OpenMP ARB, 2007

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OpenMP 3.0

OpenMP ARB

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Tasks

- Adding tasking is the biggest addition for 3.0
- Worked on by a separate subcommittee
  - led by Jay Hoeflinger at Intel
- Re-examined issue from ground up
  - quite different from Intel taskq's

General task characteristics

- A task has
  - Code to execute
  - A data environment (it *owns* its data)
  - An assigned thread that executes the code and uses the data
- Two activities: packaging and execution
  - Each encountering thread packages a new instance of a task (code and data)
  - Some thread in the team executes the task at some (potentially later) time

Definitions

- ***Task construct*** **–** **`task` directive plus structured block**
- ***Task*** **– the package of code and instructions for allocating data created when a thread encounters a task construct**
- ***Task region*** **– the dynamic sequence of instructions produced by the execution of a task by a thread**

Tasks and OpenMP

- **Tasks have been fully integrated into OpenMP**
- **Key concept: OpenMP has always had tasks, we just never called them that.**
  - **Thread encountering `parallel` construct packages up a set of *implicit* tasks, one per thread.**
  - **Team of threads is created.**
  - **Each thread in team is assigned to one of the tasks (and *tied* to it).**
  - **Barrier holds original master thread until all implicit tasks are finished.**
- **We have simply added a way to create a task explicitly for the team to execute.**
- **Every part of an OpenMP program is part of one task or another!**

`task` Construct

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

where *clause* **can be one of:**

```
if (expression)
untied
shared (list)
private (list)
firstprivate (list)
default( shared | none  )
```

The `if` clause on a `task` construct

- **When the `if` clause argument is false**
  - The current task region is suspended.
  - The new task is executed immediately by the encountering thread.
  - The suspended task region is not resumed until the new task is complete.
  - The data environment is still local to the new task...
  - ...and it's still a different task with respect to synchronization.
- **It's a user directed optimization**
  - when the cost of deferring the task is too great compared to the cost of executing the task code
  - to control cache and memory affinity

When/where are tasks complete?

- At barriers, explicit or implicit
  - applies to all tasks generated in the current parallel region up to the barrier
  - matches user expectation
- At a `taskwait` directive
  - applies only to child tasks of the current task, not to further “descendants”

Example – parallel pointer chasing using tasks

```
#pragma omp parallel
{
  #pragma omp single private(p)
   {
    p = listhead ;
    while (p) {
       #pragma omp task
               process (p)
       p=next (p) ;
     }
   }
}
```

p is firstprivate by default here

Example – parallel pointer chasing on multiple lists using tasks

```
#pragma omp parallel
{
   #pragma omp for private(p)
   for ( int i =0; i <numlists ; i++) {
       p = listheads [ i ] ;
       while (p ) {
       #pragma omp task
           process (p)
       p=next (p ) ;
       }
   }
}
```

Example: tree traversal, children before parents

```
void traverse(node *p) {
    if (p->left)
      #pragma omp task
        traverse(p->left);
    if (p->right)
      #pragma omp task
        traverse(p->right);
    #pragma omp taskwait
    process(p->data);
}
```

Parent task suspended until child tasks complete

Task switching

- Certain constructs have task scheduling points at defined locations within them
- When a thread encounters a task scheduling point, it is allowed to suspend the current task and execute another (called *task switching*)
- It can then return to the original task and resume

Task switching example

```
#pragma omp single
{
  for (i=0; i<ONEZILLION; i++)
    #pragma omp task
      process(item[i]);
}
```

- Too many tasks generated in an eye-blink
- Generating task will have to suspend for a while
- With task switching, the executing thread can:
  - execute an already generated task (draining the "*task pool*")
  - dive into the encountered task (could be very cache-friendly)

