

# Parallel design patterns

## ARCHER course

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Practical four: Divide and conquer using  
fork/join



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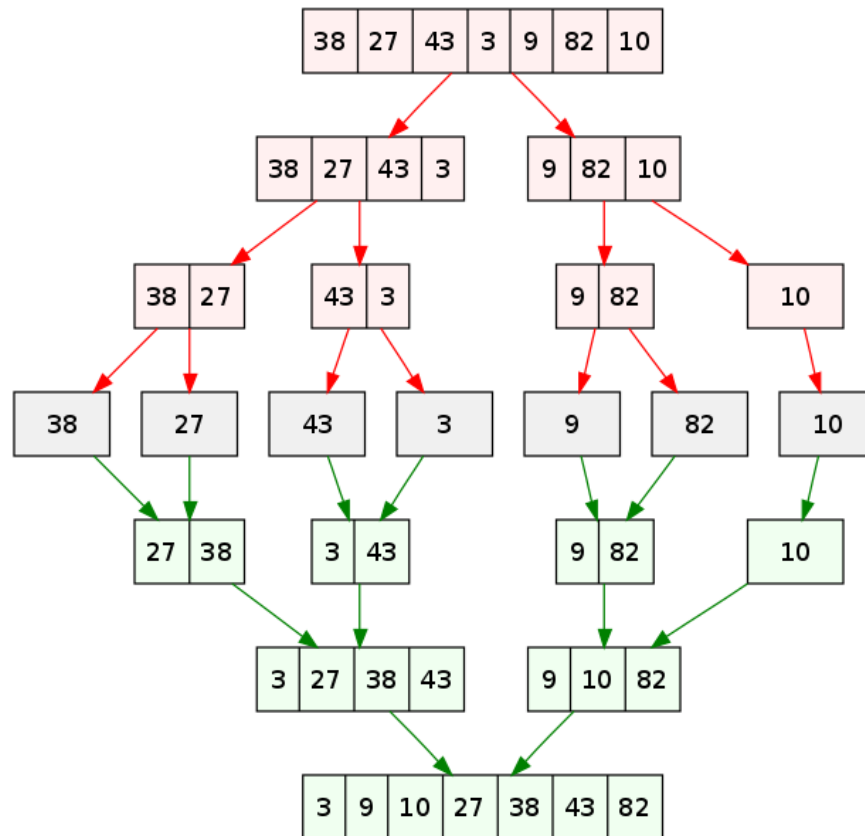
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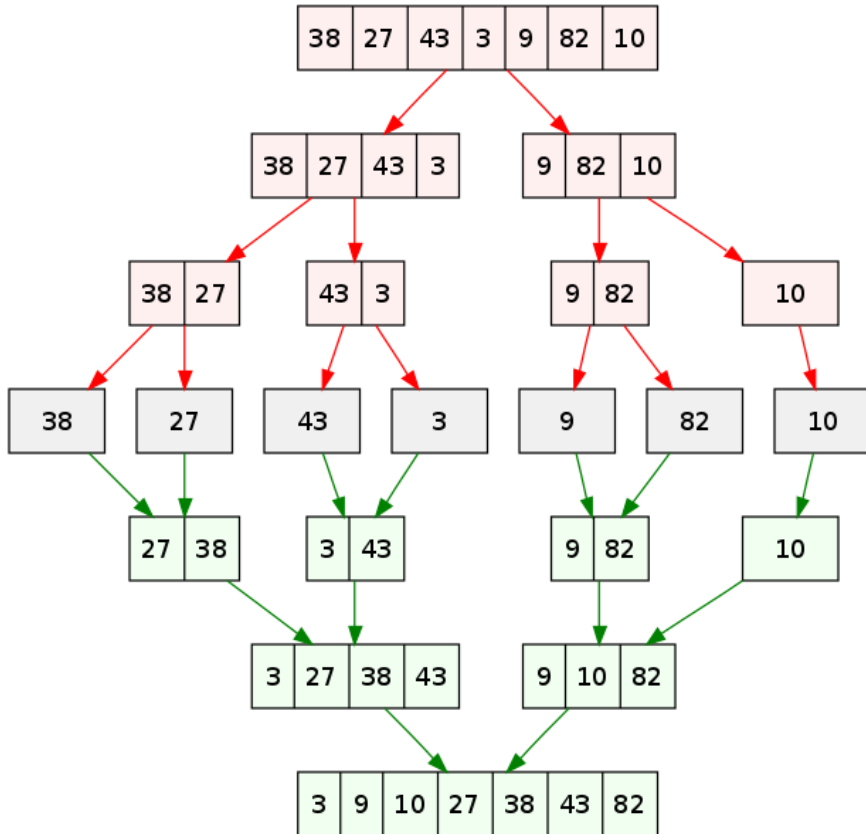
# Mergesort

- Starting from some randomly generated, unsorted data.



