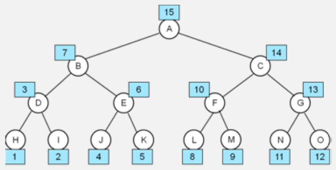
OpenMP Tasks



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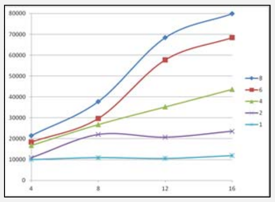

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Remember OpenMP Sections?

Sections are independent blocks of code, able to be assigned to separate threads if they are available.

```
#pragma omp parallel sections
{
        #pragma omp section
        {
                Task 1
        }
        #pragma omp section
        {
                Task 2
        }
}
```

There is an **implied barrier** at the end

OpenMP sections are ***static***, that is, they are good if you know, when you are writing the program, how many of them you will need.

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It would be nice to have something more Dynamic

Imagine a capability where you can write something to do down on a Post-It® note, accumulate the Post-It notes, then have all of the threads together execute that set of tasks.

You would also like to not have to know, ahead of time, how many of these Post-It notes you will write. That is, you want the total number to be ***dynamic***.

Well, congratulations, you have just invented ***OpenMP Tasks***!

OpenMP Tasks

• An OpenMP task is a single line of code or a structured block which is immediately “written down” in a list of tasks.

• The new task can be executed immediately, or it can be deferred.

• If the *if* clause is used and the argument evaluates to 0, then the task is executed immediately, superseding whatever else that thread is doing.

• There has to be an existing parallel thread team for this to work. Otherwise one thread ends up doing all tasks and you don’t get any contribution to parallelism.

• One of the best uses of this is to process elements of a linked list or a tree.

You can create a task barrier with:

#pragma omp taskwait

Tasks are very much like OpenMP **Sections**, but Sections are static, that is, the number of sections is set when you write the code, whereas **Tasks** can be created anytime, and in any number, under control of your program’s logic.

OpenMP Task Example: Something (Supposedly) Simple

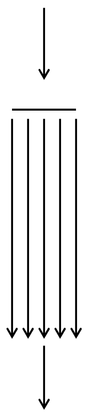
```
omp_set_num_threads( 2 );
#pragma omp parallel default(none)
{
            #pragma omp task
                        fprintf( stderr, "A\n" );

            #pragma omp task
                        fprintf( stderr, "B\n" );
}
```

Without this, thread #0 has to do everything

Writes fprintf(stderr, "A\n"); on a sticky note and adds it to the list

Writes fprintf(stderr, "B\n"); on a sticky note and adds it to the list



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If You Run This a Number of Times, You Get This: (What Happened?)

Run #	1	2	3	4	5
	B	B	B	B	B
	A	B	A	A	A
	B	A	A	A	B
	A	A	B	B	A

1. Why do we not get the same output every time?
2. Why do we get 4 things printed when we only have print statements in 2 tasks?

Not so simple, huh?

The first answer is easy. Unless you make some special arrangements, the order of execution of the different tasks is *undefined*.

The second answer is that we actually asked each of the two threads to put two tasks on the sticky notes, for a total of four. How can we get only one thread to do this?

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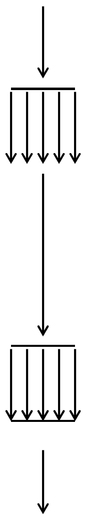
The “single” Pragma

```
omp_set_num_threads( 2 );
#pragma omp parallel default(none)
{
        #pragma omp single
        {
                #pragma omp task
                        fprintf( stderr, “A\n” );

                #pragma omp task
                        fprintf( stderr, “B\n” );

        }
}
```



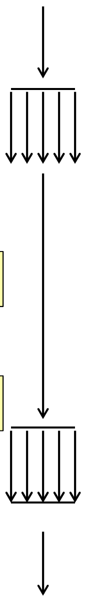
When using Tasks, you only want *one* thread to write the things to do down on the sticky note, but you want *all* of the threads to be able to execute the sticky notes.

