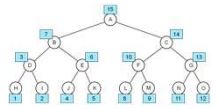
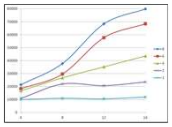
1

# OpenMP Tasks




Mike Bailey
mjb@cs.oregonstate.edu







2

## 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.



3

## 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***!



4

## 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.



5

## 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 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



6

## If You Run This a Number of Times, You Get This: (Uh-oh, 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 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:

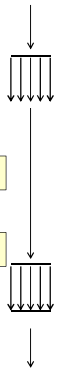


```
omp_set_num_threads( 2 );
#pragma omp parallel
{
        #pragma omp single default(none)
        {
                #pragma omp task
                        fprintf( stderr, "A\n" );

                #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



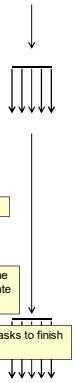
Without this, thread #0 has to do everything

```
#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 );

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

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





## 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
}
```

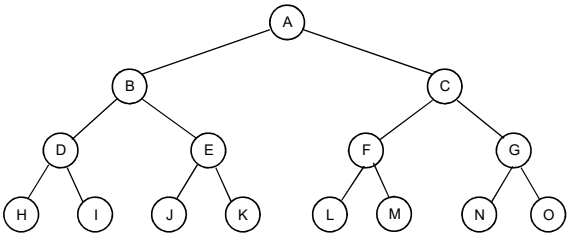
This maintains the proper dependencies, but, because it involves all of the tasks, it essentially serializes the parallelism out of them. Be careful not to go overboard with dependencies!



## 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.

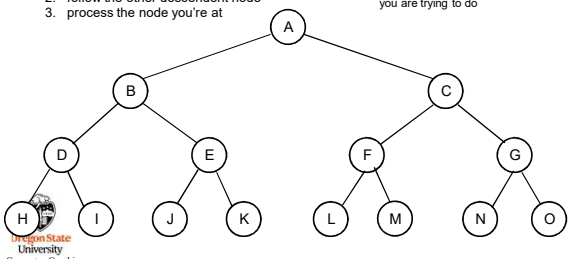


## Tree Traversal Algorithms



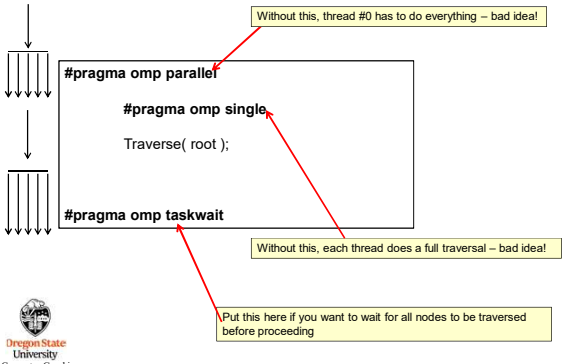
- This is common in graph algorithms, such as searching.
- If the tree is binary and is balanced, then the maximum depth of the tree is $\log_2$(# of Nodes)
- Strategy at a node:
  1. follow one descendent node
  2. follow the other descendent node
  3. process the node you're at

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



## Tree Traversal Algorithms

13

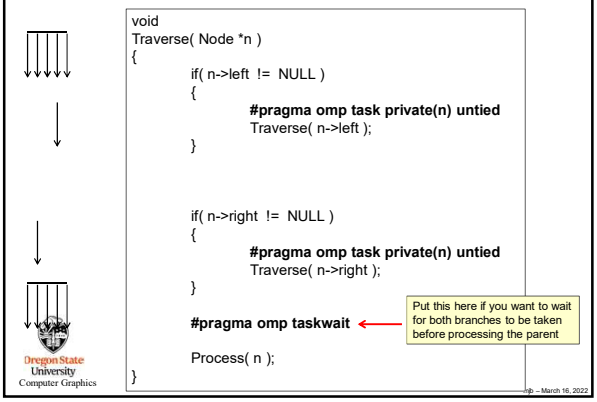



Oregon State University Computer Graphics

mjb – March 16, 2022

## Parallelizing a Binary Tree Traversal with Tasks

14




Oregon State University Computer Graphics

mjb – March 16, 2022

## 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 );
        }
}
```

