LAB 3

Introduction

In this laboratory we are going to study the implementation of "divide and conquer" strategy using OpneMP paralization. **(ha de continuar)**

Task decomposition analysis for Mergesort

Divide and conquer

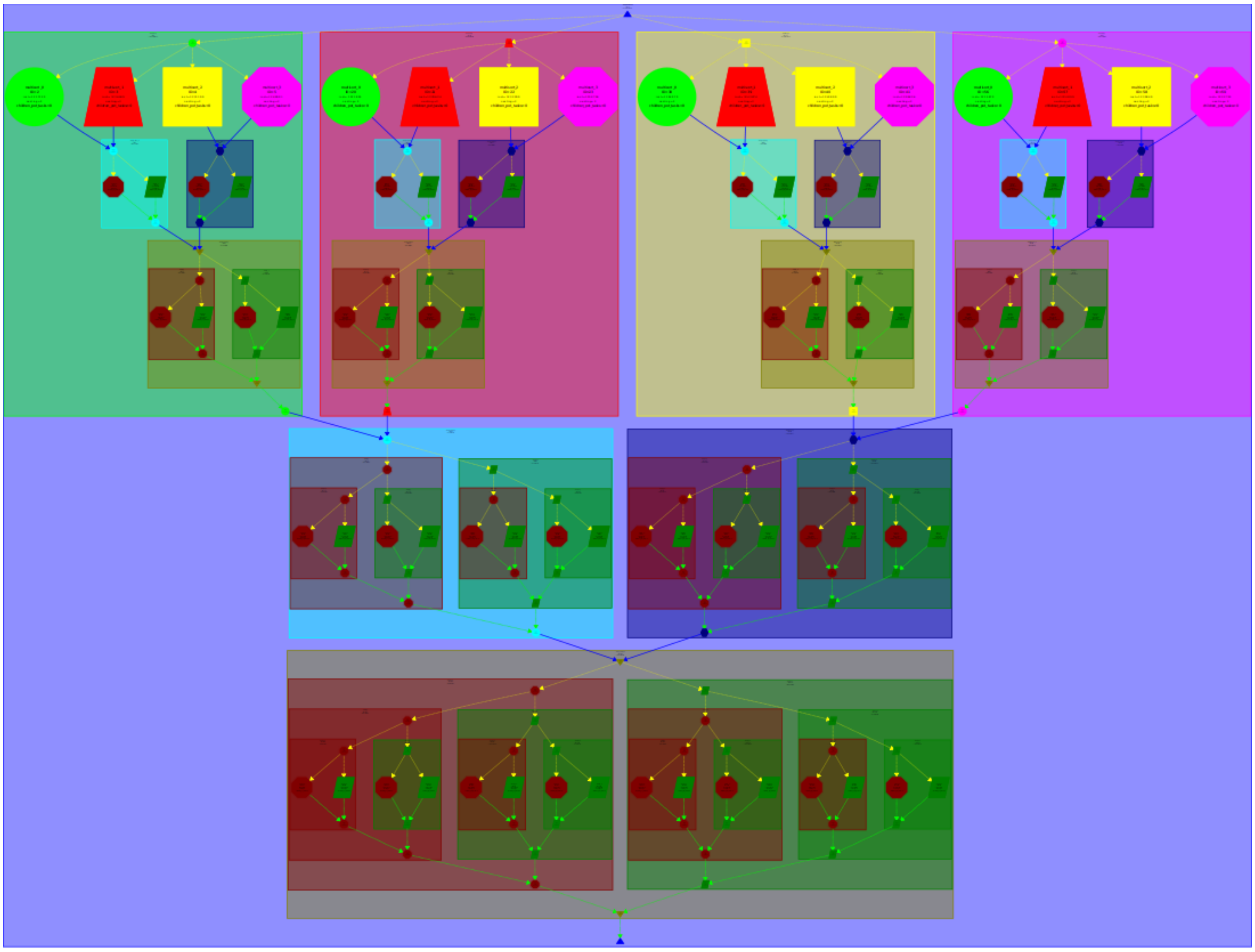
Task decomposition analysis with Tareador

```
void merge(long n, T left[n], T right[n], T result[n*2], long start, long
length) {
                if (length < MIN_MERGE_SIZE*2L) {
                                // Base case
                                basicmerge(n, left, right, result, start,
length);
                } else {
                                // Recursive decomposition
                                tareador_start_task("merge 0");
                                merge(n, left, right, result, start,
length/2);
                                tareador_end_task("merge 0");
                                tareador_start_task("merge 1");
                                merge(n, left, right, result, start +
length/2, length/2);
                                tareador_end_task("merge 1");
                }
}

void multisort(long n, T data[n], T tmp[n]) {

                if (n >= MIN_SORT_SIZE*4L) {
                                // Recursive decomposition
                                tareador_start_task("multisort 0");
                                multisort(n/4L, &data[0], &tmp[0]);
                   tareador_end_task("multisort 0");
                                tareador_start_task("multisort 1");
                                multisort(n/4L, &data[n/4L], &tmp[n/4L]);
                                tareador_end_task("multisort 1");
                                tareador_start_task("multisort 2");
                                multisort(n/4L, &data[n/2L], &tmp[n/2L]);
                                tareador_end_task("multisort 2");
                                tareador_start_task("multiosrt 3");
                                multisort(n/4L, &data[3L*n/4L],
&tmp[3L*n/4L]);
                                tareador_end_task("multisort 3");

                                tareador_start_task("merge_multi 0");
                                merge(n/4L, &data[0], &data[n/4L], &tmp[0],
0, n/2L);
                                tareador_end_task("merge_multi 0");
                                tareador_start_task("merge_multi 1");
                                merge(n/4L, &data[n/2L], &data[3L*n/4L],
&tmp[n/2L], 0, n/2L);
                                tareador_end_task("merge_multi 1");
```