But, if you run this, the order of printing will still be non-deterministic. To solve that problem, do this:

```
omp_set_num_threads( 2 );
#pragma omp parallel
{
        #pragma omp single default(none)
        {
                #pragma omp task
                        fprintf( stderr, “A\n” );

                #pragma omp taskwait

                #pragma omp task
                        fprintf( stderr, “B\n” );

                #pragma omp taskwait
        }
}
```

Causes all tasks to wait until they are completed

Causes all tasks to wait until they are completed



A Better OpenMP Task Example: Processing each Element of a Linked List

Without this, thread #0 has to do everything

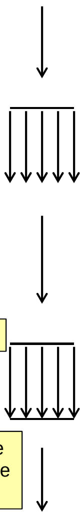
Without this, each thread does a full traversal – bad idea!

Write “Process(p)” on a sticky note and add it to the list

Copies the current value of p into the task and immediately makes it private (i.e., not shared)

Put this here if you want to wait for all tasks to finish being executed before proceeding

```
#pragma omp parallel default(none)
{

        #pragma omp single default(none)
        {
                element *p = listHead;
                while( p != NULL )
                {
                        #pragma omp task firstprivate(p)
                                Process( p );

                        p = p->next;
                }
        }

        #pragma omp taskwait
}
```



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One more thing – Task Dependencies

Remember from before: unless you make some special arrangements, the order of execution of the different tasks is *undefined*. Here come the special arrangements.

```
omp_set_num_threads( 3 );
#pragma omp parallel
{
        #pragma omp single default(none)
        {
                float a, b, c;
                #pragma omp task depend( OUT: a )
                        a = 10.;

                #pragma omp task depend( IN: a, OUT: b )
                        b = a + 16.;

                #pragma omp task depend( IN: b )
                        c = b + 12.;
        }
        #pragma omp taskwait
}
```

This maintains the proper dependencies, but, because it involves all of the tasks, it essentially serializes the parallelism out of them.
Be careful not to go overboard with dependencies!

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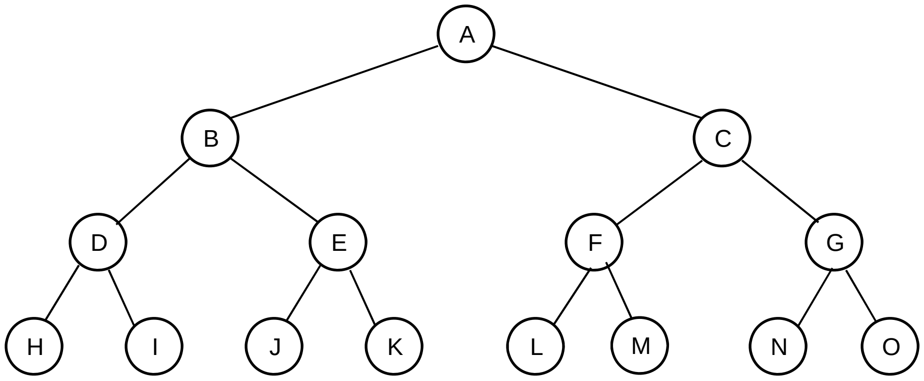
Tree Traversal Algorithms

Given a tree:



- We would like to traverse it as quickly as possible.
- We are assuming that we do not need to traverse it in order.
- We just need to visit all nodes.

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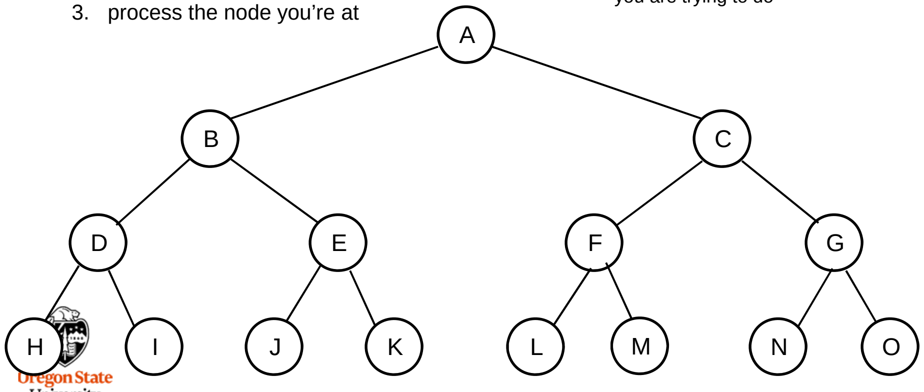
Tree Traversal Algorithms

• This is common in graph algorithms, such as searching.

