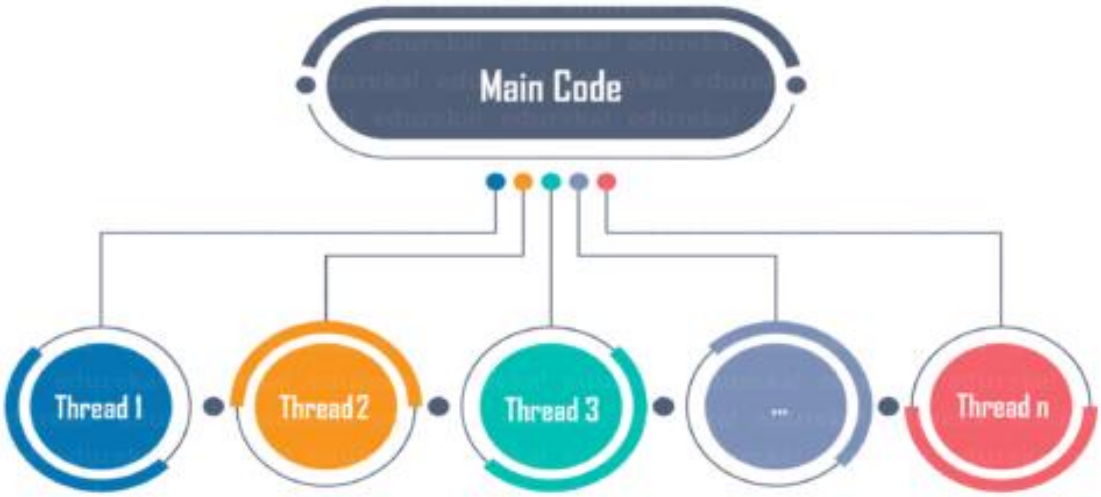
Report ContestOMP for Counting Sort Algorithm



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Sommario

Problem description

The problem is how to parallelize and evaluate performances of "**COUNTING SORT**" Algorithm, by using OpenMP.

Counting sort is a sorting algorithm for integer numerical values with linear complexity. The algorithm is based on a priori knowledge of the range in which the values to be sorted are included. It is not a comparison-based sorting algorithm.

The algorithm counts the number of occurrences of each value in the array to be sorted, storing this information in a temporary array of size equal to the range of values. The number of repetitions of the lower values indicates the position of the immediately following value.

Experimental setup

Hardware

This is the hardware configuration of the system used to run the algorithm.