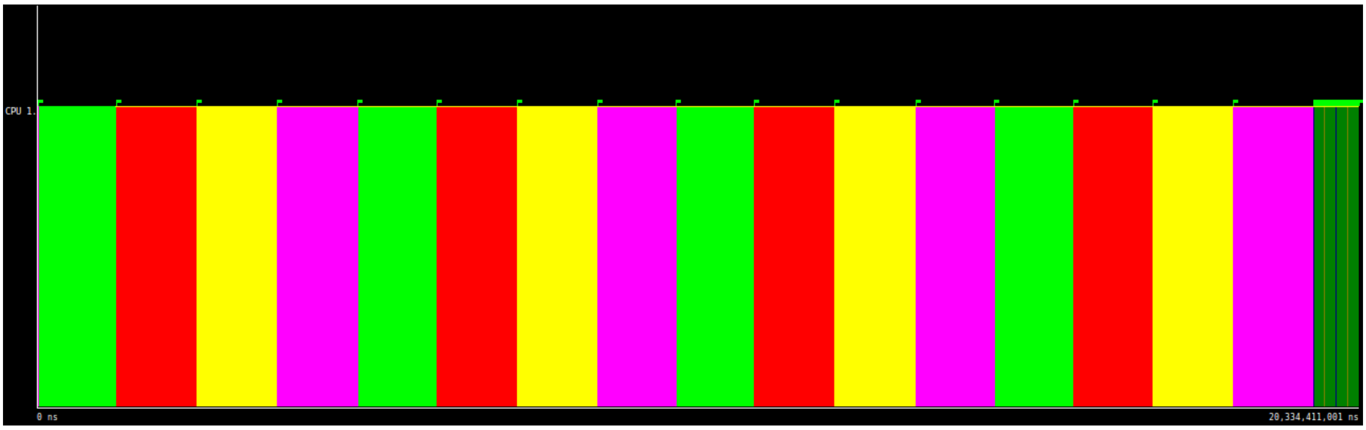
```
                                tareador_start_task("merge_multi 2");
                                merge(n/2L, &tmp[0], &tmp[n/2L], &data[0],
0, n);
                                tareador_end_task("merge_multi 2");
        } else {
                // Base case
                basicsort(n, data);
        }
}
```

multisort-tareador.c

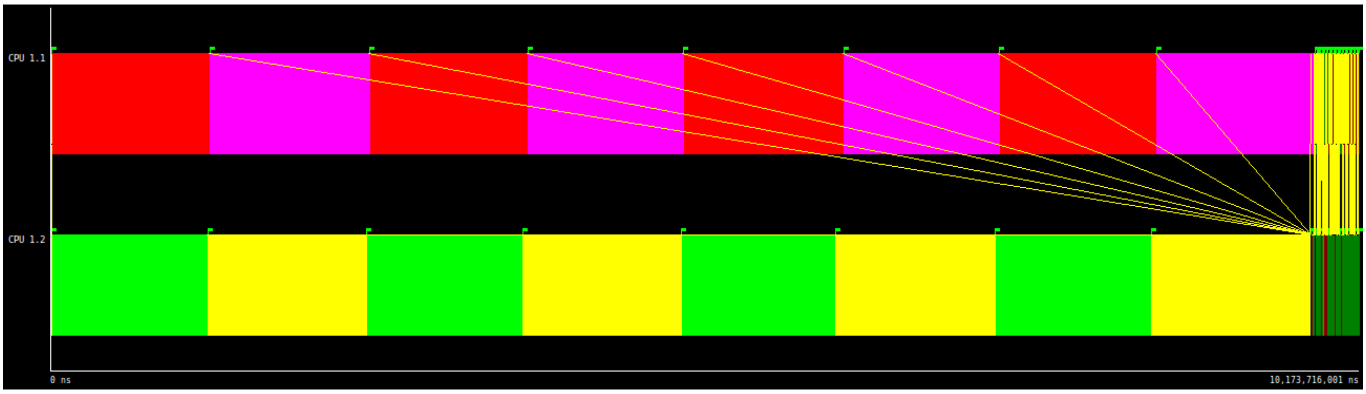
That peace of code give us the following depencence graph:



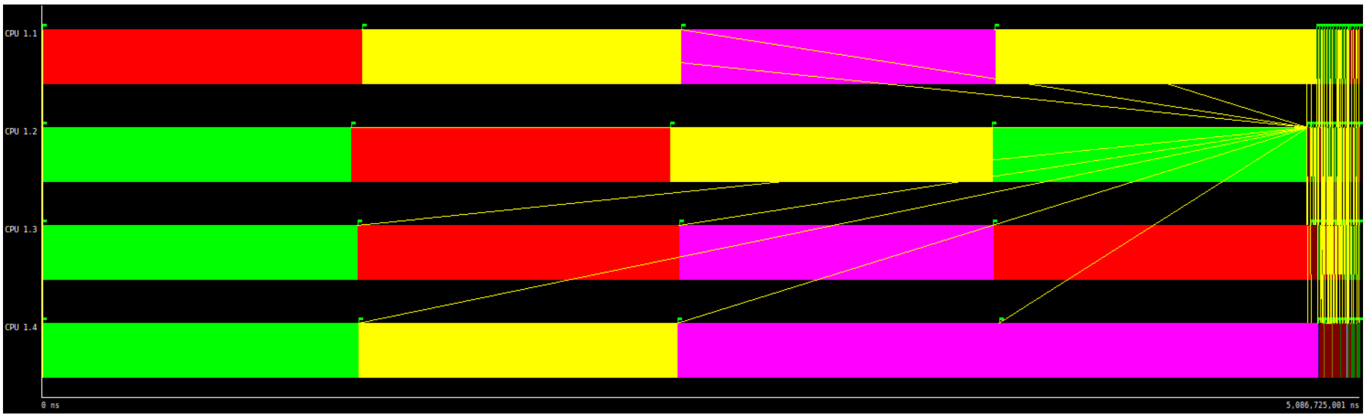
We have added a tareador task in each of the recursive tasks, to fully visualize the possible parallelizations of the code.