• If the tree is binary and is balanced, then the maximum depth of the tree is $\log_2$(# of Nodes)

• Strategy at a node:
1. follow one descendent node
2. follow the other descendent node
3. process the node you're at

This order could be re-arranged, depending on what you are trying to do



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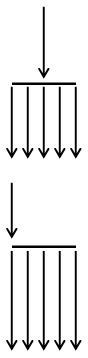
Tree Traversal Algorithms



Without this, thread #0 has to do everything

```
#pragma omp parallel

          #pragma omp single

          Traverse( root );



#pragma omp taskwait
```

Without this, each thread does a full traversal – bad idea!

Put this here if you want to wait for all nodes to be traversed before proceeding

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Parallelizing a Binary Tree Traversal with Tasks

```
void
Traverse( Node *n )
{
          if( n->left  !=  NULL )
          {
                    #pragma omp task private(n) untied
                    Traverse( n->left );
          }



          if( n->right  !=  NULL )
          {
                    #pragma omp task private(n) untied
                    Traverse( n->right );
          }

          #pragma omp taskwait

          Process( n );
}
```

Put this here if you want to wait for both branches to be taken before processing the parent

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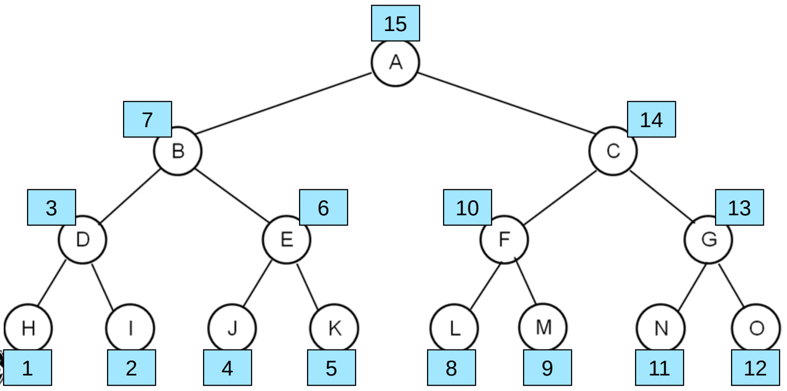
Parallelizing a Binary Tree Traversal with Tasks

Traverse(A);



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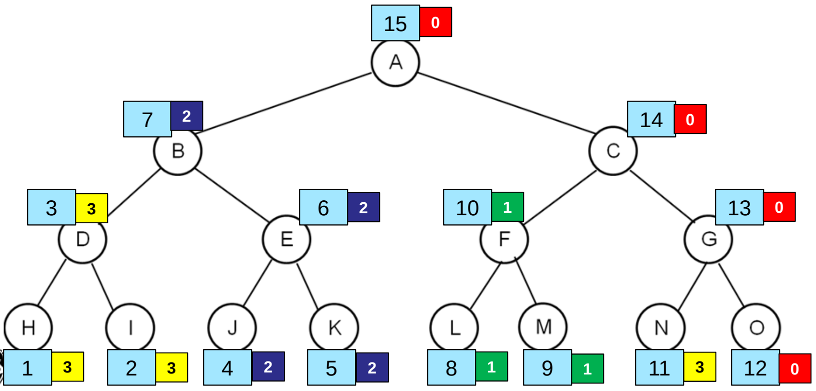
Parallelizing a Binary Tree Traversal with Tasks: *Tied* (gcc 8.2)