- Repeatedly divide the data (problem) up until it is trivial to solve
- Then merge the small answers together to form the overall sorted list of numbers
- Maps very well to D&C pattern

# Fork/join based mergesort

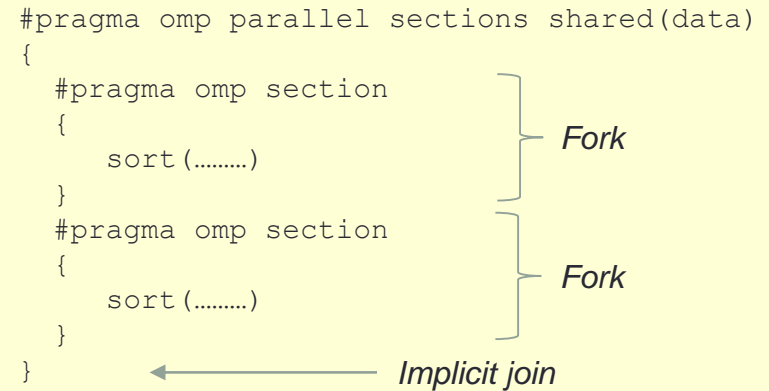


- Each division is a task, working down to some serial threshold (in the image this is 1, but in reality you probably want it to be higher than this.)
- At each division you can fork a new thread and the merge then involves a join
- Instead of threads we can also use OpenMP tasks

# Wash up

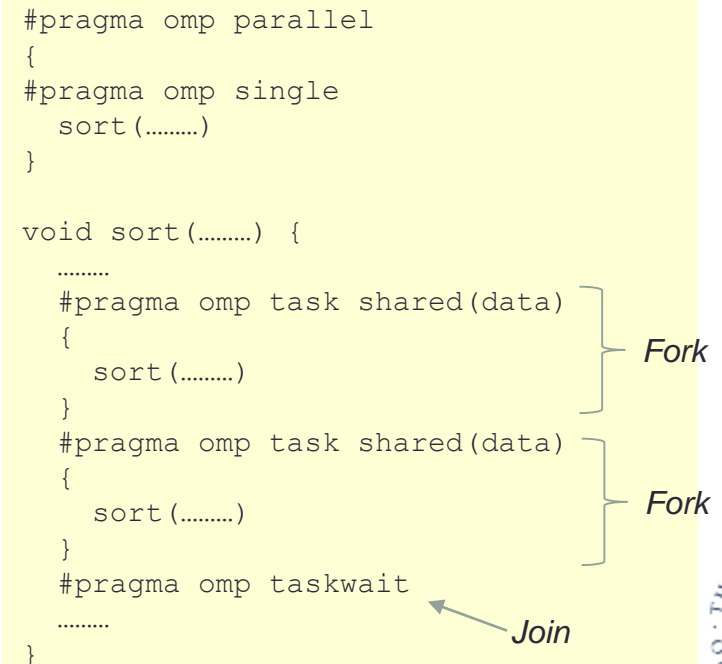
- Sample solutions are available
- Two main versions if you completed the entire exercise
  - Using sections (fork join via threads)
  - Using tasks (are scheduled and will run when a thread is available)
- Crucially with sections we are forced to create a parallel region per level, this is not so with tasks

```
#pragma omp parallel sections shared(data)
{
  #pragma omp section
  {
    sort(.....)
  }
  #pragma omp section
  {
    sort(.....)
  }
}
← Implicit join
```

The diagram shows two OpenMP sections within a parallel region. Each section is enclosed in curly braces. To the right of each section, a bracket labeled 'Fork' spans the section's boundaries. A horizontal arrow labeled 'Implicit join' points to the closing brace of the second section, indicating the end of the parallel region.

```
#pragma omp parallel
{
  #pragma omp single
  sort(.....)
}

void sort(.....) {
  .....
  #pragma omp task shared(data)
  {
    sort(.....)
  }
  #pragma omp task shared(data)
  {
    sort(.....)
  }
  #pragma omp taskwait
  .....
}
← Join
```

The diagram shows a parallel region containing a single task that calls a 'sort' function. Inside the 'sort' function, there are two OpenMP tasks, each enclosed in curly braces. To the right of each task, a bracket labeled 'Fork' spans the task's boundaries. A horizontal arrow labeled 'Join' points to the '#pragma omp taskwait' line, indicating the end of the parallel region.