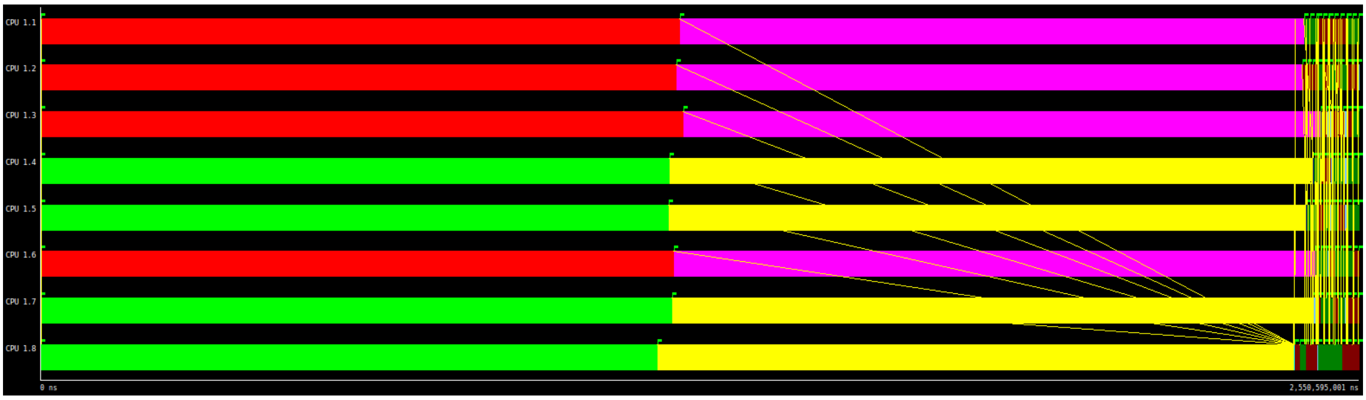
Trace of multisort-tareador using 1 core



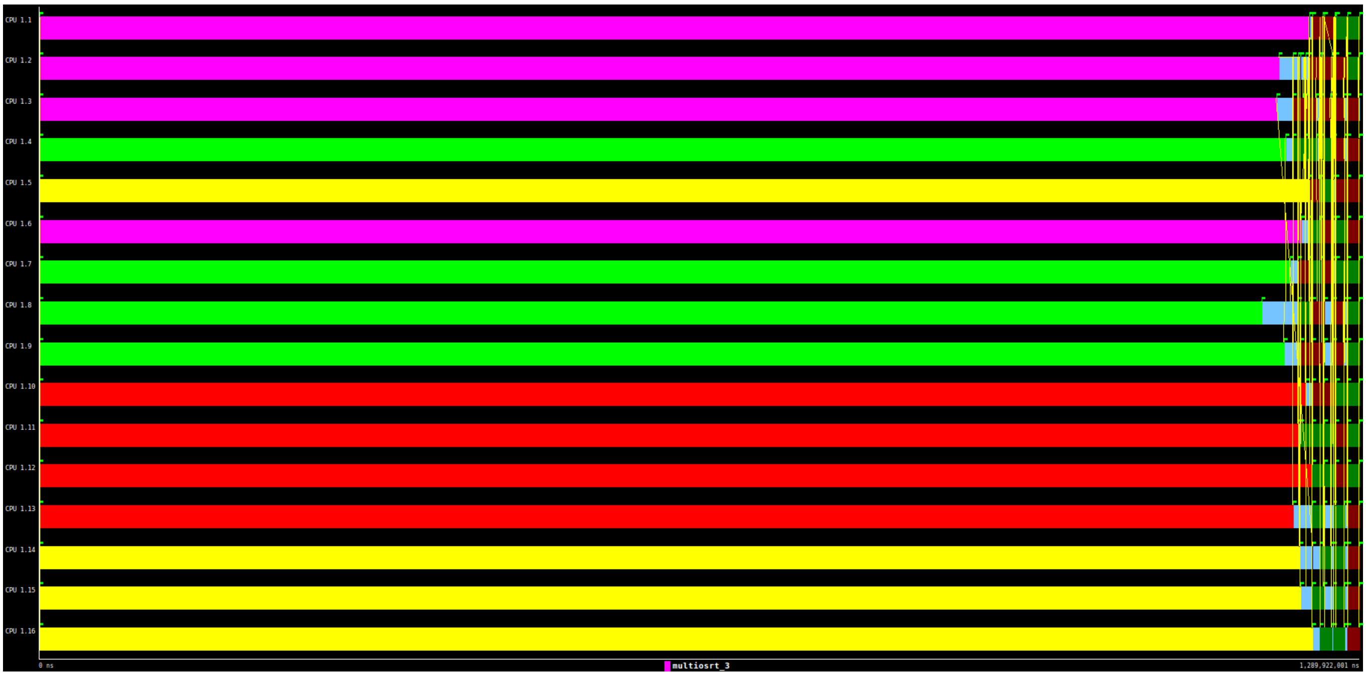
Trace of multisort-tareador using 2 core