CPU

```
processor   : 0
vendor_id   : GenuineIntel
cpu family  : 6
model       : 94
model name  : Intel(R) Core(TM) i7-6700K CPU @ 4.00GHz
stepping    : 3
microcode   : 0xea
cpu MHz             : 4000.000
cache size  : 8192 KB
physical id : 0
siblings    : 8
core id             : 0
cpu cores   : 4
apicid              : 0
initial apicid      : 0
fpu         : yes
fpu_exception       : yes
cpuid level : 22
wp          : yes
flags       : fpu vme de pse tsc msr pae mce cx8 apic sep mtrr pge mca cmov pat
pse36 clflush dts acpi mmx fxsr sse sse2 ss ht tm pbe syscall nx pdpe1gb rdtscp
lm constant_tsc art arch_perfmon pebs bts rep_good nopl xtopology nonstop_tsc
cpuid aperfmperf pni pclmulqdq dtes64 monitor ds_cpl vmx est tm2 ssse3 sdbg fma
cx16 xtpr pdcm pcid sse4_1 sse4_2 x2apic movbe popcnt tsc_deadline_timer aes xsave
avx f16c rdrand lahf_lm abm 3dnowprefetch cpuid_fault epb invpcid_single pti ssbd
ibrs ibpb stibp tpr_shadow vnmi flexpriority ept vpid ept_ad fsgsbase tsc_adjust
bmi1 hle avx2 smep bmi2 erms invpcid rtm mpx rdseed adx smap clflushopt intel_pt
xsaveopt xsavec xgetbv1 xsaves dtherm ida arat pln pts hwp hwp_notify
hwp_act_window hwp_epp md_clear flush_l1d
```

```
vmx flags   : vnmi preemption_timer invvpid ept_x_only ept_ad ept_1gb flexpriority
tsc_offset vtpr mtf vapic ept vpid unrestricted_guest ple shadow_vmcs pml
bugs        : cpu_meltdown spectre_v1 spectre_v2 spec_store_bypass l1tf mds swapgs
taa itlb_multihit srbds
bogomips    : 7999.96
clflush size      : 64
cache_alignment   : 64
address sizes     : 39 bits physical, 48 bits virtual
power management:

processor   : 1
vendor_id   : GenuineIntel
cpu family  : 6
model       : 94
model name  : Intel(R) Core(TM) i7-6700K CPU @ 4.00GHz
stepping    : 3
microcode   : 0xea
cpu MHz           : 3782.217
cache size  : 8192 KB
physical id : 0
siblings    : 8
core id           : 1
cpu cores   : 4
apicid            : 2
initial apicid    : 2
fpu         : yes
fpu_exception     : yes
cpuid level : 22
wp          : yes
flags       : fpu vme de pse tsc msr pae mce cx8 apic sep mtrr pge mca cmov pat
pse36 clflush dts acpi mmx fxsr sse sse2 ss ht tm pbe syscall nx pdpe1gb rdtscp
lm constant_tsc art arch_perfmon pebs bts rep_good nopl xtopology nonstop_tsc
cpuid aperfmperf pni pclmulqdq dtes64 monitor ds_cpl vmx est tm2 ssse3 sdbg fma
cx16 xtpr pdcm pcid sse4_1 sse4_2 x2apic movbe popcnt tsc_deadline_timer aes xsave
avx f16c rdrand lahf_lm abm 3dnowprefetch cpuid_fault epb invpcid_single pti ssbd
ibrs ibpb stibp tpr_shadow vnmi flexpriority ept vpid ept_ad fsgsbase tsc_adjust
bmi1 hle avx2 smep bmi2 erms invpcid rtm mpx rdseed adx smap clflushopt intel_pt
xsaveopt xsavec xgetbv1 xsaves dtherm ida arat pln pts hwp hwp_notify
hwp_act_window hwp_epp md_clear flush_l1d
vmx flags   : vnmi preemption_timer invvpid ept_x_only ept_ad ept_1gb flexpriority
tsc_offset vtpr mtf vapic ept vpid unrestricted_guest ple shadow_vmcs pml
bugs        : cpu_meltdown spectre_v1 spectre_v2 spec_store_bypass l1tf mds swapgs
taa itlb_multihit srbds
bogomips    : 7999.96
clflush size      : 64
cache_alignment   : 64
address sizes     : 39 bits physical, 48 bits virtual
power management:

processor   : 2
vendor_id   : GenuineIntel
cpu family  : 6
model       : 94
model name  : Intel(R) Core(TM) i7-6700K CPU @ 4.00GHz
stepping    : 3
```

```
microcode   : 0xea
cpu MHz         : 3649.101
cache size  : 8192 KB
physical id : 0
siblings    : 8
core id         : 2
cpu cores   : 4
apicid          : 4
initial apicid  : 4
fpu         : yes
fpu_exception   : yes
cpuid level : 22
wp          : yes
flags       : fpu vme de pse tsc msr pae mce cx8 apic sep mtrr pge mca cmov pat
pse36 clflush dts acpi mmx fxsr sse sse2 ss ht tm pbe syscall nx pdpe1gb rdtscp
lm constant_tsc art arch_perfmon pebs bts rep_good nopl xtopology nonstop_tsc
cpuid aperfmperf pni pclmulqdq dtes64 monitor ds_cpl vmx est tm2 ssse3 sdbg fma
cx16 xtpr pdcm pcid sse4_1 sse4_2 x2apic movbe popcnt tsc_deadline_timer aes xsave
avx f16c rdrand lahf_lm abm 3dnowprefetch cpuid_fault epb invpcid_single pti ssbd
ibrs ibpb stibp tpr_shadow vnmi flexpriority ept vpid ept_ad fsgsbase tsc_adjust
bmi1 hle avx2 smep bmi2 erms invpcid rtm mpx rdseed adx smap clflushopt intel_pt
xsaveopt xsavec xgetbv1 xsaves dtherm ida arat pln pts hwp hwp_notify
hwp_act_window hwp_epp md_clear flush_l1d
vmx flags   : vnmi preemption_timer invvpid ept_x_only ept_ad ept_1gb flexpriority
tsc_offset vtpr mtf vapic ept vpid unrestricted_guest ple shadow_vmcs pml
bugs        : cpu_meltdown spectre_v1 spectre_v2 spec_store_bypass l1tf mds swapgs
taa itlb_multihit srbds
bogomips    : 7999.96
clflush size    : 64
cache_alignment   : 64
address sizes     : 39 bits physical, 48 bits virtual
power management:

processor   : 3
vendor_id   : GenuineIntel
cpu family  : 6
model       : 94
model name  : Intel(R) Core(TM) i7-6700K CPU @ 4.00GHz
stepping    : 3
microcode   : 0xea
cpu MHz         : 3712.994
cache size  : 8192 KB
physical id : 0
siblings    : 8
core id         : 3
cpu cores   : 4
apicid          : 6
initial apicid  : 6
fpu         : yes
fpu_exception   : yes
cpuid level : 22
wp          : yes
flags       : fpu vme de pse tsc msr pae mce cx8 apic sep mtrr pge mca cmov pat
pse36 clflush dts acpi mmx fxsr sse sse2 ss ht tm pbe syscall nx pdpe1gb rdtscp
lm constant_tsc art arch_perfmon pebs bts rep_good nopl xtopology nonstop_tsc
```

```
cpuid aperfmperf pni pclmulqdq dtes64 monitor ds_cpl vmx est tm2 ssse3 sdbg fma
cx16 xtpr pdcm pcid sse4_1 sse4_2 x2apic movbe popcnt tsc_deadline_timer aes xsave
avx f16c rdrand lahf_lm abm 3dnowprefetch cpuid_fault epb invpcid_single pti ssbd
ibrs ibpb stibp tpr_shadow vnmi flexpriority ept vpid ept_ad fsgsbase tsc_adjust
bmi1 hle avx2 smep bmi2 erms invpcid rtm mpx rdseed adx smap clflushopt intel_pt
xsaveopt xsavec xgetbv1 xsaves dtherm ida arat pln pts hwp hwp_notify
hwp_act_window hwp_epp md_clear flush_l1d
vmx flags   : vnmi preemption_timer invvpid ept_x_only ept_ad ept_1gb flexpriority
tsc_offset vtpr mtf vapic ept vpid unrestricted_guest ple shadow_vmcs pml
bugs        : cpu_meltdown spectre_v1 spectre_v2 spec_store_bypass l1tf mds swapgs
taa itlb_multihit srbds
bogomips    : 7999.96
clflush size      : 64
cache_alignment   : 64
address sizes     : 39 bits physical, 48 bits virtual
power management:

processor   : 4
vendor_id   : GenuineIntel
cpu family  : 6
model       : 94
model name  : Intel(R) Core(TM) i7-6700K CPU @ 4.00GHz
stepping    : 3
microcode   : 0xea
cpu MHz           : 3285.560
cache size  : 8192 KB
physical id : 0
siblings    : 8
core id           : 0
cpu cores   : 4
apicid            : 1
initial apicid    : 1
fpu         : yes
fpu_exception     : yes
cpuid level : 22
wp          : yes
flags       : fpu vme de pse tsc msr pae mce cx8 apic sep mtrr pge mca cmov pat
pse36 clflush dts acpi mmx fxsr sse sse2 ss ht tm pbe syscall nx pdpe1gb rdtscp
lm constant_tsc art arch_perfmon pebs bts rep_good nopl xtopology nonstop_tsc
cpuid aperfmperf pni pclmulqdq dtes64 monitor ds_cpl vmx est tm2 ssse3 sdbg fma
cx16 xtpr pdcm pcid sse4_1 sse4_2 x2apic movbe popcnt tsc_deadline_timer aes xsave
avx f16c rdrand lahf_lm abm 3dnowprefetch cpuid_fault epb invpcid_single pti ssbd
ibrs ibpb stibp tpr_shadow vnmi flexpriority ept vpid ept_ad fsgsbase tsc_adjust
bmi1 hle avx2 smep bmi2 erms invpcid rtm mpx rdseed adx smap clflushopt intel_pt
xsaveopt xsavec xgetbv1 xsaves dtherm ida arat pln pts hwp hwp_notify
hwp_act_window hwp_epp md_clear flush_l1d
vmx flags   : vnmi preemption_timer invvpid ept_x_only ept_ad ept_1gb flexpriority
tsc_offset vtpr mtf vapic ept vpid unrestricted_guest ple shadow_vmcs pml
bugs        : cpu_meltdown spectre_v1 spectre_v2 spec_store_bypass l1tf mds swapgs
taa itlb_multihit srbds
bogomips    : 7999.96
clflush size      : 64
cache_alignment   : 64
address sizes     : 39 bits physical, 48 bits virtual
power management:
```

```
processor   : 5
vendor_id   : GenuineIntel
cpu family  : 6
model       : 94
model name  : Intel(R) Core(TM) i7-6700K CPU @ 4.00GHz
stepping    : 3
microcode   : 0xea
cpu MHz         : 4000.000
cache size  : 8192 KB
physical id : 0
siblings    : 8
core id         : 1
cpu cores   : 4
apicid          : 3
initial apicid  : 3
fpu         : yes
fpu_exception   : yes
cpuid level : 22
wp          : yes
flags       : fpu vme de pse tsc msr pae mce cx8 apic sep mtrr pge mca cmov pat
pse36 clflush dts acpi mmx fxsr sse sse2 ss ht tm pbe syscall nx pdpe1gb rdtscp
lm constant_tsc art arch_perfmon pebs bts rep_good nopl xtopology nonstop_tsc
cpuid aperfmperf pni pclmulqdq dtes64 monitor ds_cpl vmx est tm2 ssse3 sdbg fma
cx16 xtpr pdcm pcid sse4_1 sse4_2 x2apic movbe popcnt tsc_deadline_timer aes xsave
avx f16c rdrand lahf_lm abm 3dnowprefetch cpuid_fault epb invpcid_single pti ssbd
ibrs ibpb stibp tpr_shadow vnmi flexpriority ept vpid ept_ad fsgsbase tsc_adjust
bmi1 hle avx2 smep bmi2 erms invpcid rtm mpx rdseed adx smap clflushopt intel_pt
xsaveopt xsavec xgetbv1 xsaves dtherm ida arat pln pts hwp hwp_notify
hwp_act_window hwp_epp md_clear flush_l1d
vmx flags   : vnmi preemption_timer invvpid ept_x_only ept_ad ept_1gb flexpriority
tsc_offset vtpr mtf vapic ept vpid unrestricted_guest ple shadow_vmcs pml
bugs        : cpu_meltdown spectre_v1 spectre_v2 spec_store_bypass l1tf mds swapgs
taa itlb_multihit srbds
bogomips    : 7999.96
clflush size      : 64
cache_alignment   : 64
address sizes     : 39 bits physical, 48 bits virtual
power management:

processor   : 6
vendor_id   : GenuineIntel
cpu family  : 6
model       : 94
model name  : Intel(R) Core(TM) i7-6700K CPU @ 4.00GHz
stepping    : 3
microcode   : 0xea
cpu MHz         : 4000.000
cache size  : 8192 KB
physical id : 0
siblings    : 8
core id         : 2
cpu cores   : 4
apicid          : 5
initial apicid  : 5
```

```
fpu         : yes
fpu_exception     : yes
cpuid level : 22
wp          : yes
flags       : fpu vme de pse tsc msr pae mce cx8 apic sep mtrr pge mca cmov pat
pse36 clflush dts acpi mmx fxsr sse sse2 ss ht tm pbe syscall nx pdpe1gb rdtscp
lm constant_tsc art arch_perfmon pebs bts rep_good nopl xtopology nonstop_tsc
cpuid aperfmperf pni pclmulqdq dtes64 monitor ds_cpl vmx est tm2 ssse3 sdbg fma
cx16 xtpr pdcm pcid sse4_1 sse4_2 x2apic movbe popcnt tsc_deadline_timer aes xsave
avx f16c rdrand lahf_lm abm 3dnowprefetch cpuid_fault epb invpcid_single pti ssbd
ibrs ibpb stibp tpr_shadow vnmi flexpriority ept vpid ept_ad fsgsbase tsc_adjust
bmi1 hle avx2 smep bmi2 erms invpcid rtm mpx rdseed adx smap clflushopt intel_pt
xsaveopt xsavec xgetbv1 xsaves dtherm ida arat pln pts hwp hwp_notify
hwp_act_window hwp_epp md_clear flush_l1d
vmx flags   : vnmi preemption_timer invvpid ept_x_only ept_ad ept_1gb flexpriority
tsc_offset vtpr mtf vapic ept vpid unrestricted_guest ple shadow_vmcs pml
bugs        : cpu_meltdown spectre_v1 spectre_v2 spec_store_bypass l1tf mds swapgs
taa itlb_multihit srbds
bogomips    : 7999.96
clflush size      : 64
cache_alignment   : 64
address sizes     : 39 bits physical, 48 bits virtual
power management:

processor   : 7
vendor_id   : GenuineIntel
cpu family  : 6
model       : 94
model name  : Intel(R) Core(TM) i7-6700K CPU @ 4.00GHz
stepping    : 3
microcode   : 0xea
cpu MHz           : 4000.000
cache size  : 8192 KB
physical id : 0
siblings    : 8
core id           : 3
cpu cores   : 4
apicid            : 7
initial apicid    : 7
fpu         : yes
fpu_exception     : yes
cpuid level : 22
wp          : yes
flags       : fpu vme de pse tsc msr pae mce cx8 apic sep mtrr pge mca cmov pat
pse36 clflush dts acpi mmx fxsr sse sse2 ss ht tm pbe syscall nx pdpe1gb rdtscp
lm constant_tsc art arch_perfmon pebs bts rep_good nopl xtopology nonstop_tsc
cpuid aperfmperf pni pclmulqdq dtes64 monitor ds_cpl vmx est tm2 ssse3 sdbg fma
cx16 xtpr pdcm pcid sse4_1 sse4_2 x2apic movbe popcnt tsc_deadline_timer aes xsave
avx f16c rdrand lahf_lm abm 3dnowprefetch cpuid_fault epb invpcid_single pti ssbd
ibrs ibpb stibp tpr_shadow vnmi flexpriority ept vpid ept_ad fsgsbase tsc_adjust
bmi1 hle avx2 smep bmi2 erms invpcid rtm mpx rdseed adx smap clflushopt intel_pt
xsaveopt xsavec xgetbv1 xsaves dtherm ida arat pln pts hwp hwp_notify
hwp_act_window hwp_epp md_clear flush_l1d
vmx flags   : vnmi preemption_timer invvpid ept_x_only ept_ad ept_1gb flexpriority
tsc_offset vtpr mtf vapic ept vpid unrestricted_guest ple shadow_vmcs pml
```

```
bugs        : cpu_meltdown spectre_v1 spectre_v2 spec_store_bypass l1tf mds swapgs
taa itlb_multihit srbds
bogomips    : 7999.96
clflush size      : 64
cache_alignment   : 64
address sizes     : 39 bits physical, 48 bits virtual
power management:
```

