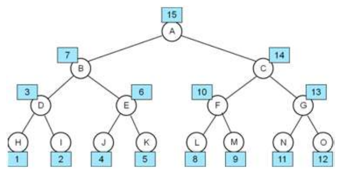
OpenMP Tasks



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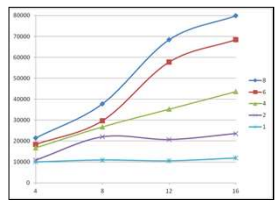


Remember OpenMP Sections?

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.

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

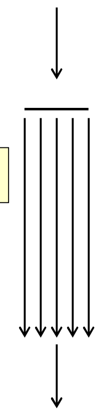
5

```
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 of tasks

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



#pragma omp task

Adds the next line of code (or block of code) to the list of tasks

If You Run This a Number of Times, You Get This: (Uh-oh, what Happened?)

6

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 the two threads to each put two tasks on the sticky notes, for a total of four. How can we get only one thread to do this?

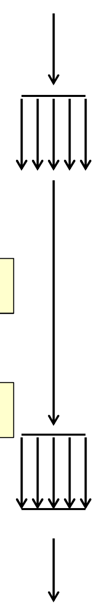
The “single” Pragma

```
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. If you care about order, 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      <- Causes all tasks to wait until they are completed

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

                #pragma omp taskwait      <- 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

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

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

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

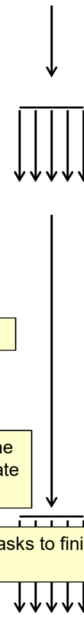
Write "Process(p)" on a sticky note and add it to the list

```
                        #pragma omp task firstprivate(p)
                                Process( p );
```

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

```
                        p = p->next;
                }
        }
        #pragma omp taskwait
}
```

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



One more thing – Task Dependencies

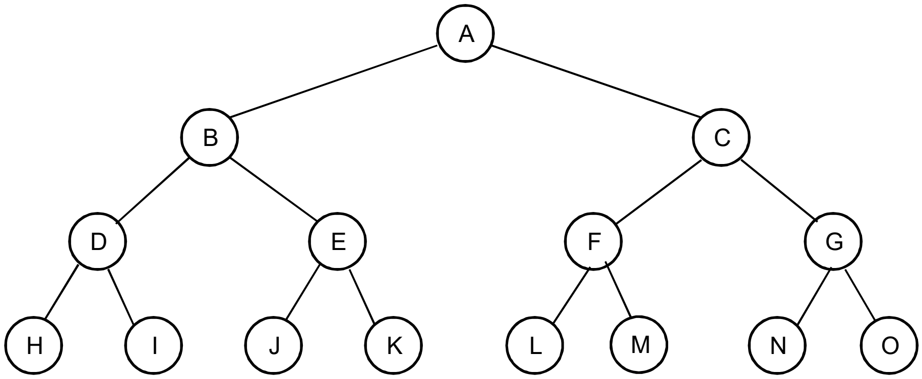
Remember from before: unless you make some special arrangements, the order of execution of the different tasks is *undefined*. Here come some special arrangements.

```
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!

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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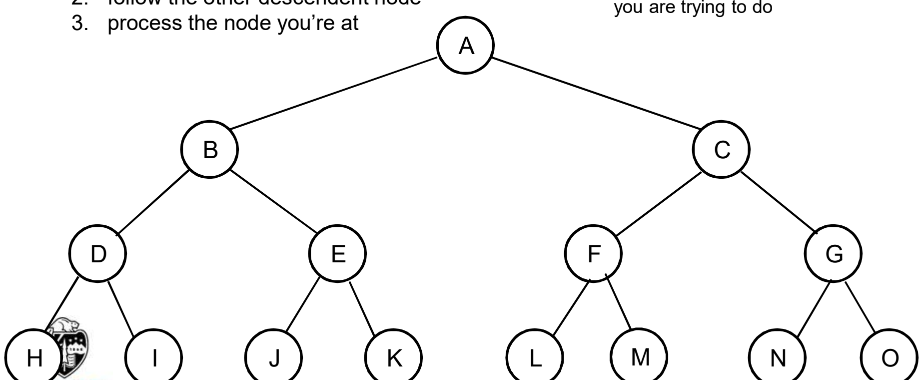
Tree Traversal Algorithms

- 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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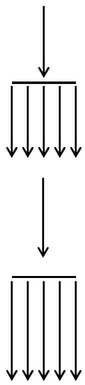
Tree Traversal Algorithms



Without this, thread #0 has to do everything – bad idea!