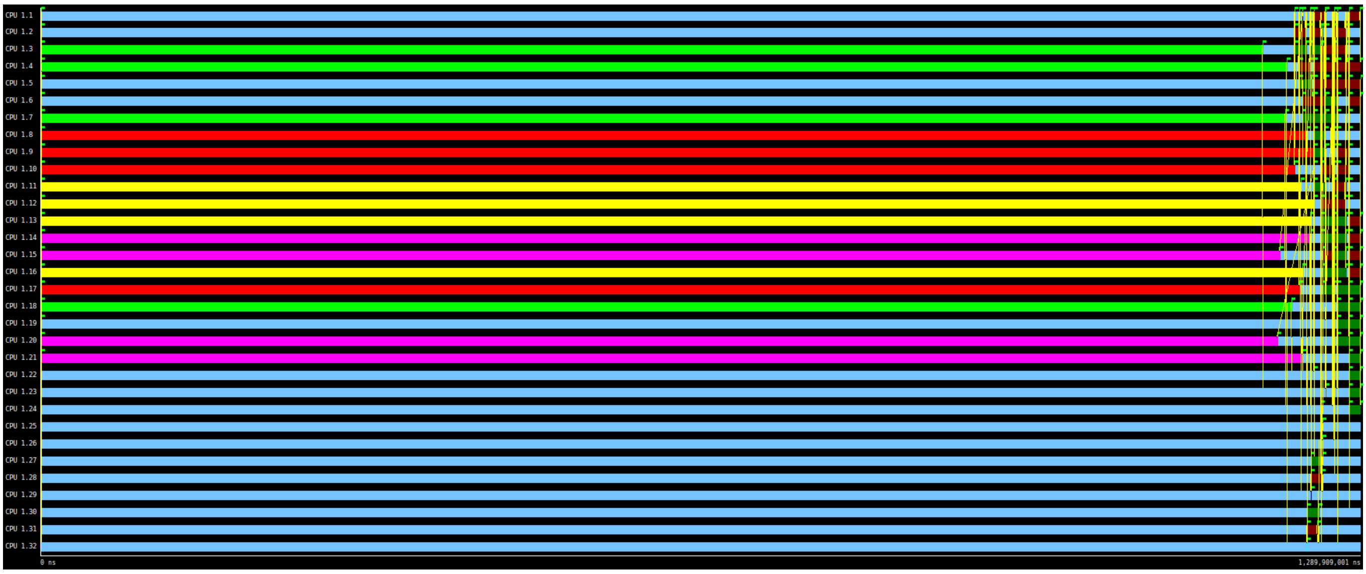
Trace of multisort-tareador using 4 core



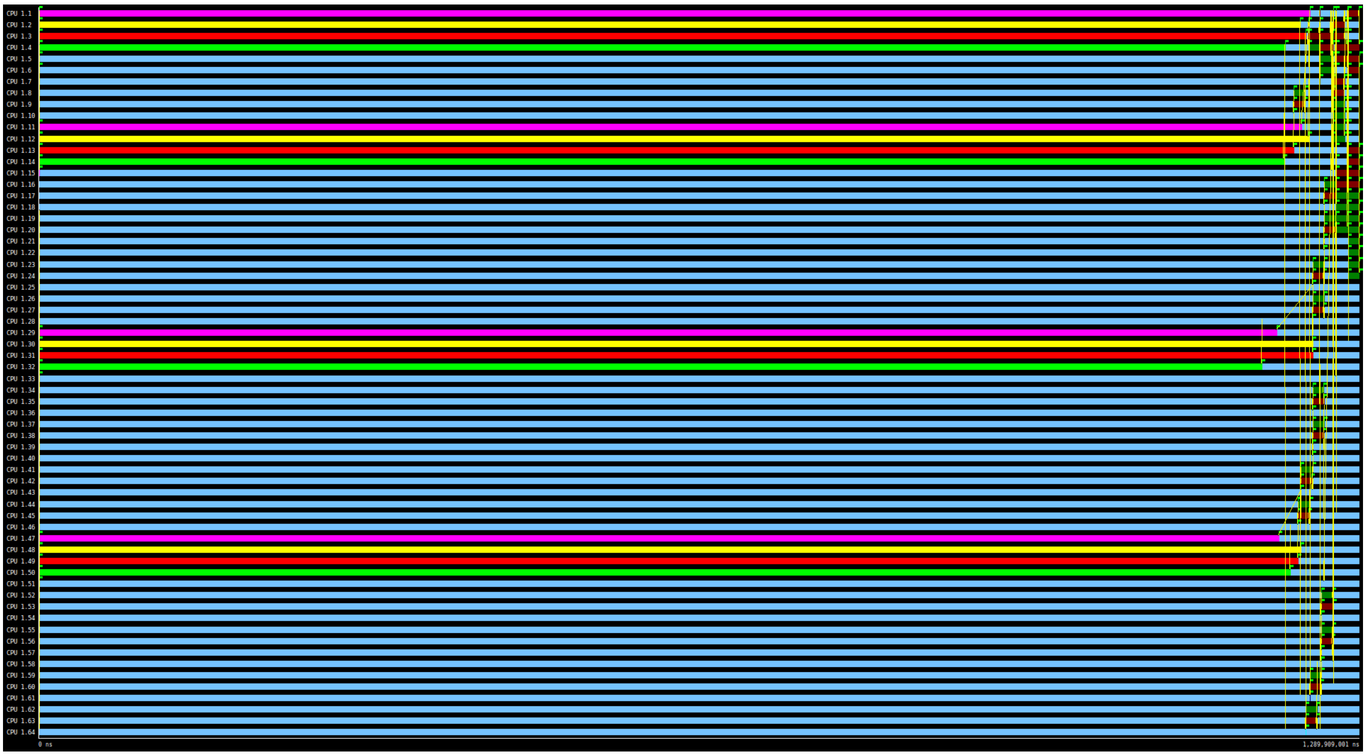
Trace of multisort-tareador using 8 core