MEM

```
MemTotal:       32814448 kB
MemFree:        29286960 kB
MemAvailable:   30341472 kB
Buffers:           76664 kB
Cached:          1514944 kB
SwapCached:            0 kB
Active:           736452 kB
Inactive:        2380884 kB
Active(anon):      83584 kB
Inactive(anon):  1655448 kB
Active(file):     652868 kB
Inactive(file):   725436 kB
Unevictable:          48 kB
Mlocked:              48 kB
SwapTotal:             0 kB
SwapFree:              0 kB
Dirty:               132 kB
Writeback:             0 kB
AnonPages:       1525956 kB
Mapped:           593820 kB
Shmem:            214492 kB
KReclaimable:      88204 kB
Slab:             196208 kB
SReclaimable:      88204 kB
SUnreclaim:       108004 kB
KernelStack:       14480 kB
PageTables:        31664 kB
NFS_Unstable:          0 kB
Bounce:                0 kB
WritebackTmp:          0 kB
CommitLimit:    16407224 kB
Committed_AS:    9900640 kB
VmallocTotal:   34359738367 kB
VmallocUsed:       72716 kB
VmallocChunk:          0 kB
Percpu:             7264 kB
HardwareCorrupted:     0 kB
AnonHugePages:         0 kB
ShmemHugePages:        0 kB
ShmemPmdMapped:        0 kB
FileHugePages:         0 kB
FilePmdMapped:         0 kB
HugePages_Total:       0
HugePages_Free:        0
```

```
HugePages_Rsvd:        0
HugePages_Surp:        0
Hugepagesize:       2048 kB
Hugetlb:               0 kB
DirectMap4k:      361100 kB
DirectMap2M:     3770368 kB
DirectMap1G:    29360128 kB
```

Software

This is the software configuration of the system used to run the algorithm.

OPERATIVE SYSTEM: Ubuntu 21.10

GCC version: 11.2.0

Performance, Speedup & Efficiency

This section is about two different implementations of Counting Sort that have linear time complexity.

- **Case Study 1**: The first version of the algorithm has a non-parallelized part which is the actual sorting
- **Case Study 2**: The second version of the algorithm has a non-parallelized part which is the sum of the occurrences of the previous elements

In the following section it is illustrated the behavior of both to understand which version of the algorithm manages to achieve the best performance when they are parallelized

Case Study 1

In this case study (**ProjectCountingSortFinal1** folder), the main purpose is to analyze the performance of our program in the following build setup:

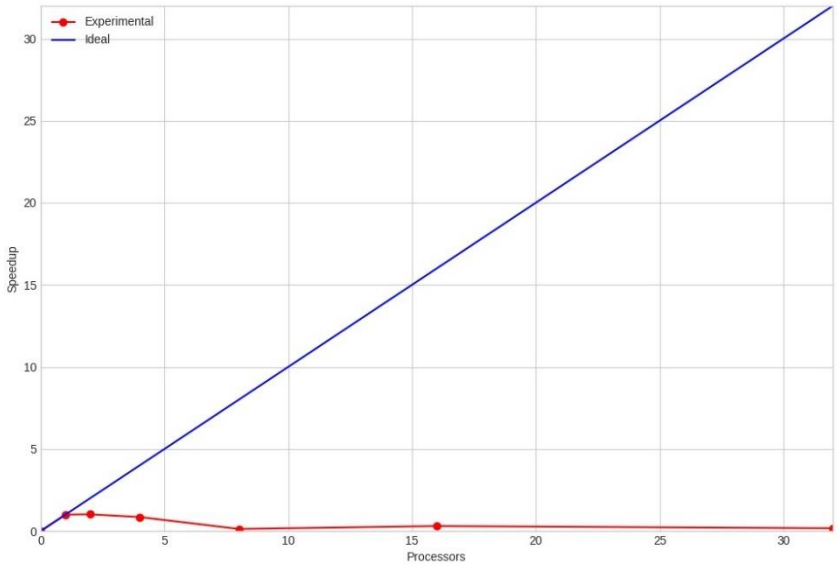
- The sequential version of the first version of the algorithm is compiled with the gcc optimization -Ox where x = 0,1,2,3
- The parallel program is compiled with the gcc optimization -Ox where x = 0,1,2,3

The compilation with -O0 means without optimization.

