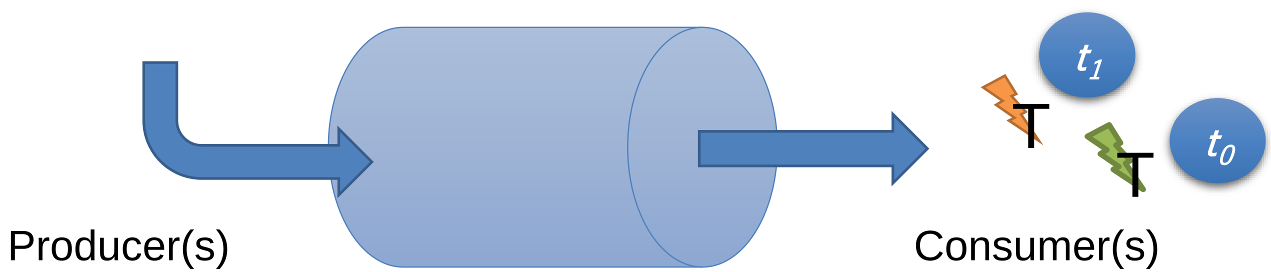



Timing de-coupling

› One thread produces

› All of the thread consume

```
/* Create threads */
#pragma omp parallel num_treads(2)
{
  #pragma omp single
  {
    #pragma omp task
      t0();

    #pragma omp task
      t1();
  } // Implicit barrier

} // Implicit barrier
```



Exercise

Let's code!

- Create an array of N elements
  - Put inside each array element its index, multiplied by '2'
  - `arr[0] = 0; arr[1] = 2; arr[2] = 4;` ...and so on..
- Now, do it in parallel with a team of T threads
  - Using the `task` construct instead of `for`
  - Remember: if not specified, data sharing is unknown! (NOT SHARED)
- Mimic `dynamic` loops semantic (chunk = 1 ➔ 1 iteration per thread)
  - "Tasks made of 1 iteration"

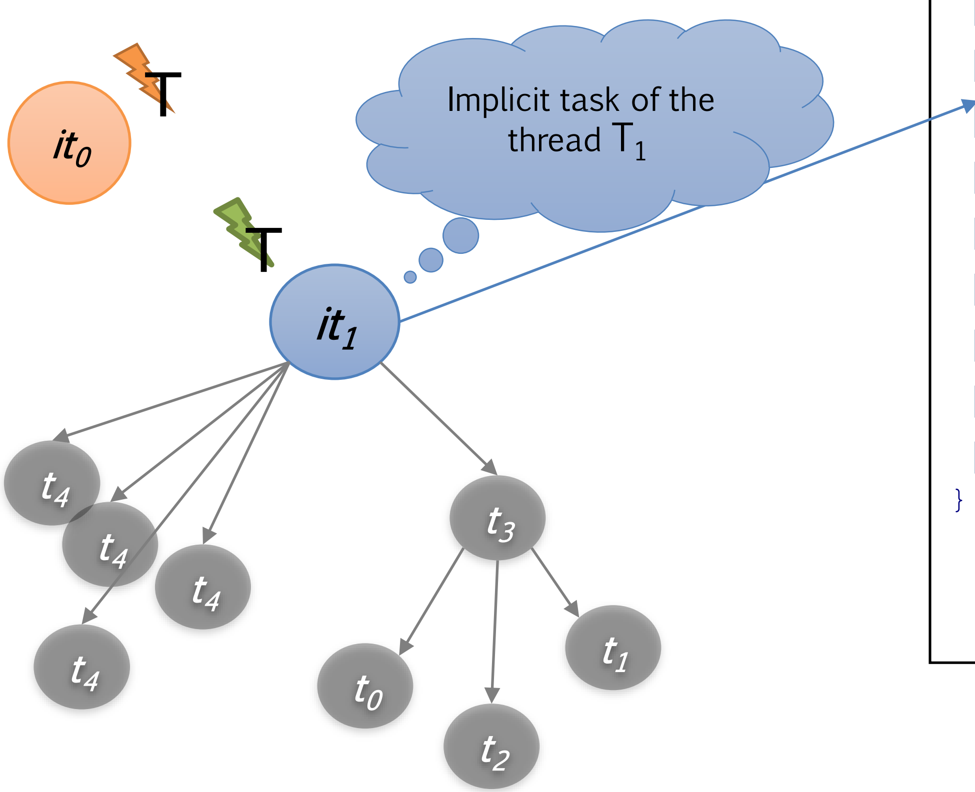
Exercise

Let's code!