Trace of multisort-tareador using 16 core



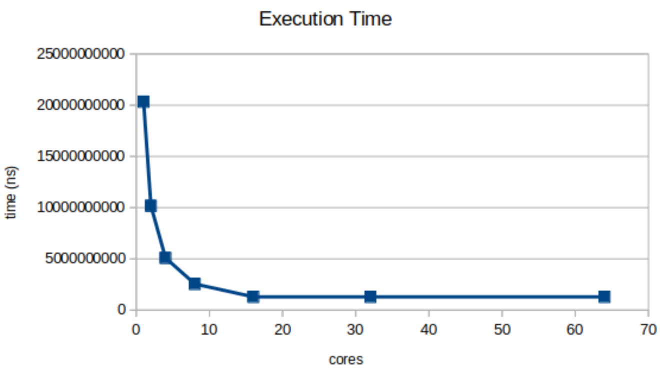
Trace of multisort-tareador using 32 core

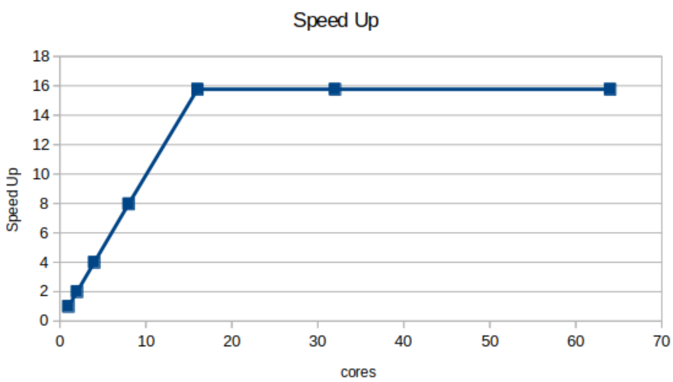


Trace of multisort-tareador using 64 core

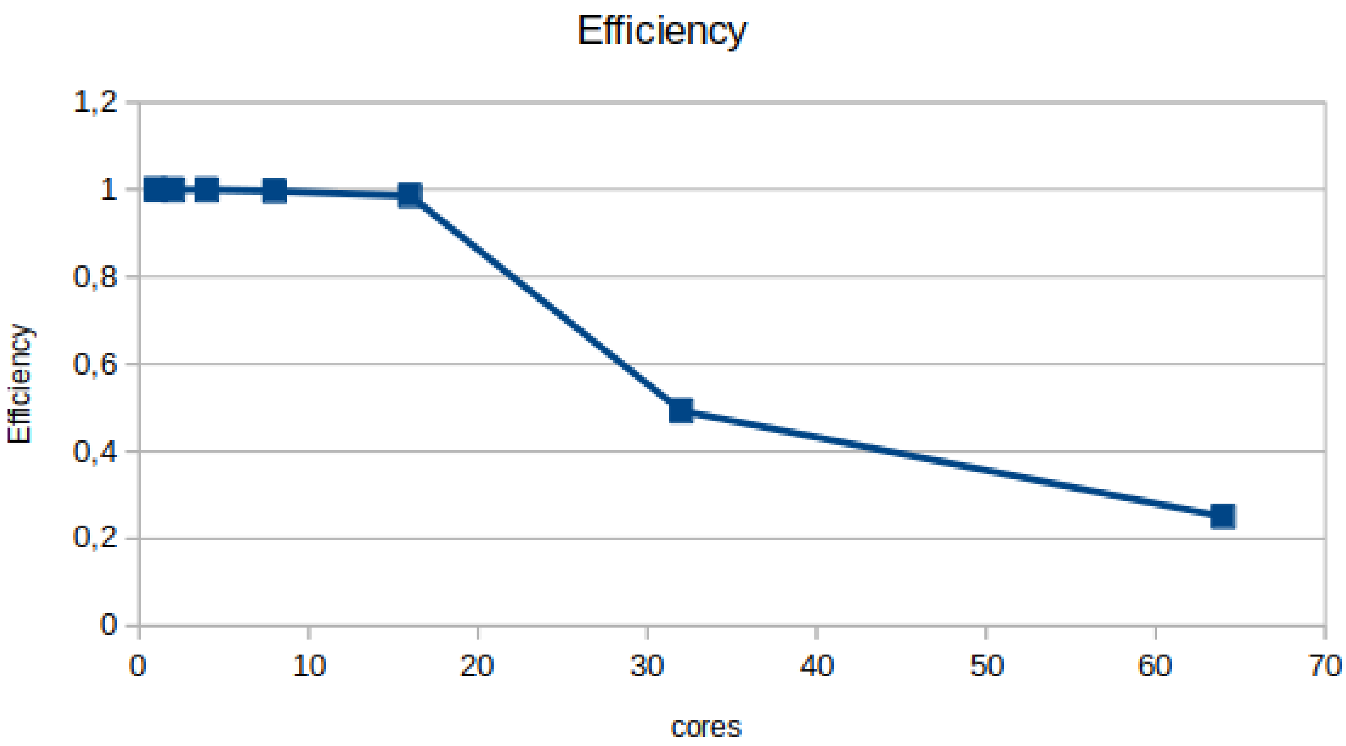
NUM CPUs	time (ns)	SPEED UP	EFFICIENCY
1	20334411001	1	0.999360066616823
2	10173716001	1.99872013323365	0.99938619627572
4	5086725001	3.99754478510288	0.99938619627572
8	2550595001	7.97241858979085	0.996552323723856
16	1289922001	15.7640624667507	0.985253904171916
32	1289909001	15.7642213406029	0.492631916893841
64	1289909001	15.7642213406029	0.246315958446921

The following pots represents number of cores vs. plot of time, speed up and efficiency, respectively.