Here we want to highlight the difference between a simple sequential program compared to a parallel one, furthermore the case study is done on multiple size that are 5000, 100000, 10000000 and with different number of threads (0, 1, 2, 4, 8, 16, 32). We consider the maximum value inserted in the array to be ordered as 100000.

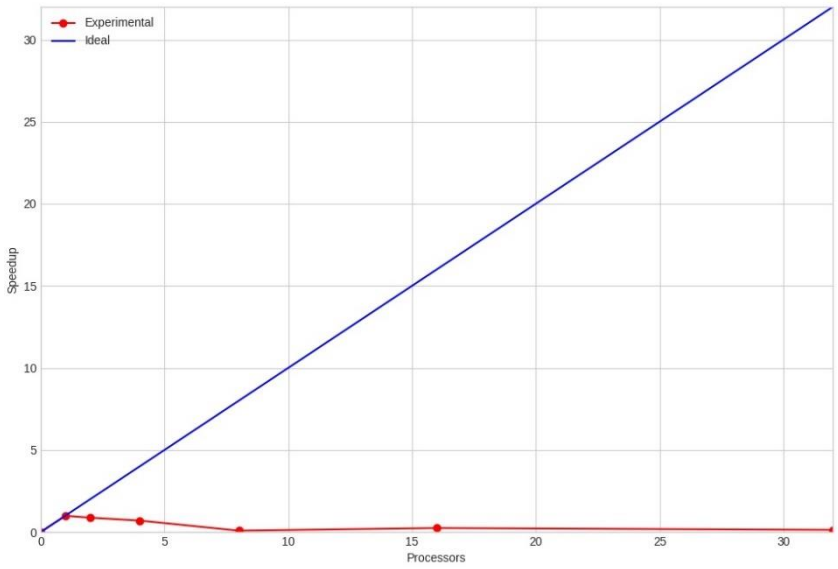
Size-5000-Max-100000-O0

Version	Threads	TimeInt	User	Sys	Real	Speedup	Efficiency
Serial	1	0.0007577388888888889	0.0010000000000000005	0.0	0.0010000000000000002	1.0	1.0
Parallel	1	0.0007572941176470589	0.0010000000000000005	0.0	0.0010000000000000002	1.0005873163827318	1.0005873163827318
Parallel	2	0.0007459898989899	0.0020465116279069773	0.0	0.0012626262626262 6263	1.0157495294707053	0.5078747647353526
Parallel	4	0.0008919128205128205	0.0040930232558139545	2.312138728323699 6e-05	0.0020102564102564411	0.8495660915079 28	0.2123915228769 82
Parallel	8	0.0061261666666666666	0.0412792207792207 84	0.0003798882681564 2463	0.0089565217391304 34	0.1236889118625 9308	0.0154611139828 24135
Parallel	16	0.0025197070707070703	0.0081125	0.0003562499999999 99996	0.0036683417085427144	0.3007249920826135	0.0187953120051 63343
Parallel	32	0.0045684687 5	0.0131151515151515 1515	0.0024727272727272 2727	0.0060648648648648 64864	0.1658627716100 4745	0.0051832116128 13983



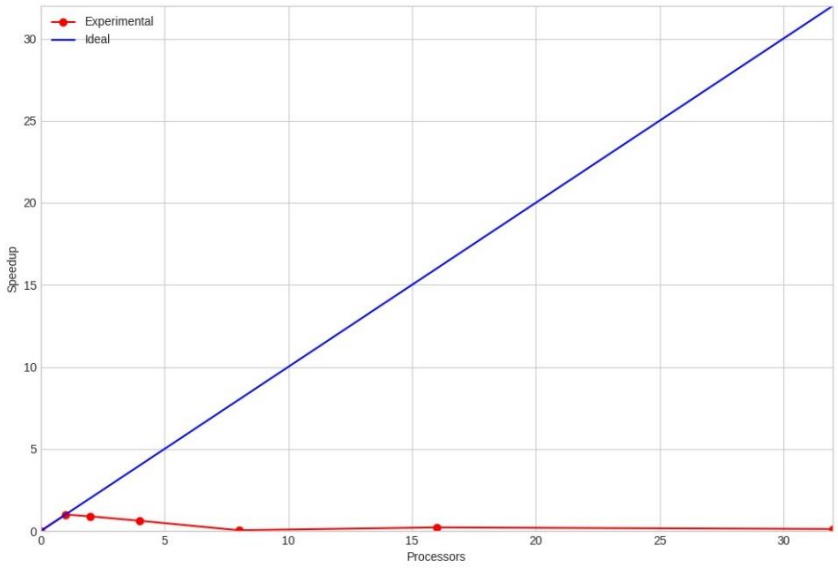
Size-5000-Max-100000-O1

Version	Threads	TimeInt	User	Sys	Real	Speedup	Efficiency
Serial	1	0.0004920053191489362	0.0010000000000000002	0.0	0.0010000000000000002	1.0	1.0
Parallel	1	0.0004981851851851852	0.0010000000000000002	0.0	0.0010000000000000002	0.9875952432548717	0.9875952432548717
Parallel	2	0.0005637121212121211	0.0019822485207100595	0.0	0.0010606060606061	0.8727953518029978	0.436397675901489
Parallel	4	0.0007070979381443 3	0.0033699421965317925	0.0	0.0012628865979381447	0.6958092968565693	0.17395232421414233
Parallel	8	0.0060569572192513375	0.0449764705882353	0.0004943181818181818	0.006994652406417111	0.08122978276702274	0.010153722845877842
Parallel	16	0.0020396734693877553	0.0074315068493150 68	0.0005136986301369864	0.0030684210526315788	0.24121768828842025	0.015076105518026265
Parallel	32	0.0038248505154 63917	0.0099333333333333334	0.005876404494382022	0.00528125	0.12863386873807298	0.004019808398064 7805