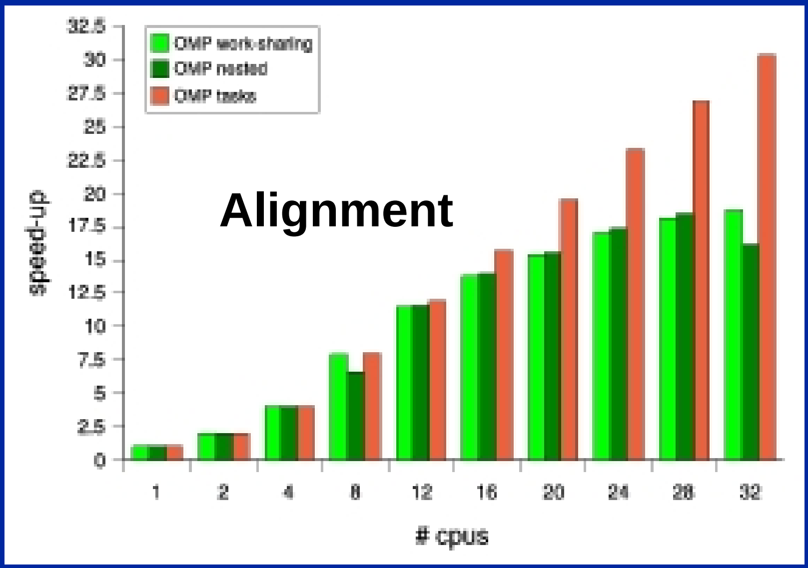
Thread switching

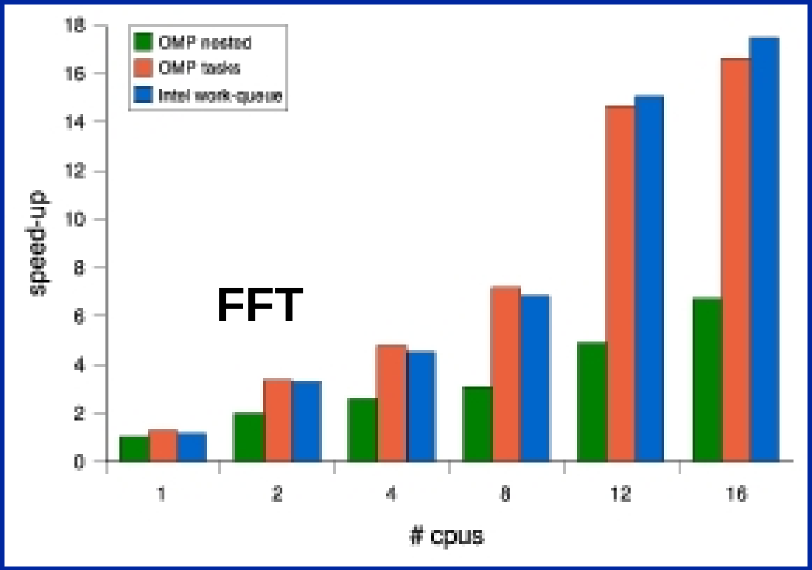
```
#pragma omp single
{
  #pragma omp task untied
    for (i=0; i<ONEZILLION; i++)
      #pragma omp task
        process(item[i]);
}
```

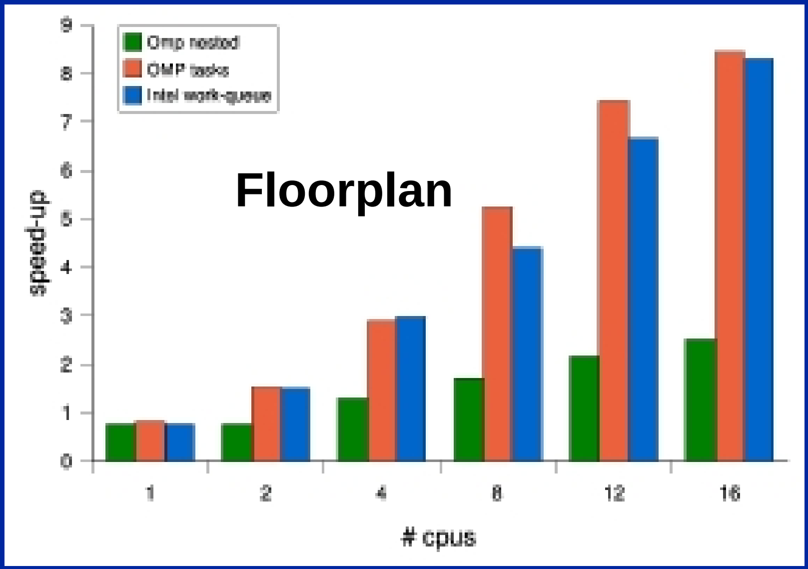
- Eventually, too many tasks are generated
- Generating task is suspended and executing thread switches to a long and boring task
- Other threads get rid of all already generated tasks, and start starving…