Number of cores vs. execution time plot and number of cores vs. speed up plot.



Number of cores vs. efficiency plot.

The multisort program parallizes ideally untill 16 cores, when , the dependences between the multisort marge calls, as seen in the tareador capture of the tasks, doesn't allow for more. The efficiency drops going further than 16 threads (i.e fig: efficiency plot and 32,64 captures) Proving that adding more CPUs is pointless.

Shared-memory parallelization with OpenMP tasks

Task cut–off mechanism

Firs of all we are going to implement two versions of multisort algorithm. One using a tree strategy and another using leaf strategy.

Tree stragey code:

```
void merge(long n, T left[n], T right[n], T result[n*2], long start, long
length) {
    if (length < MIN_MERGE_SIZE*2L) {
        // Base case
        basicmerge(n, left, right, result, start, length);
    } else {
        // Recursive decomposition
        #pragma omp taskgroup
        {
            #pragma omp task
            merge(n, left, right, result, start, length/2);
            #pragma omp task
            merge(n, left, right, result, start + length/2, length/2);
        }
    }
}

void multisort(long n, T data[n], T tmp[n]) {
    if (n >= MIN_SORT_SIZE*4L)
    {
        #pragma omp taskgroup
        {
            #pragma omp task
            multisort(n/4L, &data[0], &tmp[0]);
            #pragma omp task
            multisort(n/4L, &data[n/4L], &tmp[n/4L]);
            #pragma omp task
            multisort(n/4L, &data[n/2L], &tmp[n/2L]);
            #pragma omp task
            multisort(n/4L, &data[3L*n/4L], &tmp[3L*n/4L]);
        }
        #pragma omp taskgroup
        {
            #pragma omp task
            merge(n/4L, &data[0], &data[n/4L], &tmp[0], 0, n/2L);
            #pragma omp task
            merge(n/4L, &data[n/2L], &data[3L*n/4L], &tmp[n/2L], 0, n/2L);
            //#pragma omp taskwait
        }
        #pragma omp task
        merge(n/2L, &tmp[0], &tmp[n/2L], &data[0], 0, n);
        }
```

```
    else
    {
                basicsort(n, data);
        }
}
```

multisort-omp-tree.c

	multisort	merge
THREAD 1.1.1	266	3,098
THREAD 1.1.2	259	2,956
THREAD 1.1.3	329	1,990
THREAD 1.1.4	280	2,782
THREAD 1.1.5	329	2,028
THREAD 1.1.6	294	1,812
THREAD 1.1.7	301	1,872
THREAD 1.1.8	329	1,896
Total	2,387	18,434
Average	298.38	2,304.25
Maximum	329	3,098
Minimum	259	1,812
StDev	26.87	506.70
Avg/Max	0.91	0.74

Paraver capture of number of tasks created using tree strategy

Lear stragegy code:

```
void multisort(long n, T data[n], T tmp[n]) {
        if (n >= MIN_SORT_SIZE*4L) {
                // Recursive decomposition
                multisort(n/4L, &data[0], &tmp[0]);
                multisort(n/4L, &data[n/4L], &tmp[n/4L]);
                multisort(n/4L, &data[n/2L], &tmp[n/2L]);
                multisort(n/4L, &data[3L*n/4L], &tmp[3L*n/4L]);

                merge(n/4L, &data[0], &data[n/4L], &tmp[0], 0, n/2L);
                merge(n/4L, &data[n/2L], &data[3L*n/4L], &tmp[n/2L], 0,
n/2L);

                merge(n/2L, &tmp[0], &tmp[n/2L], &data[0], 0, n);
        }
    else {
                // Base case
                #pragma omp taskgroup
                {
                        #pragma omp task
                        basicsort(n, data);
                }
                //#pragma omp taskwait
        }
}
```

multisort-omp-leaf.c

	multisort
THREAD 1.1.1	136
THREAD 1.1.2	102
THREAD 1.1.3	100
THREAD 1.1.4	167
THREAD 1.1.5	147
THREAD 1.1.6	104
THREAD 1.1.7	158
THREAD 1.1.8	110
Total	1,024
Average	128
Maximum	167
Minimum	100
StDev	25.51
Avg/Max	0.77

Paraver capture of number of tasks created using leaf strategy

For a cut-off stragegy we need to marge tree and leaf methods. Until a specified number of created tasks the program will create tasks like tree strategy, recursively. Then, when the limit is reached, the program is going to create sequentially one task for each leaf of leaf task.