```
#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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Benchmarking a Binary Task-driven Tree Traversal

15

```
#define NUM  1024*1024

void
Process( Node *n )
{
        for( int i = 0; i < NUM; i++ )
        {
                n->value = pow( n->value, 1.01 );
        }
}
```

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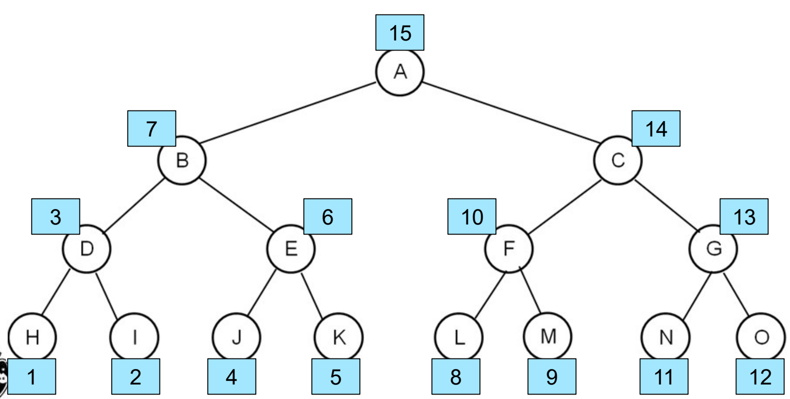
Parallelizing a Binary Tree Traversal with Tasks

16

Traverse(A);



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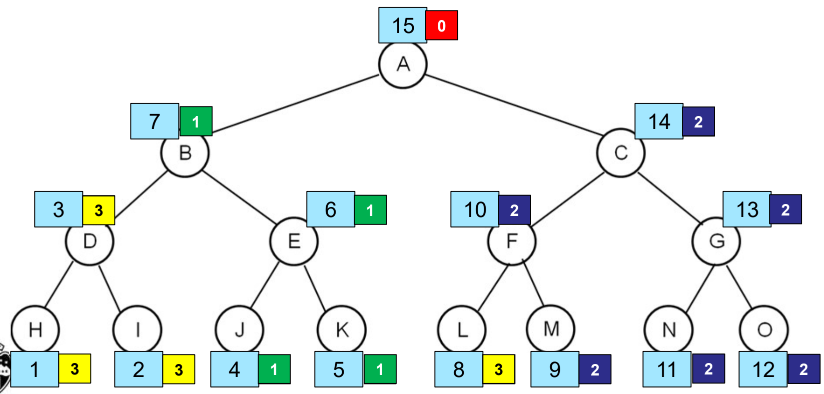
Parallelizing a Binary Tree Traversal with Tasks: *Tied* (g++ 10.2)

Threads:
0 1 2 3

Traverse(A);



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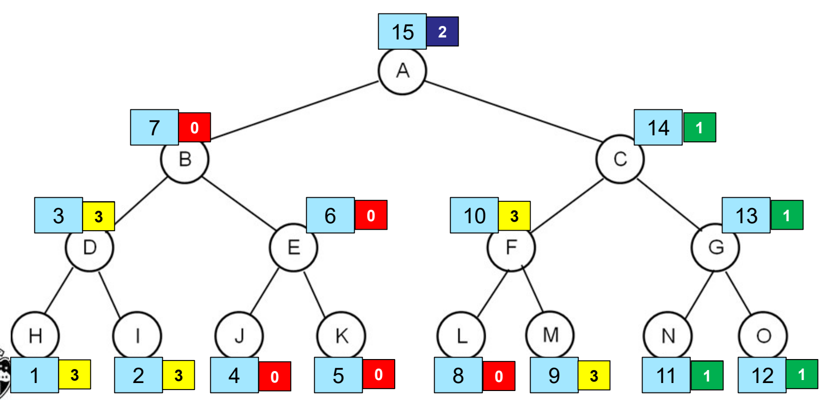
Parallelizing a Binary Tree Traversal with Tasks: *Untied* (g++ 10.2)

Threads:
0 1 2 3

Traverse(A);



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How Evenly Tasks Get Assigned to Threads
g++ vs. icpc