Threads:

Traverse(A);



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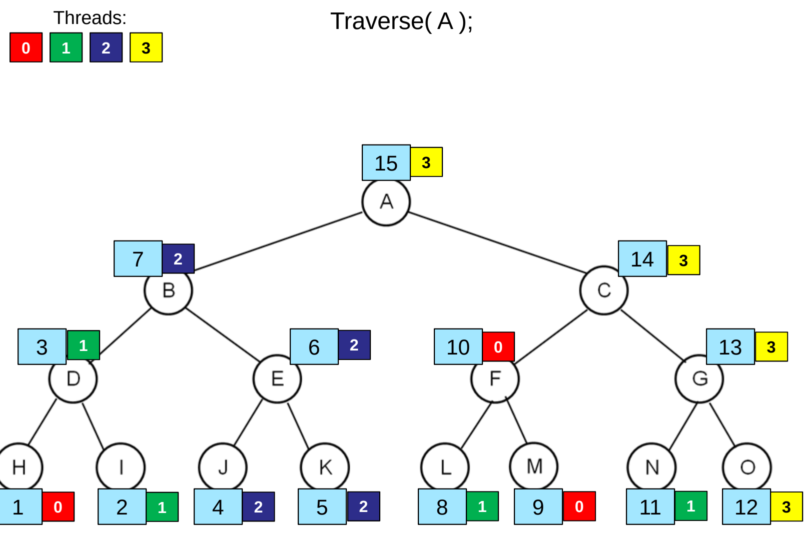
Parallelizing a Binary Tree Traversal with Tasks: *Untied* (gcc 8.2)



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How Evenly Tasks Get Assigned to Threads

6 Levels – g++ 4.9:

Thread #	Number of Tasks
0	1
1	32
2	47
3	47

6 Levels – g++ 8.2:

Thread #	Number of Tasks
0	31
1	46
2	32
3	18

12 Levels – g++ 4.9:

Thread #	Number of Tasks
0	2561
1	2
2	2813
3	2815

12 Levels – g++ 8.2:

Thread #	Number of Tasks
0	1
1	2048
2	3071
3	3071

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How Evenly Tasks Get Assigned to Threads

6 Levels – g++ 8.2:

Thread #	Number of Tasks
0	31
1	46
2	32
3	18

6 Levels – icpc 15.0.0:

Thread #	Number of Tasks
0	29
1	31
2	41
3	26

12 Levels – g++ 8.2:

Thread #	Number of Tasks
0	1
1	2048
2	3071
3	3071

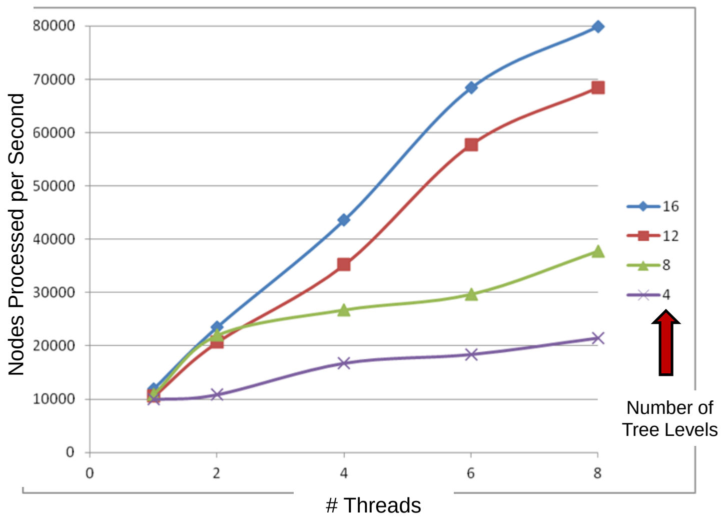
12 Levels – icpc 15.0.0:

Thread #	Number of Tasks
0	1999
1	2068
2	2035
3	2089

Benchmarking a Binary Task-driven Tree Traversal

```
void
Process( Node *n )
{
        for( int i = 0; i < 1024; i++ )
        {
                n->value = pow( n->value, 1.1 );
        }
}
```