- Create an array of N elements
  - Put inside each array element its index, multiplied by '2'
  - `arr[0] = 0; arr[1] = 2; arr[2] = 4;` ...and so on..
- Mimic `dynamic` loops semantic
  - Now, find a way to increase chunking
  - Tasks made of `CHUNK` = 1..2..4..5 iterations
  - (simple: N = 20)

Implicit task

- In parregs, threads perform work
  - Called implicit task
  - One for each thread in parreg




```
#pragma omp parallel num_threads(2)
{
 #pragma omp single
 {
   for(i<10000)
     #pragma omp task
       t4_i();

   #pragma omp task
   {
      #pragma omp task
        t0();
      #pragma omp task
        t1();
      #pragma omp task
        t2();

      work();

   } // end of task
 } // end of single (bar)
} // parreg end
```

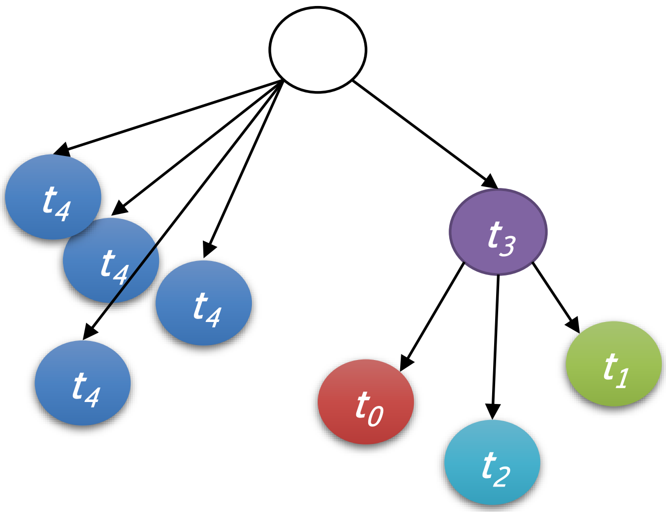
Task synchronization

- Implicit or explicit barriers
  - Join all threads in a parrreg
- Need something lighter
  - That involves only tasks
  - That do not involve all tasks!

Wait them all?

Sometimes you don't need to..

- t3 needs output from
  - t0
  - t1
  - t2
- t3 doesn't need output from t4*s*




```
#pragma omp parallel
{
  #pragma omp single
  {
    for(i<10000)
      #pragma omp task
        t4i_work();

    #pragma omp task
    {
       #pragma omp task
         t0_work();
       #pragma omp task
         t1_work();
       #pragma omp task
         t2_work();

      #pragma omp taskgroup

       // Requires the output of t0,
       //    t1, t2, but not of t4s
       t3_work();

    } // end of task t3
  } // bar
} // parreg end
```

The `taskgroup` directive

```
#pragma omp taskgroup
```

Standalone directive

- Wait on the the completion of children tasks, and their descendants

- Implicit TSP

OMP specs

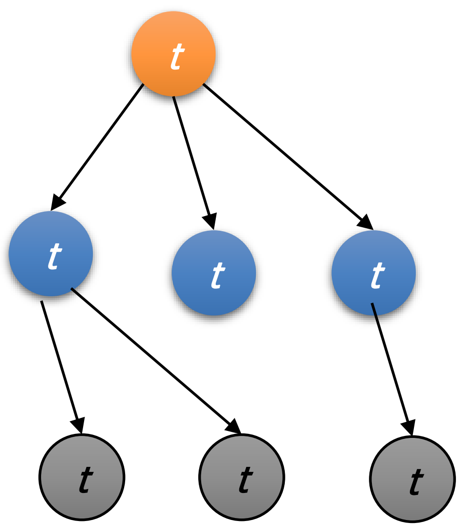
a. the point immediately following the generation of an explicit task;
b. after the point of completion of a task region;
c. in a `taskyield` region;
d. in a `taskwait` region;
e. at the end of a `taskgroup` region;
f. in an implicit and explicit barrier region;

The `taskwait` directive

```
#pragma omp taskwait
```

Standalone directive

- Implicit TSP
- Strangely..
  - Older than `taskgroup`



OMP specs

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e. at the end of a `taskgroup` region;
f. in an implicit and explicit barrier region;

The `taskyeld` directive

```
#pragma omp taskyield
```

Standalone directive

- Explicit TSP
  - Extracts (and exec) one task from the queue

OMP specs

a. the point immediately following the generation of an explicit task;
b. after the point of completion of a task region;
c. in a `taskyield` region;
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How to run the examples

Let's code!

- Download the `Code/` folder from the course website
- Compile
- `$ gcc -fopenmp code.c -o code`
- Run (Unix/Linux)

```
$ ./code
```

- Run (Win/Cygwin)

```
$ ./code.exe
```

References

- "Calcolo parallelo" website
  - http://hipert.unimore.it/people/paolob/pub/PhD/index.html
- My contacts
  - paolo.burgio@unimore.it
  - http://hipert.mat.unimore.it/people/paolob/
- Useful links
  - http://www.openmp.org
  - http://www.google.com