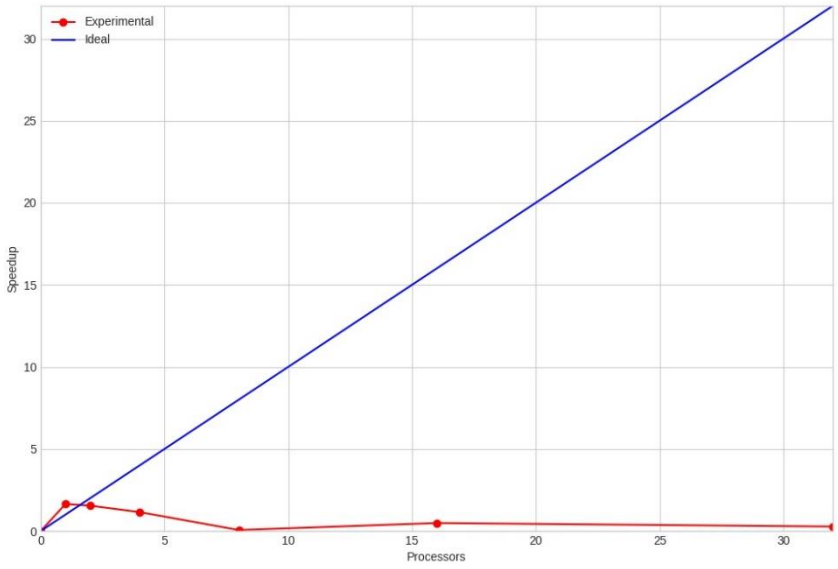
Size-5000-Max-100000-O2

Version	Threads	TimeInt	User	Sys	Real	Speedup	Efficiency
Serial	1	0.000430364 64088397786	0.00100000000 00000002	0.0	0.0010000000000 000002	1.0	1.0
Parallel	1	0.000428590 1639344262	0.00100000000 00000002	0.0	0.0010000000000 000002	1.00414026522 04197	1.0041402652204 197
Parallel	2	0.000482242 4242424243	0.00200000000 00000005	0.0	0.0010000000000 000002	0.89242385001 70458	0.4462119250085 229
Parallel	4	0.000690591 8367346938	0.00284693877 55102045	1.21951219512195 13e-05	0.0011897435897 4359	0.62318234591 1963	0.1557955864779 9074
Parallel	8	0.009727029 411764706	0.06489855072 463768	0.00041081081081 081086	0.0105259259259 25926	0.04424420063 575195	0.0055305250794 689936
Parallel	16	0.001970593 9086294413	0.00645323741 0071942	0.00051677852348 9933	0.0030414507772 02073	0.21839336811 068233	0.0136495855069 17646
Parallel	32	0.003620907 216494845	0.00996478873 2394366	0.00662857142857 143	0.0050756756756 75675	0.11885547327 020014	0.0037142335396 937545



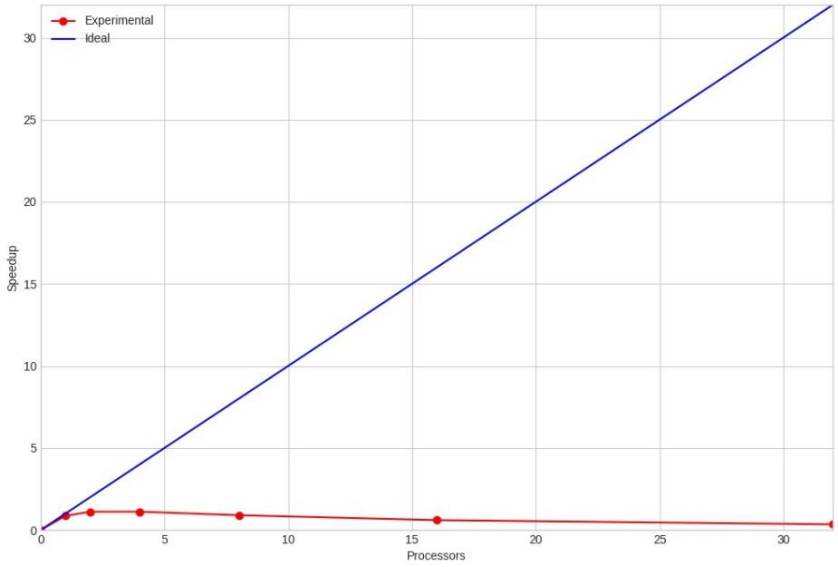
Size-5000-Max-100000-O3

Version	Threads	TimeInt	User	Sys	Real	Speedup	Efficiency
Serial	1	0.0006597575757575757	0.001612903225806452	9.696969696969698e-05	0.002000000000000005	1.0	1.0
Parallel	1	0.0004010163043478260	0.001000000000000002	0.0	0.001000000000000002	1.6452138444359297	1.6452138444359297
Parallel	2	0.0004276884422110552	0.001908045977011494	0.0	0.001005025125628141	1.5426125904800056	0.7713062952400028
Parallel	4	0.0005742124352331607	0.002666666666666666	2.824858757062147e-05	0.001056994818653285	1.1489782095883716	0.2872445523970929
Parallel	8	0.0109327697368421105	0.071638157894736842	0.000481675392670157	0.011710526315789472	0.0603467914936754655	0.0075433489367094330
Parallel	16	0.0013631487179487183	0.005359477124183006	0.000616352201257861	0.002213903743315508	0.4839953022516768	0.0302497063907298040
Parallel	32	0.0024230793650793650	0.005344827586206897	0.005576923076923077	0.003875647668393783	0.2722806298736179	0.0085087696836755056



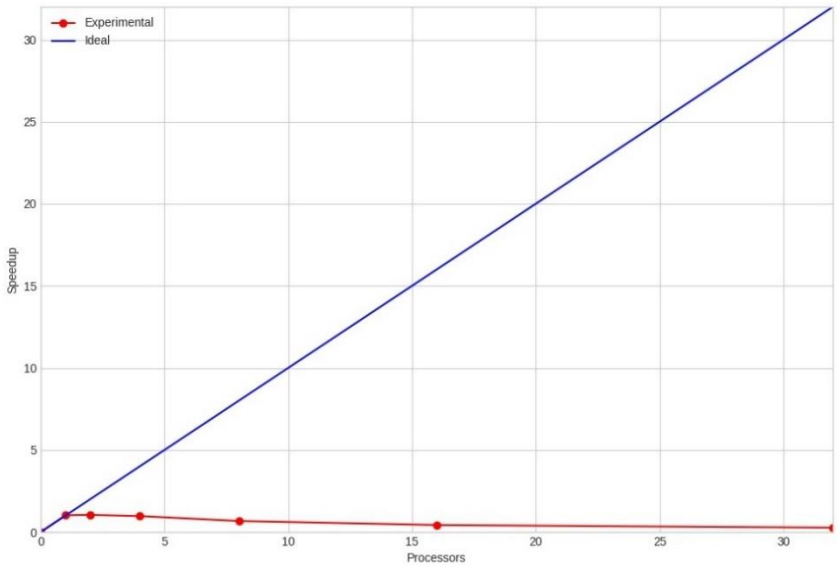
Size-100000-Max-100000-O0

Version	Threads	TimeInt	User	Sys	Real	Speedup	Efficiency
Serial	1	0.0021165875000000002	0.004988235294117647	0.0	0.004999999999999999	1.0	1.0
Parallel	1	0.0024641968911917 1	0.005194244604316546	0.0	0.005626262626262626	0.8589360320864611	0.8589360320864611
Parallel	2	0.0018996519337016573	0.006137724550898203	3.333333333333335e-05	0.004286458333333334	1.1141975340059391	0.5570987670029696
Parallel	4	0.0019001271676300 58	0.010277456647398844	0.00014857142857142857	0.004000000000000002	1.1139188660935538	0.27847971652338 45
Parallel	8	0.0023493089887640 45	0.020993749999999995	0.0003128491620111732	0.005	0.9009404510530023	0.1126175563816 2788
Parallel	16	0.0035321448275862067	0.011388535031847133	0.0013057324840764332	0.006	0.5992357627777204	0.0374522351736 07525
Parallel	32	0.0061192340425531 92	0.016074074074074 07	0.005771084337349398	0.01	0.3458909211972017	0.0108090912874 12554