Cut-off strategy code:

```
void merge(long n, T left[n], T right[n], T result[n*2], long start, long
length) {
        if (length < MIN_MERGE_SIZE*2L) {
                // Base case
                basicmerge(n, left, right, result, start, length);
        } else {
                if(NUM_TASKS < CUTOFF){
                                        #pragma omp taskgroup
                                        {
                                                NUM_TASKS++;
                                                #pragma omp task
                                                merge(n, left, right,
result, start, length/2);
                                                NUM_TASKS++;
                                                #pragma omp task
                                                merge(n, left, right,
result, start + length/2, length/2);
                                        }
                                        NUM_TASKS -= 2;
                                }
                                else{
                                        merge(n, left, right, result,
```

```
start, length/2);
                                        merge(n, left, right, result, start
+ length/2, length/2);
                                }
        }
}

void multisort(long n, T data[n], T tmp[n]) {
        if (n >= MIN_SORT_SIZE*4L) {
                // Recursive decomposition
                if(NUM_TASKS < CUTOFF){
                                        #pragma omp taskgroup
                                        {
                                                NUM_TASKS++;
                                                #pragma omp task
                                                multisort(n/4L, &data[0],
&tmp[0]);
                                                NUM_TASKS++;
                                                #pragma omp task
                                                multisort(n/4L,
&data[n/4L], &tmp[n/4L]);
                                                NUM_TASKS++;
                                                #pragma omp task
                                                multisort(n/4L,
&data[n/2L], &tmp[n/2L]);
                                                NUM_TASKS++;
                                                #pragma omp task
                                                multisort(n/4L,
&data[3L*n/4L], &tmp[3L*n/4L]);
                                        }
                                        NUM_TASKS -= 4;
                                        #pragma omp taskgroup
                                        {
                                                NUM_TASKS++;
                                                #pragma omp task
                                                merge(n/4L, &data[0],
&data[n/4L], &tmp[0], 0, n/2L);
                                                NUM_TASKS++;
                                                #pragma omp task
                                                merge(n/4L, &data[n/2L],
&data[3L*n/4L], &tmp[n/2L], 0, n/2L);
                                                //#pragma omp taskwait
                                        }
                                        NUM_TASKS -= 2;

                                        NUM_TASKS++;
                                        #pragma omp task
                                        merge(n/2L, &tmp[0], &tmp[n/2L],
&data[0], 0, n);
                                }
                                else{
                                        // Recursive decomposition
                                        multisort(n/4L, &data[0], &tmp[0]);
                                        multisort(n/4L, &data[n/4L],
```

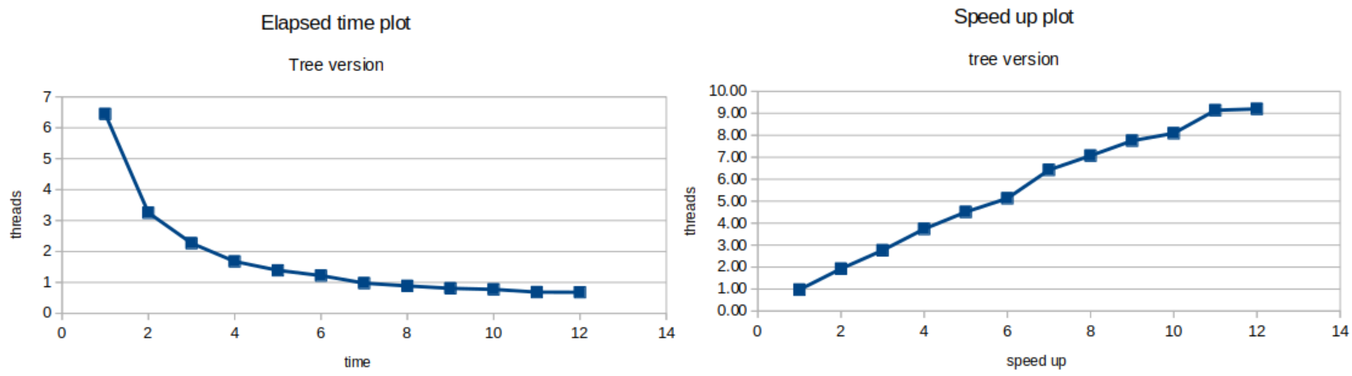
```
&tmp[n/4L]);
                                        multisort(n/4L, &data[n/2L],
&tmp[n/2L]);
                                        multisort(n/4L, &data[3L*n/4L],
&tmp[3L*n/4L]);

                                        merge(n/4L, &data[0], &data[n/4L],
&tmp[0], 0, n/2L);
                                        merge(n/4L, &data[n/2L],
&data[3L*n/4L], &tmp[n/2L], 0, n/2L);

                                        merge(n/2L, &tmp[0], &tmp[n/2L],
&data[0], 0, n);
                                }
        } else {
                if(NUM_TASKS >= CUTOFF){
                        #pragma omp task
                        basicsort(n, data);
                        #pragma omp taskwait
                }
                else{
                        basicsort(n, data);
                }
        }
}
```

multisort-omp-cutoff.c

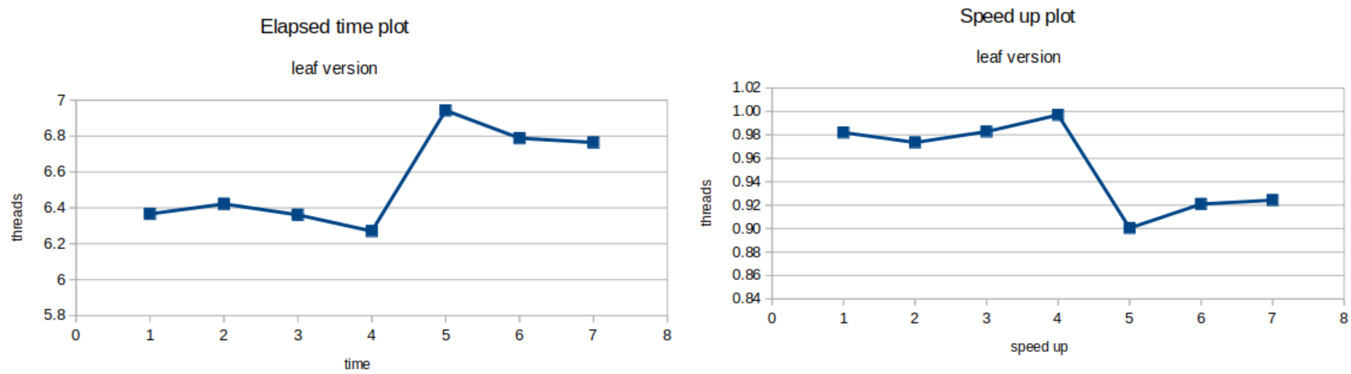
	multisort	merge
THREAD 1.1.1	263	-
THREAD 1.1.2	256	-
THREAD 1.1.3	256	2
THREAD 1.1.4	256	2
THREAD 1.1.5	-	-
THREAD 1.1.6	-	-
THREAD 1.1.7	-	-
THREAD 1.1.8	-	2
Total	1,031	6
Average	257.75	2
Maximum	263	2
Minimum	256	2
StDev	3.03	0
Avg/Max	0.98	1