6 Levels – g++ 10.2:

Thread #	Number of Tasks
0	1
1	41
2	42
3	43

6 Levels – icpc 15.0.0:

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

12 Levels – g++ 10.2:

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

12 Levels – icpc 15.0.0:

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

How Evenly Tasks Get Assigned to Threads
g++ 4.9 vs. g++ 10.2

6 Levels – g++ 4.9:

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

6 Levels – g++ 10.2:

Thread #	Number of Tasks
0	1
1	41
2	42
3	43

12 Levels – g++ 4.9:

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

12 Levels – g++ 10.2:

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

21

How Evenly Tasks Get Assigned to Threads
Tied vs. Untied

6 Levels – g++ 10.2 -- Tied:

Thread #	Number of Tasks
0	1
1	41
2	42
3	43

6 Levels – g++ 10.2 -- Untied:

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

12 Levels – g++ 10.2 -- Tied:

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

12 Levels – g++ 10.2 -- Untied:

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

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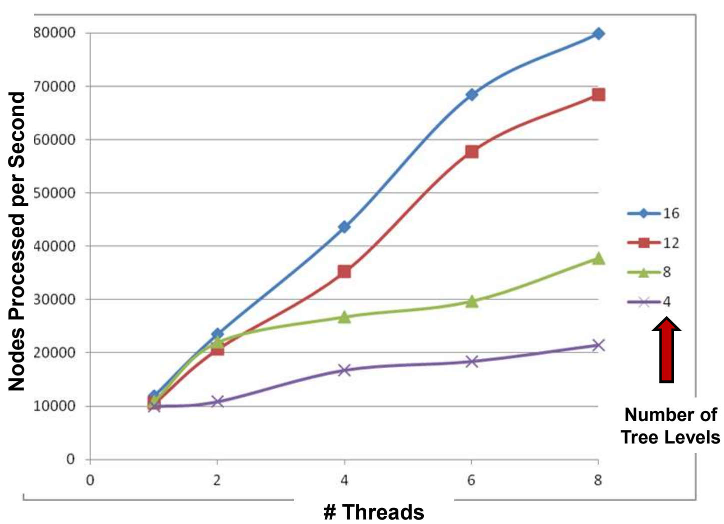
22

Performance vs. Number of Threads



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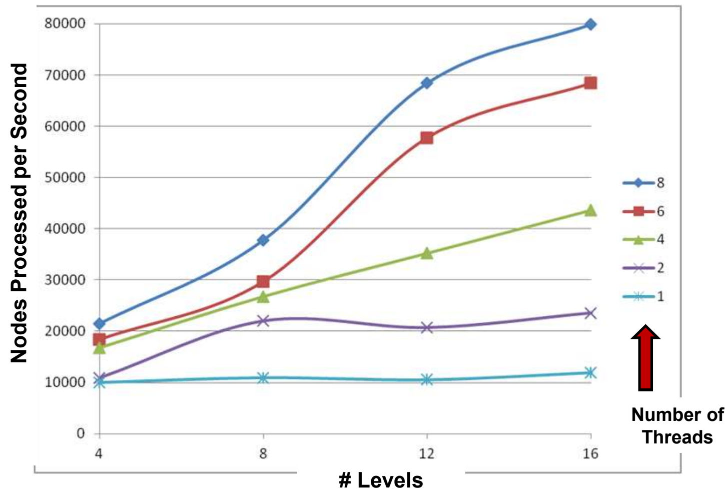
Performance vs. Number of Levels



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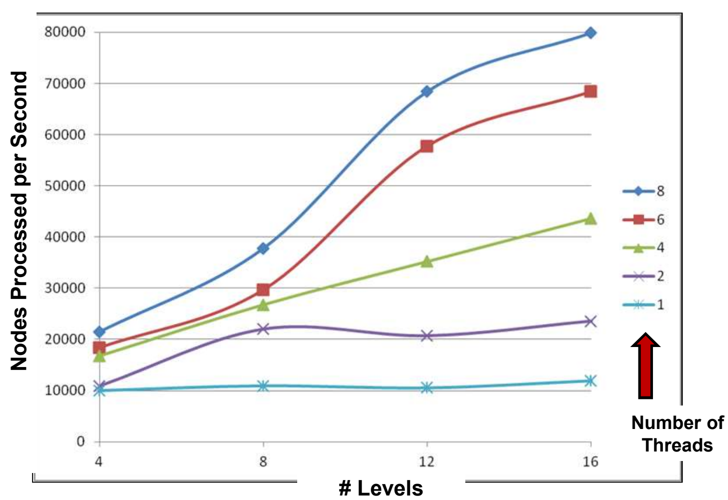
Performance vs. Number of Levels



8-thread Speed-up ≈ 6.7

F_p ≈ 97%

Max Speed-up ≈ 33x

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Parallelizing a Tree Traversal with Tasks: Summary

- 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.