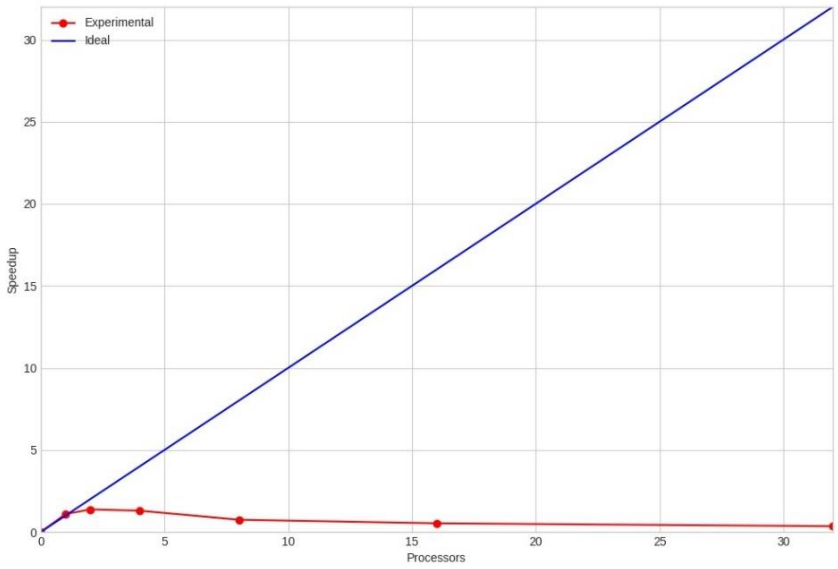
Size-100000-Max-100000-O1

Version	Threads	TimeInt	User	Sys	Real	Speedup	Efficiency
Serial	1	0.001061601063829787	0.0035574712643678167	0.0	0.003000000000000005	1.0	1.0
Parallel	1	0.0010372349397590362	0.0033173652694610778	0.0	0.0029999999999999996	1.023491422373808	1.023491422373808
Parallel	2	0.0010184463276836158	0.0049058823529411774	4.597701149425287e-05	0.0029999999999999996	1.042373107912641 5	0.5211865539563207
Parallel	4	0.0010947925925925924	0.0068988764044943833	0.00010674157303370789	0.004	0.9696823590263759	0.24242058975659397
Parallel	8	0.0015850337837837844	0.0151617647058823 55	0.0004880952380952381	0.0042597402597402 6	0.6697655751510474	0.08372069689388092
Parallel	16	0.0025010753424657534	0.0094156626506024 09	0.0015964912280701756	0.0049999999999999999	0.4244578505112839 3	0.026528615656955246
Parallel	32	0.0040152847222222222	0.0140609756097561	0.0030060975609756 1	0.0070000000000000001	0.2643899840911154	0.008262187002848562



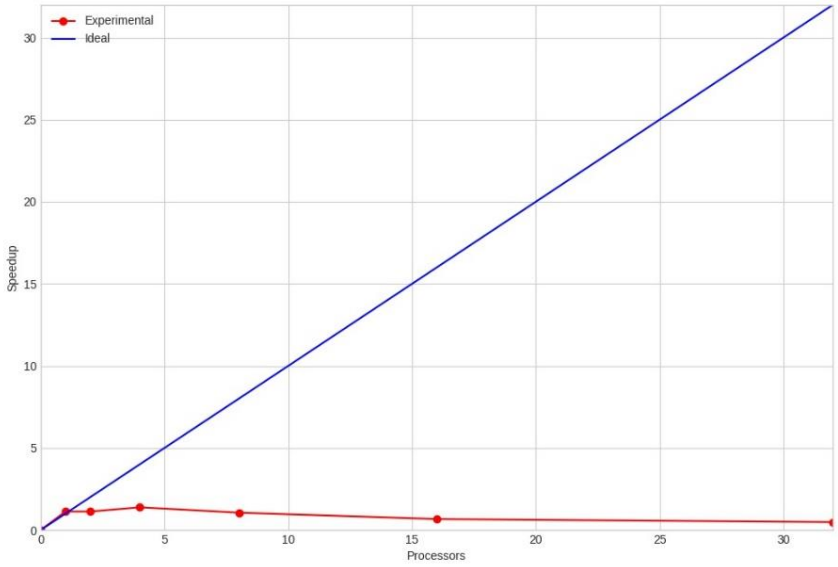
Size-100000-Max-100000-O2

Version	Threads	TimeInt	User	Sys	Real	Speedup	Efficiency
Serial	1	0.001388789156626506	0.005068965517241379	0.0	0.005	1.0	1.0
Parallel	1	0.001274351063829787 3	0.004745762711864407	0.0	0.004040816326530613	1.0898010729106307	1.0898010729106307
Parallel	2	0.001009592814371257 6	0.004863095238095237 5	8.045977011494253e-05	0.003	1.3755933450174165	0.6877966725087082
Parallel	4	0.001070967391304347 8	0.006946745562130178	5.325443786982249e-05	0.004000000000000001	1.2967613840558 47	0.3241903460139617 4
Parallel	8	0.001859570512820512 5	0.01725	0.0005664739884393064	0.005685534591194968	0.7468332859935778	0.0933541607491972 2
Parallel	16	0.002626413793103448	0.008530612244897796	0.0023818181818182	0.006	0.5287777425907711	0.0330486089119232
Parallel	32	0.003946605442176870	0.013703947368421053	0.0023081761006289313	0.007000000000000002	0.3518946033430889	0.0109967063544 71529



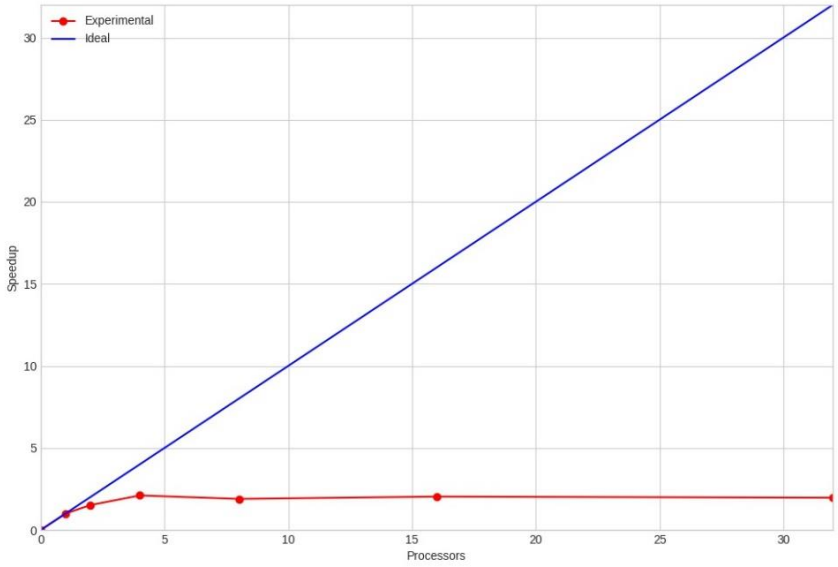
Size-100000-Max-100000-O3

Version	Threads	TimeInt	User	Sys	Real	Speedup	Efficiency
Serial	1	0.00134240206185567	0.004895027624309392	0.0	0.005	1.0	1.0
Parallel	1	0.001191014814814815	0.003872093023255815	0.0	0.004000000000000001	1.1271077783061778	1.1271077783061778
Parallel	2	0.001196287425149700 7	0.005140127388535032	0.0	0.004065476190476191	1.1221400757327904	0.5610700378663952
Parallel	4	0.000972020134228187 8	0.006327380952380953	7.05882352941176e-05	0.003	1.3810434728510805	0.3452608682127 7013
Parallel	8	0.001272633333333334	0.012888888888888889	0.00024550898203592813	0.004000000000000001	1.0548223331064224	0.1318527916383028
Parallel	16	0.002009552325581394 7	0.008793103448275863	0.0012701149425287358	0.004999999999999999	0.6680105040147647	0.0417506565009 2279
Parallel	32	0.002781965986394558	0.007423076923076924	0.006584415584415584	0.005999999999999999	0.4825371943513335	0.0150792873234 79173