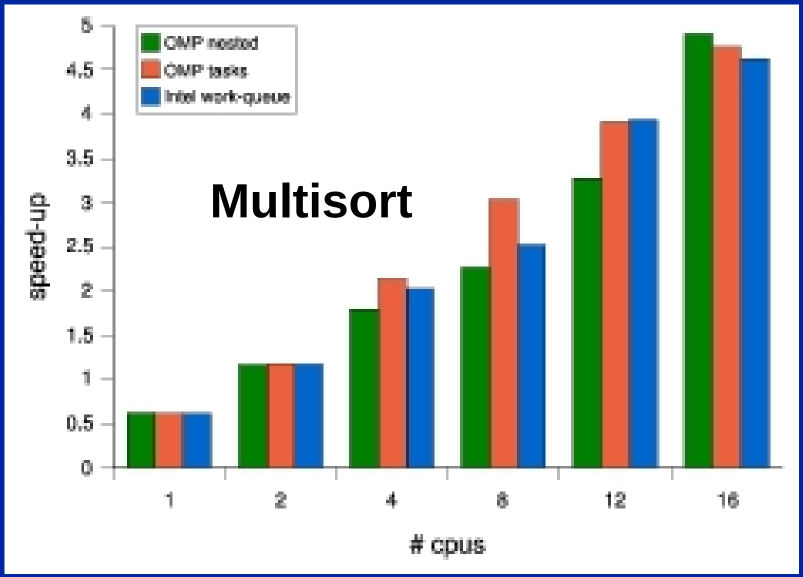
- With thread switching, the generating task can be resumed by a different thread, and starvation is over
- Too strange to be the default: the programmer is responsible!