Paraver capture of number of tasks created using cut-off strategy

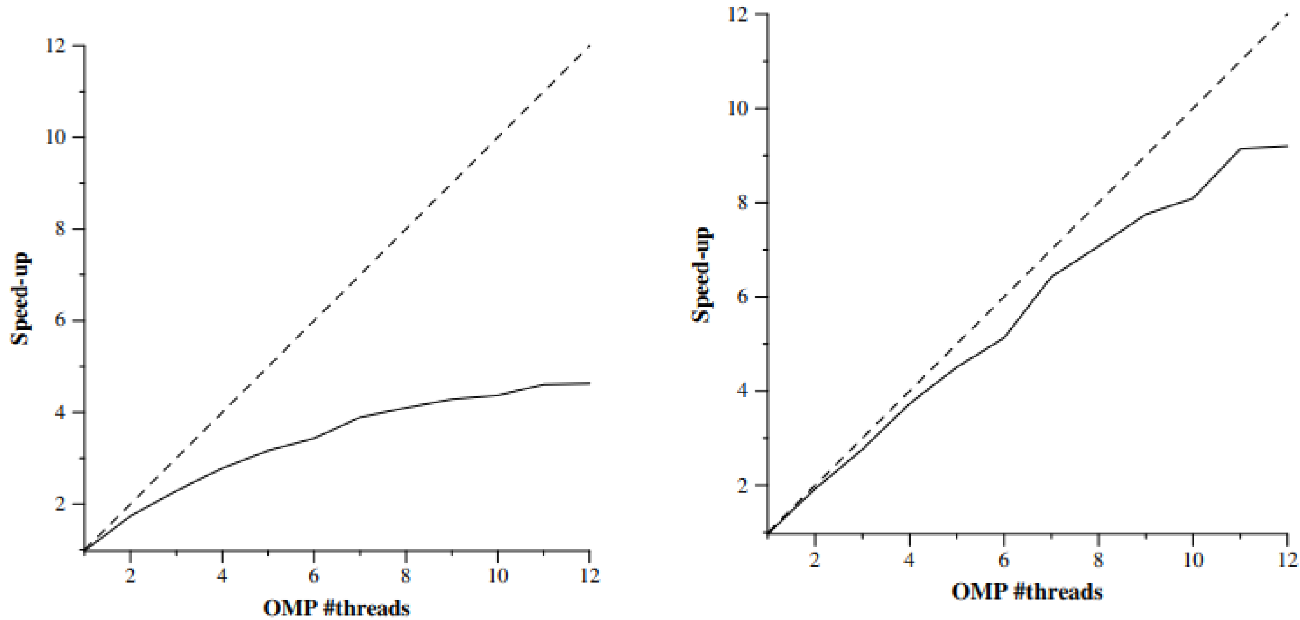
Donw bellow we are going to study the strong scalability of the three diferent versions of the multisort algorithm using cores vs time/speed up plots.



Elapsed time plot and speed up plot for tree version of multisort algorithm



Elapsed time plot and speed up plot for leaf version of multisort algorithm



PostScript plots generated by submit-cutoff.sh

We can observe that the speed up at first plot (using the execution time of the whole program) reach a limit 10 cores equal than the second plot (only using the time of multisort function). Nevertheless the scalability ratio is better on the second plot, because is where the parallelization makes higher work.

Using OpenMP task dependencies

At last, we are going to implement, based in tree strategy, a task dependence model.

```
void merge(long n, T left[n], T right[n], T result[n*2], long start, long
length) {
        if (length < MIN_MERGE_SIZE*2L) {
                // Base case
                basicmerge(n, left, right, result, start, length);
        } else {
                // Recursive decomposition
                #pragma omp taskgroup
                {
                                        #pragma omp task
                                        merge(n, left, right, result,
start, length/2);
                                        #pragma omp task
                                        merge(n, left, right, result, start
+ length/2, length/2);
                                }
        }
}

void multisort(long n, T data[n], T tmp[n]) {
        if (n >= MIN_SORT_SIZE*4L) {
                // Recursive decomposition
                #pragma omp taskgroup
                {
                                        #pragma omp task
                                        multisort(n/4L, &data[0], &tmp[0]);
                                        #pragma omp task
                                        multisort(n/4L, &data[n/4L],
&tmp[n/4L]);
                                        #pragma omp task
                                        multisort(n/4L, &data[n/2L],
&tmp[n/2L]);
                                        #pragma omp task
                                        multisort(n/4L, &data[3L*n/4L],
&tmp[3L*n/4L]);
                                }
                                #pragma omp taskgroup
                                {
                                        #pragma omp task
                                        merge(n/4L, &data[0], &data[n/4L],
&tmp[0], 0, n/2L);
                                        #pragma omp task
                                        merge(n/4L, &data[n/2L],
&data[3L*n/4L], &tmp[n/2L], 0, n/2L);
                                        //#pragma omp taskwait
                                }

                                #pragma omp task
```

```
                merge(n/2L, &tmp[0], &tmp[n/2L], &data[0], 0, n);
        } else {
                // Base case
                basicsort(n, data);
        }
}
```

multisort-omp-depencences.c

Conclusions

- Acabar explicar coses s2
  - explicar cutoff
- Fer s3
  - tot
  - opcionals
- Fer conclusió
- Acabar intro