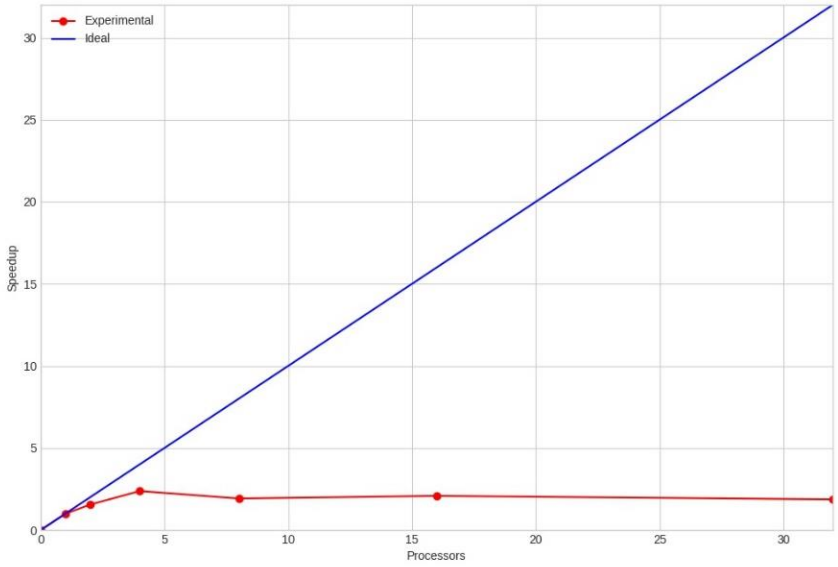
Size-10000000-Max-100000-O0

Version	Threads	TimeInt	User	Sys	Real	Speedup	Efficiency
Serial	1	0.07279282608695652	0.25629341317365273	0.007942857142857144	0.26473737373737377	1.0	1.0
Parallel	1	0.07268631034448276	0.25632596685082876	0.007911764705882354	0.26466834170854275	1.0014654168250334	1.0014654168250334
Parallel	2	0.04803866429530205	0.26926984126984127	0.008198581560283689	0.23995384615384613	1.5152966251536646	0.7576483125768323
Parallel	4	0.03457490740740741	0.2903928571428572	0.011437956204379563	0.22641206030150754	2.1053657564202535	0.5263414391050634
Parallel	8	0.03843114754098364	0.3975027027027027	0.010668750000000001	0.23238251366120216	1.8941101357779926	0.23676376697224907
Parallel	16	0.03575840909090909	0.3105503355704697	0.009782051282051282	0.22822564102564105	2.0356841352168193	0.1272302584510512
Parallel	32	0.03700520979020979	0.3143473053892215	0.013734848484848487	0.22983756345177667	1.9670967006979327	0.06147177189681044



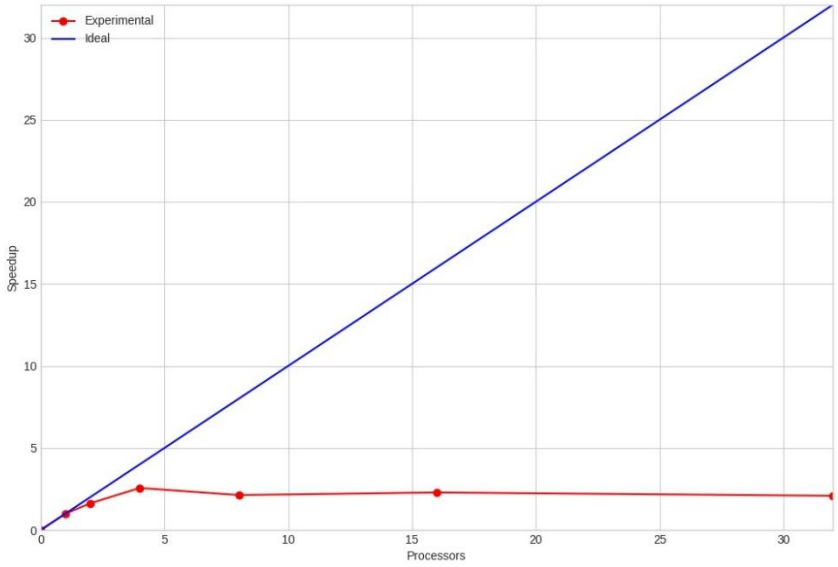
Size-10000000-Max-100000-O1

Version	Threads	TimeInt	User	Sys	Real	Speedup	Efficiency
Serial	1	0.02202114024390244	0.20021917808219178	0.008189189189189919	0.20833333333333334	1.0	1.0
Parallel	1	0.02226724064171226	0.20098540145985405	0.007914893617021277	0.20911518324607328	0.9889478718190261	0.9889478718190261
Parallel	2	0.01418441772151898	0.20784615384615385	0.007939393939393939	0.20083756345177667	1.5524881370699108	0.7762440685349554
Parallel	4	0.00928907638888888	0.21965789473684214	0.008314102564102565	0.19578172588832488	2.3706490636941027	0.5926622659235257
Parallel	8	0.01146972189349112	0.2850365853658537	0.008771084337349397	0.19918274111675133	1.9199367210811862	0.2399920901351482
Parallel	16	0.01059054887218045	0.2276756756756757	0.010348101265822786	0.19771065989847714	2.079320015391099	0.1299575009619437
Parallel	32	0.01180477622377622	0.2325540540540541	0.013450819672131149	0.19931122448979591	1.8654432601229022	0.05829510187884069



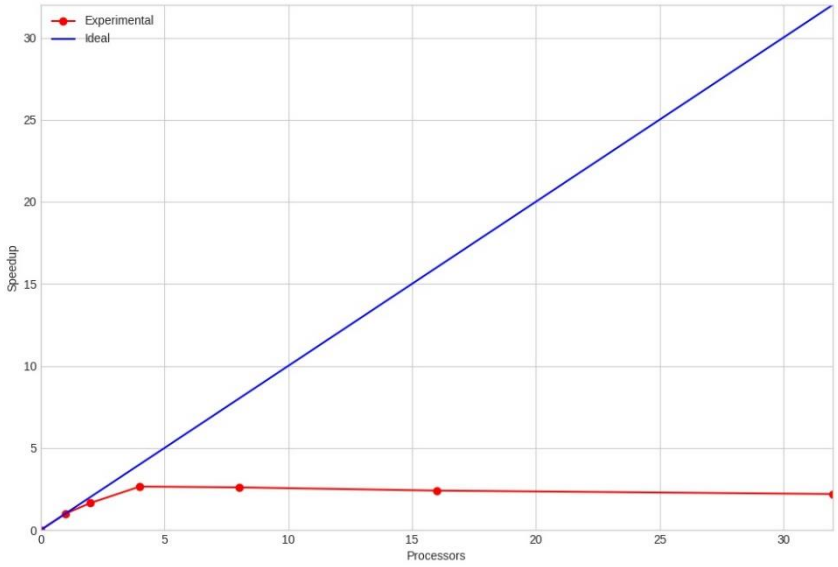
Size-10000000-Max-100000-O2

Version	Threads	TimeInt	User	Sys	Real	Speedup	Efficiency
Serial	1	0.026478640 8839779	0.20646428571 428574	0.0100550458715 59634	0.2153556701030 9276	1.0	1.0
Parallel	1	0.026602763 513513514	0.20660606060 606065	0.0094842767295 5975	0.2152244897959 184	0.995334220466 5104	0.9953342204665 104
Parallel	2	0.016281594 77124183	0.21337012987 012988	0.0096484848484 84849	0.2050151515151 5154	1.626292832858 5542	0.8131464164292 771
Parallel	4	0.010342010 1010101	0.22580000000 000006	0.0079090909090 9091	0.19925	2.560299267295 4112	0.6400748168238 528
Parallel	8	0.012451346 733668342	0.29433510638 29787	0.0095523255813 95349	0.2021616161616 1618	2.126568430736 883	0.2658210538421 1036
Parallel	16	0.011577582 191780822	0.23527972027 97203	0.0130661764705 88234	0.2010256410256 4108	2.287061360944 2274	0.1429413350590 142
Parallel	32	0.012711666 666666666	0.24069934640 522875	0.0133546099290 78014	0.2024693877551 021	2.083018818721 2193	0.0650943380850 381



