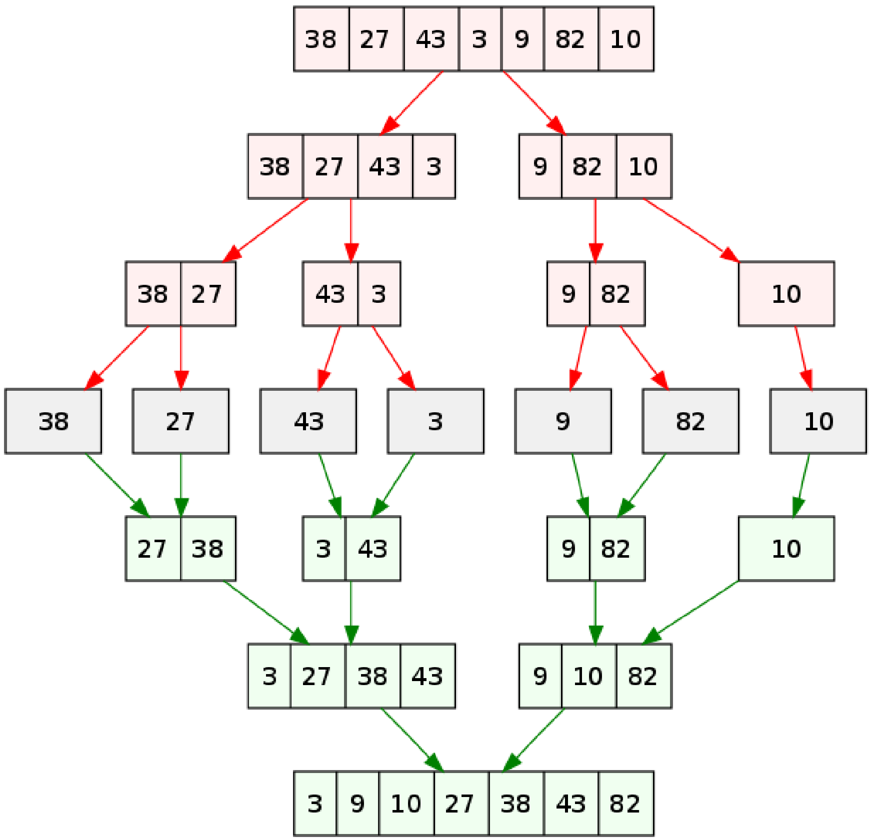
Parallel design patterns ARCHER course

Practical four: Divide and conquer using fork/join

Reusing this material

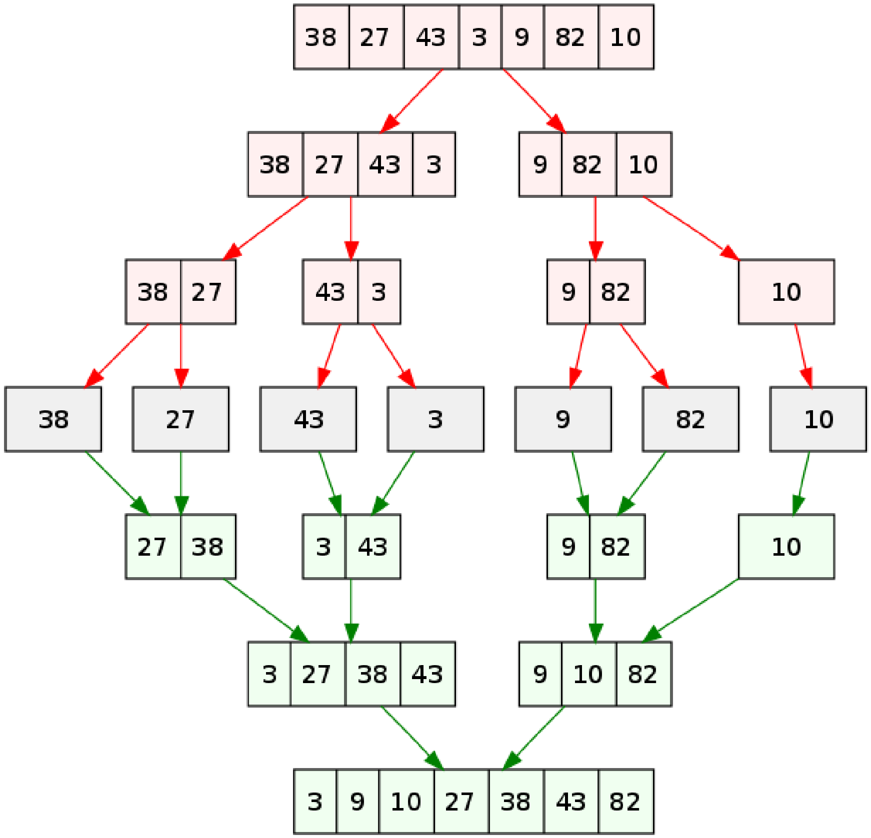
Mergesort

- 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

In the C version runtime is reported in ns, whereas in the Fortran version it is in ms

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
  {                                  Fork
     sort(………)
  }
  #pragma omp section
  {                                  Fork
     sort(………)
  }
}          <------------  Implicit join
```

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

void sort(………) {
  ………
  #pragma omp task shared(data)
  {                                   Fork
    sort(………)
  }
  #pragma omp task shared(data)
  {                                   Fork
    sort(………)
  }
  #pragma omp taskwait   <--- Join
  ………
}
```

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 1 my depth 4 pivot=6
My id 0 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
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 0 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
```

Nested tasks

Performance numbers

Code	Runtime (ns)
Serial	6
Sections	82974
Sections (3 threads/region)	3868
Sections (1 section)	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 section)	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