# With verbose on.....

My id 0 my depth 1 pivot=50  
My id 1 my depth 1 pivot=50  
My id 0 my depth 2 pivot=25  
My id 1 my depth 2 pivot=25  
My id 0 my depth 2 pivot=25  
My id 1 my depth 2 pivot=25  
My id 1 my depth 3 pivot=12  
My id 0 my depth 3 pivot=12  
My id 1 my depth 3 pivot=12  
My id 0 my depth 3 pivot=12  
My id 0 my depth 3 pivot=12  
My id 1 my depth 3 pivot=12  
My id 0 my depth 4 pivot=6  
My id 1 my depth 4 pivot=6  
My id 0 my depth 4 pivot=6  
My id 1 my depth 4 pivot=6  
My id 0 my depth 3 pivot=12  
My id 1 my depth 3 pivot=12  
My id 0 my depth 4 pivot=6  
My id 1 my depth 4 pivot=6  
My id 0 my depth 4 pivot=6  
My id 1 my depth 4 pivot=6  
My id 0 my depth 4 pivot=6  
My id 1 my depth 4 pivot=6  
My id 0 my depth 4 pivot=6  
My id 1 my depth 4 pivot=6  
My id 0 my depth 4 pivot=6  
My id 1 my depth 4 pivot=6  
My id 0 my depth 4 pivot=6  
My id 1 my depth 4 pivot=6

Sections



My id 0 my depth 1 pivot=50  
My id 6 my depth 1 pivot=50  
My id 0 my depth 1 pivot=25  
My id 11 my depth 1 pivot=25  
My id 0 my depth 1 pivot=12  
My id 0 my depth 1 pivot=6  
My id 3 my depth 1 pivot=12  
My id 0 my depth 1 pivot=6  
My id 6 my depth 1 pivot=25  
My id 6 my depth 1 pivot=12  
My id 3 my depth 1 pivot=6  
My id 14 my depth 1 pivot=6  
My id 15 my depth 1 pivot=25  
My id 11 my depth 1 pivot=12  
My id 6 my depth 1 pivot=6  
My id 9 my depth 1 pivot=12  
My id 0 my depth 1 pivot=6  
My id 11 my depth 1 pivot=6  
My id 3 my depth 1 pivot=6  
My id 6 my depth 1 pivot=12  
My id 6 my depth 1 pivot=6  
My id 6 my depth 1 pivot=6  
My id 15 my depth 1 pivot=12  
My id 4 my depth 1 pivot=6  
My id 15 my depth 1 pivot=6  
My id 8 my depth 1 pivot=12  
My id 1 my depth 1 pivot=6  
My id 9 my depth 1 pivot=6  
My id 8 my depth 1 pivot=6  
My id 19 my depth 1 pivot=6

Tasks

My id 0 my depth 1 pivot=50  
My id 1 my depth 1 pivot=50  
My id 0 my depth 2 pivot=25  
My id 1 my depth 2 pivot=25  
My id 0 my depth 3 pivot=12  
My id 1 my depth 3 pivot=12  
My id 0 my depth 2 pivot=25  
My id 1 my depth 2 pivot=25  
My id 0 my depth 4 pivot=6  
My id 1 my depth 4 pivot=6  
My id 0 my depth 3 pivot=12  
My id 1 my depth 3 pivot=12  
My id 0 my depth 3 pivot=12  
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My id 0 my depth 4 pivot=6  
My id 1 my depth 4 pivot=6  
My id 0 my depth 4 pivot=6  
My id 1 my depth 4 pivot=6

*Nested tasks*



# Performance numbers

Code	Runtime (ns)
Serial	6
Sections	82974
Sections (3 threads/region)	3868
Sections (1 thread/region)	1546
Tasks	1882
Tasks (1 task)	1775
Nested tasks	732030
Nested tasks (2 threads/region)	1874

*With 100 elements and serial threshold of 10*

Code	Runtime (ms)
Serial	0.136
Sections (1 thread)	1.977
Tasks	0.0265
Tasks (1 task)	0.152
Nested tasks (2 threads/region)	0.447

*With 1000000 elements, serial threshold 10000*

Available cores	Runtime (ms)
12	0.0486
13	0.0551

*NUMA region effects with tasks  
(1000000 elements, serial threshold 100)*

# Conclusions

- Sections are a useful OpenMP construct for fork/join
  - But are limited, especially if you have multiple levels as you can easily over subscribe threads to cores
- OpenMP tasks are more flexible and can avoid this problem
  - This was actually one of the main motivations behind OpenMP tasks
- Be careful of going across NUMA regions
  - Not a huge amount you can do with tasks as they will be mapped to any available thread. Hence I often limit myself to running this sort of code on a NUMA region rather than full node