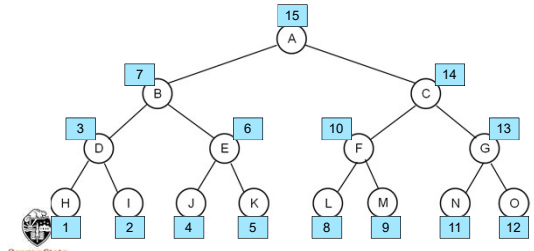
Oregon State University Computer Graphics

mjb – March 16, 2022

## Parallelizing a Binary Tree Traversal with Tasks

16

Traverse( A );




Oregon State University Computer Graphics

mjb – March 16, 2022

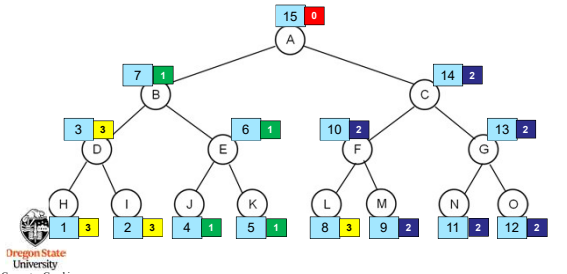
## Parallelizing a Binary Tree Traversal with Tasks: *Tied*

## (g++ 10.2)

17

Threads: 0 1 2 3

Traverse( A );




Oregon State University Computer Graphics

mjb – March 16, 2022

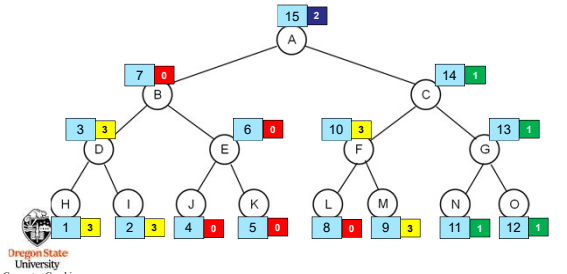
## Parallelizing a Binary Tree Traversal with Tasks: *Untied*

## (g++ 10.2)

18

Threads: 0 1 2 3

Traverse( A );




Oregon State University Computer Graphics

mjb – March 16, 2022

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

19

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 |

Oregon State University Computer Graphics

mjb – March 16, 2022

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

20

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 |

Oregon State University Computer Graphics

mjb – March 16, 2022

## How Evenly Tasks Get Assigned to Threads
## Tied vs. Untied

21

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:

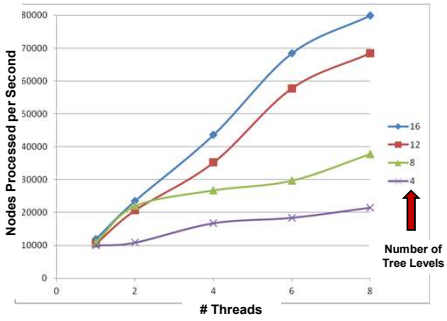
| Thread # | Number of Tasks |
|---|---|
| 0 | 3071 |
| 1 | 1 |
| 2 | 2048 |
| 3 | 3071 |

Oregon State University Computer Graphics

mjb – March 16, 2022

## Performance vs. Number of Threads

22

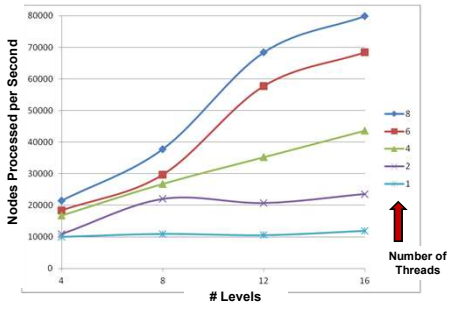



Oregon State University Computer Graphics

mjb – March 16, 2022

## Performance vs. Number of Levels

23

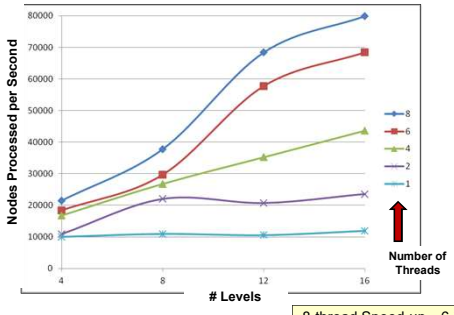



Oregon State University Computer Graphics

mjb – March 16, 2022

## Performance vs. Number of Levels

24




8-thread Speed-up ≈ 6.7

$F_p$ ≈ 97%

Max Speed-up ≈ 33x

Oregon State University Computer Graphics

mjb – March 16, 2022

## 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.