Performance vs. Number of Threads



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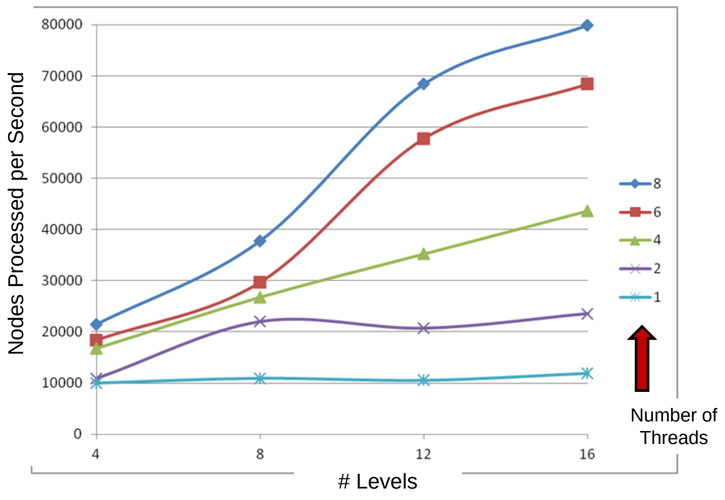
Performance vs. Number of Levels



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Parallelizing a Tree Traversal with Tasks

- Tasks get spread among the current “thread team”
- Tasks can execute immediately or can be deferred. They are executed at “some time”.
- Tasks can be moved between threads, that is, if one thread has a backlog of tasks to do, an idle thread can come steal some workload.
- Tasks are more dynamic than sections. The task paradigm would still work if there was a variable number of children at each node.

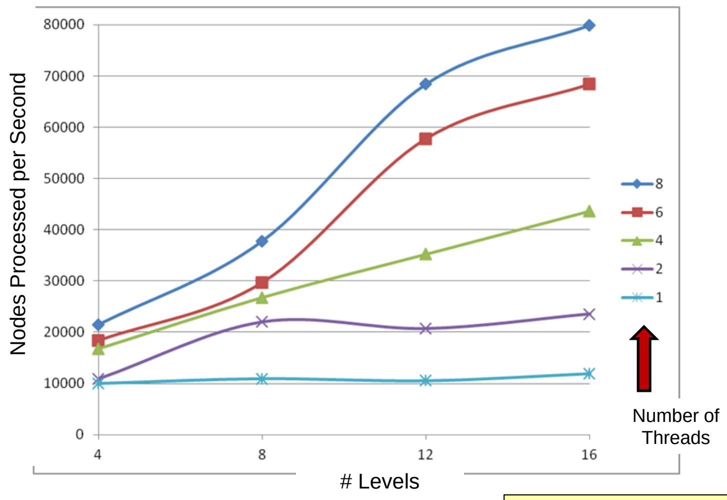
Parallelizing an N-Tree Traversal with Tasks

```
void
Traverse( Node *n )
{
        for( int i = 0; i  <  n->numChildren; i++ )
        {
                if( n->child[ i ]  !=  NULL )
                {
                        #pragma omp task
                        Traverse( n->child[ i ] );
                }
        }

        #pragma omp taskwait

        Process( n );
}
```

Performance vs. Number of Levels



8-thread Speed-up ≈ 6.7

F_p ≈ ??%

Max Speed-up ≈ ??

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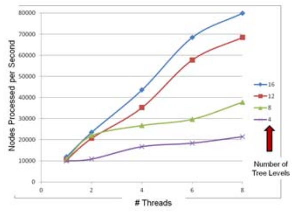
Performance vs. Number of Threads



8-thread Speed-up ≈ 6.7

F_p ≈ ??%

Max Speed-up ≈ ??

$$F_p = \frac{n}{(n-1)}\left(1 - \frac{1}{Speedup}\right) = 97\%$$

$$\max Speedup = \frac{1}{1 - F_p} = 33\text{x}$$

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