Performance Results 1



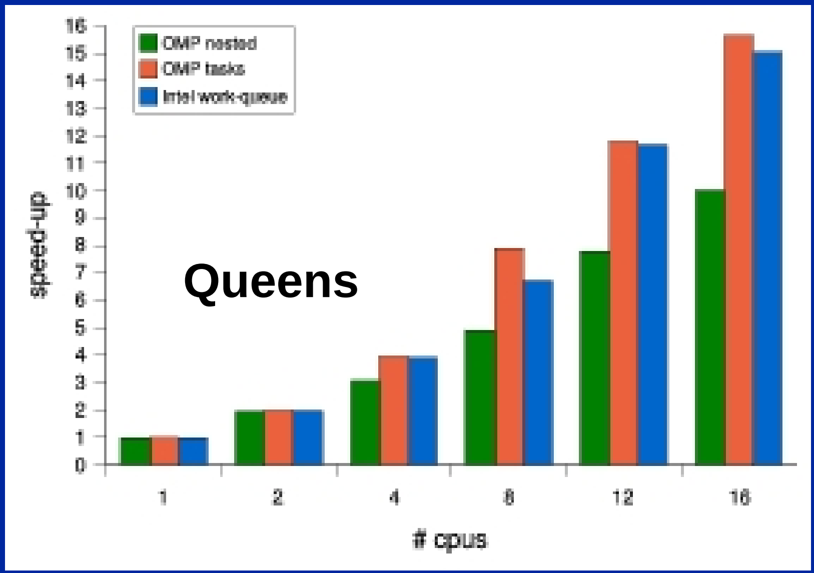


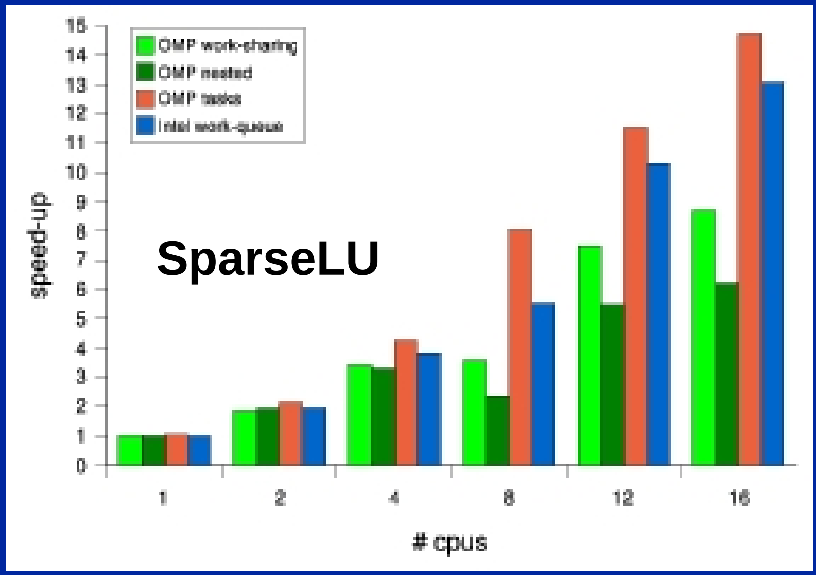


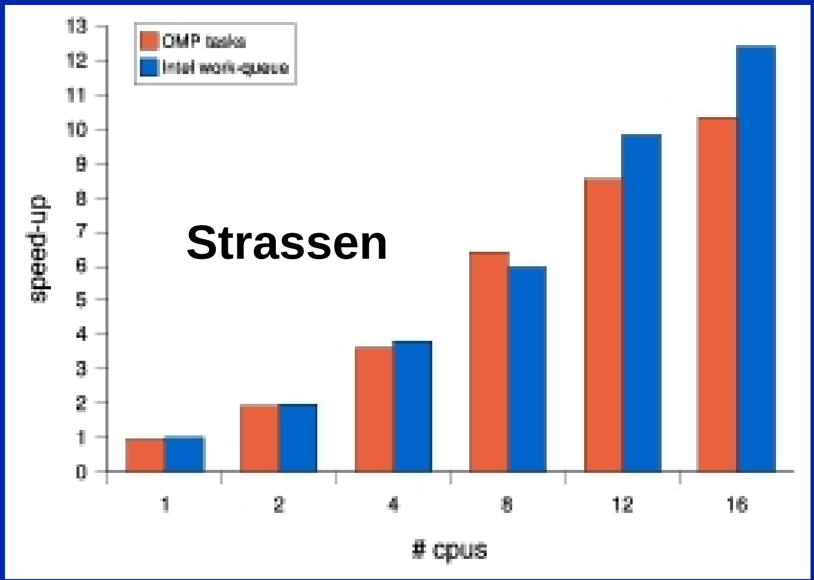


All tests run on SGI Altix 4700 with 128 processors

Performance Results 2







All tests run on SGI Altix 4700 with 128 processors

Reference Implementation

- URL:

  http://mercurium.pc.ac.upc.edu/nanos

- Made by Xavier Teruel, Roger Ferrer, Alex Duran, Eduard Ayguadé, Xavier Martorell

Conclusions on tasks

- Enormous amount of work by many people
- Tightly integrated into 2.5 spec
- Flexible model for irregular parallelism
- Provides balanced solution despite often conflicting goals
- Appears that performance can be reasonable

Better support for nested parallelism

- **Per-thread internal control variables**
  - Allows, for example, calling `omp_set_num_threads()` inside a parallel region.
  - Controls the team sizes for next level of parallelism
- **Library routines to determine depth of nesting, IDs of parent/grandparent etc. threads, team sizes of parent/grandparent etc. teams**

```
omp_get_level()
omp_get_active_level()
omp_get_ancestor_thread_num(level)
omp_get_team_size(level)
```

N.B. new defn. of active parallel region: a parallel region executed by more than one thread

Parallel loops

- Guarantee that this works:

```
!$omp do schedule(static)
do i=1,n
   a(i) = ....
end do
!$omp end do nowait
!$omp do schedule(static)
do i=1,n
  .... = a(i)
end do
```

Loops (cont.)

- Allow collapsing of perfectly nested loops

```
!$omp parallel do collapse(2)
do i=1,n
    do j=1,n
         .....
    end do
end do
```

- Will form a single loop and then parallelise that

Loops (cont.)

- Made `schedule(runtime)` more useful
  - can get/set it with library routines

    `omp_set_schedule()`

    `omp_get_schedule()`
  - allow implementations to implement their own schedule kinds
- Added a new schedule kind AUTO which gives full freedom to the runtime to determine the scheduling of iterations to threads.
- Allowed unsigned ints and C++ RandomAccessIterators as loop control variables in parallel loops

Portable control of threads

- Added environment variable to control the size of child threads' stack

  `OMP_STACKSIZE`

- Added environment variable to hint to runtime how to treat idle threads

  `OMP_WAIT_POLICY`

  `ACTIVE` keep threads alive at barriers/locks

  `PASSIVE` try to release processor at barriers/locks

- Added environment variable and runtime routines to get/set the maximum number of active levels of nested parallelism

  `OMP_MAX_NESTED_LEVELS`

  `omp_set_max_nested_levels()`

  `omp_get_max_nested_levels()`

- Added environment variable to set maximum number of threads in use

  `OMP_THREAD_LIMIT`

  `omp_get_thread_limit()`

Odds and ends

- Disallowed use of the original variable as master thread's private variable
- Made it clearer where/how private objects are constructed/destructed
- Relaxed some restrictions on allocatable arrays
- Plugged some minor gaps in memory model
- Allowed C++ static class members to be threadprivate
- Minor fixes and clarifications to 2.5

Summary

- OpenMP 3.0 is almost ready
- Been a lot of hard work by a lot of people
- We hope you like it: let us know via the public comment process what you think!

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