Remember OpenMP Sections?

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

```c
#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 Task Example: Something (Supposedly) Simple

```c
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 #pragma, thread #0 will have to do everything.

#pragmas are written on a sticky note and added 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?)

<table>
<thead>
<tr>
<th>Run #</th>
<th>B</th>
<th>B</th>
<th>B</th>
<th>B</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>A</td>
<td>A</td>
<td>A</td>
<td>A</td>
</tr>
<tr>
<td></td>
<td>A</td>
<td>B</td>
<td>A</td>
<td>B</td>
</tr>
<tr>
<td></td>
<td>A</td>
<td>A</td>
<td>B</td>
<td>A</td>
</tr>
</tbody>
</table>

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

```c
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 want:
1. One thread to write the things to do down on the sticky notes
2. All threads 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:

```c
omp_set_num_threads(2);
#pragma omp parallel default(none)
{
#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

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

```c
#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;
}
}
}
```

Without this #pragma, each thread will have to do a full traversal of the linked list – bad idea!

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

Given a tree:

```
A
  B
  D
  E
  F
  G
H
I
J
K
L
M
N
O
```

• We would like to traverse it as quickly as possible.
• If the tree is binary and is balanced, then the maximum depth of the tree is \( \log_2(\text{# of Nodes}) \)

Strategy at each node:
1. follow one descendent node
2. follow the other descendent node
3. process the node you’re at

Without this #pragma, thread #0 will have to do everything

This order could be rearranged, depending on what you are trying to do

Put this here if you want to wait for all tasks to finish being executed before proceeding
# Parallelizing a Binary Tree Traversal with Tasks

```c
void Traverse( Node *n )
{
    if( n->left != NULL )
        #pragma omp task firstprivate(n) untied
        Traverse( n->left );
    if( n->right != NULL )
        #pragma omp task firstprivate(n) untied
        Traverse( n->right );
    #pragma omp taskwait
    Process( n );
}
```

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

# Benchmarking a Binary Task-driven Tree Traversal

```c
#define NUM 1024*1024
void Process( Node *n )
{
    for( int i = 0; i < NUM; i++ )
        n->value = pow( n->value, 1.01 );
}
```

# Parallelizing a Binary Tree Traversal with Tasks: Tied (g++ 11.4)

```c
void Traverse( A );
```

# Parallelizing a Binary Tree Traversal with Tasks: Untied (g++ 11.4)

```c
void Traverse( A );
```

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

<table>
<thead>
<tr>
<th>Levels</th>
<th>g++ 11.4</th>
<th>icpc 15.0.0</th>
</tr>
</thead>
<tbody>
<tr>
<td>6</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Thread</td>
<td>Number of Tasks</td>
<td>Thread</td>
</tr>
<tr>
<td>0</td>
<td>1</td>
<td>0</td>
</tr>
<tr>
<td>1</td>
<td>41</td>
<td>1</td>
</tr>
<tr>
<td>2</td>
<td>42</td>
<td>2</td>
</tr>
<tr>
<td>3</td>
<td>43</td>
<td>3</td>
</tr>
</tbody>
</table>

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<th>Levels</th>
<th>g++ 11.4</th>
<th>icpc 15.0.0</th>
</tr>
</thead>
<tbody>
<tr>
<td>12</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Thread</td>
<td>Number of Tasks</td>
<td>Thread</td>
</tr>
<tr>
<td>0</td>
<td>3071</td>
<td>0</td>
</tr>
<tr>
<td>1</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>2</td>
<td>3071</td>
<td>2</td>
</tr>
<tr>
<td>3</td>
<td>2048</td>
<td>3</td>
</tr>
</tbody>
</table>
### How Evenly Tasks Get Assigned to Threads

#### Tied vs. Untied

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<tr>
<th>6 Levels – g++ 11.4 – Tied:</th>
<th>6 Levels – g++ 11.4 – Untied:</th>
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<tr>
<td><strong>Thread #</strong></td>
<td><strong>Number of Tasks</strong></td>
</tr>
<tr>
<td>0</td>
<td>1</td>
</tr>
<tr>
<td>1</td>
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<td><strong>Thread #</strong></td>
<td><strong>Number of Tasks</strong></td>
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<td>0</td>
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<td>2</td>
<td>3071</td>
</tr>
<tr>
<td>3</td>
<td>2048</td>
</tr>
</tbody>
</table>

---

### Performance vs. Number of Threads

#### Number of Tasks

- 6 Levels – Tied:
  - Number of Tasks: 1, 41, 42, 43
- 12 Levels – Tied:
  - Number of Tasks: 3071, 1, 3071, 2048
- 6 Levels – Untied:
  - Number of Tasks: 1, 47, 32, 47
- 12 Levels – Untied:
  - Number of Tasks: 3071, 1, 3071, 2048

#### Number of Tree Levels

- 6 Levels – Tied:
  - Number of Tree Levels: 3071, 1, 3071, 2048
- 12 Levels – Tied:
  - Number of Tree Levels: 3071, 1, 3071, 2048
- 6 Levels – Untied:
  - Number of Tree Levels: 3071, 1, 3071, 2048
- 12 Levels – Untied:
  - Number of Tree Levels: 3071, 1, 3071, 2048

---

### Performance vs. Number of Levels

#### Nodes Processed per Second

- 6 Levels – Tied:
  - # Levels: 1, 2, 3, 4
- 12 Levels – Tied:
  - # Levels: 1, 2, 3, 4
- 6 Levels – Untied:
  - # Levels: 1, 2, 3, 4
- 12 Levels – Untied:
  - # Levels: 1, 2, 3, 4

---

### 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.

8-thread Speed-up ≈ 6.7

F_p ≈ 97%

Max Speed-up ≈ 33x