Size-10000000-Max-100000-O3

Version	Threads	TimeInt	User	Sys	Real	Speedup	Efficiency
Serial	1	0.02325601595744681	0.20373880597014923	0.008119402985074627	0.2121269035532995	1.0	1.0
Parallel	1	0.02327824043715846	0.20395652173913045	0.007863945578231293	0.21213333333333334	0.9990452680574524	0.9990452680574524
Parallel	2	0.01419059375	0.21026241134751772	0.007978417266187705	0.2029289340101523	1.638833185358915	0.8194165926794575
Parallel	4	0.008786868686868685	0.21870469798657720	0.009470588235294118	0.19762051282051282	2.646678445553782	0.6616696113884455
Parallel	8	0.008951702702702702	0.26566666666666666	0.011825174825174825	0.19892857142857148	2.597943288534967	0.32474291106687087
Parallel	16	0.00968606711409396	0.23010666666666667	0.012522727272727272	0.19937563451776658	2.400976132367238	0.15006100827295238
Parallel	32	0.01061413698630137	0.23244666666666667	0.014547445255474453	0.20037563451776652	2.191041625660 2945	0.06847005080188 42



Case Study 2

In this case study (**ProjectCountingSortFinal2** folder), the main purpose is to analyze the performance of our program in the following build setup:

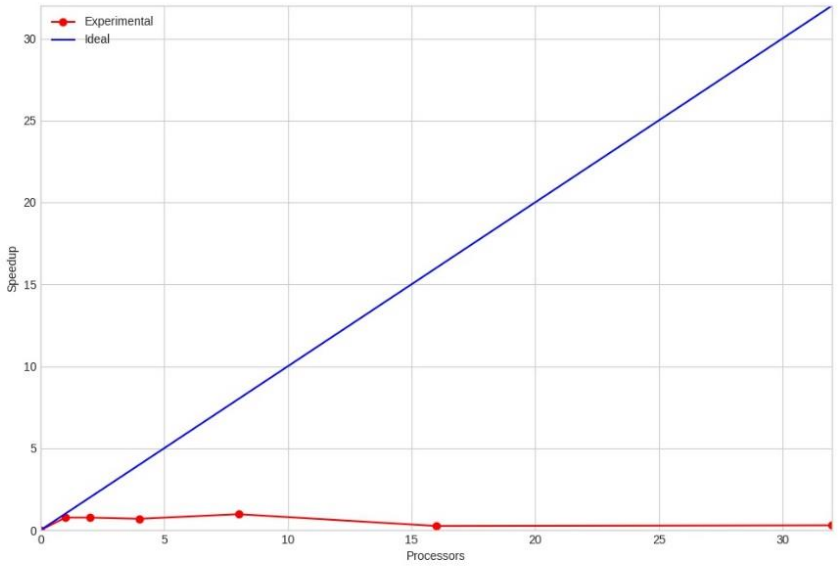
- The sequential version of the second version of the algorithm is compiled with the gcc optimization -Ox where x = 0,1,2,3
- The parallel program is compiled with the gcc optimization -Ox where x = 0,1,2,3

The compilation with -O0 means without optimization.

Here we want to highlight the difference between a simple sequential program compared to a parallel one, furthermore the case study is done on multiple size that are 5000,100000, 10000000 and with different number of threads (0, 1, 2, 4, 8, 16, 32). We consider the maximum value inserted in the array to be ordered as 100000.

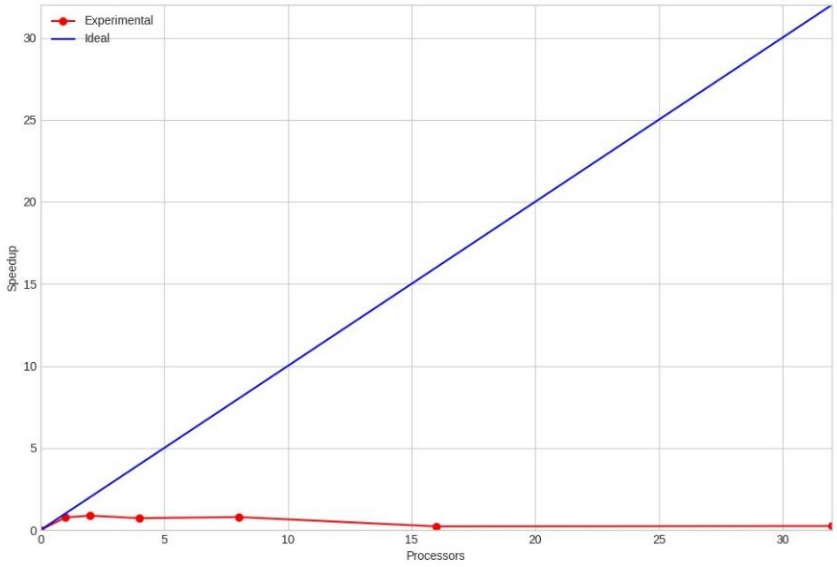
Size-5000-Max-100000-O0

Version	Threads	TimeInt	User	Sys	Real	Speedup	Efficiency
Serial	1	0.0023415706521739132	0.003925675675676	0.0	0.004000000000000001	1.0	1.0
Parallel	1	0.003075121693121694	0.004821917808219178	9.655172413793103e-05	0.005	0.7614562563203341	0.761456256320341
Parallel	2	0.003077223076923077	0.007048484848484848	0.0007939393939393939	0.004999999999999999	0.7609362706701315	0.38046813533506574
Parallel	4	0.003398923664122137	0.013880000000000002	0.001139393939393939394	0.004999999999999999	0.6889153401386219	0.17222883503465547
Parallel	8	0.002411443181818181817	0.019321212121212124	0.00025824175824175826	0.003149425287356322	0.9710246004670174	0.12137807505837718
Parallel	16	0.009368701492537311	0.026354838709677426	0.009768656716417912	0.011999999999999999	0.2499354530656254	0.015620965816601584
Parallel	32	0.008111315789473683	0.023205882352941177	0.012137096774193548	0.010098684210526315	0.2886795081030682	0.009021234628220881



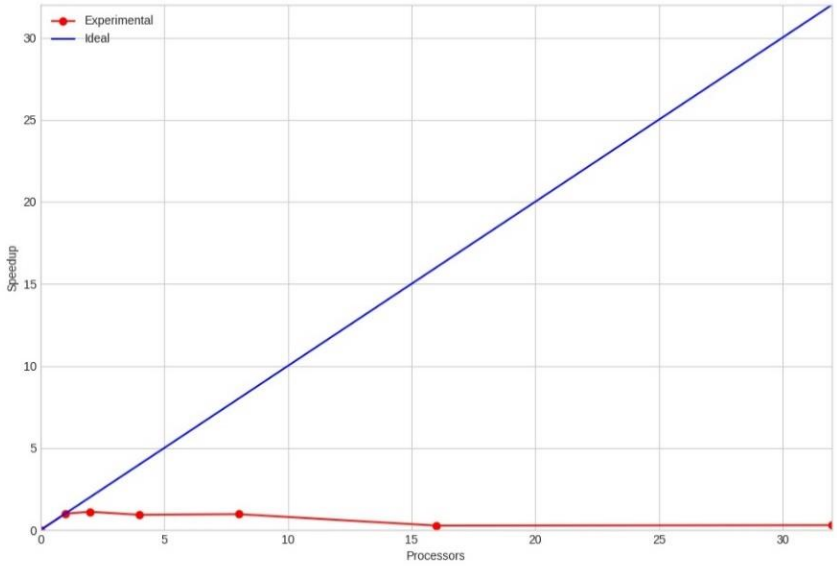
Size-5000-Max-100000-O1

Version	Threads	TimeInt	User	Sys	Real	Speedup	Efficiency
Serial	1	0.0014741210526315793	0.0029271523178807943	0.0	0.003	1.0	1.0
Parallel	1	0.0019355797872340427	0.00377049180327869	0.0	0.004000000000000001	0.7615914685377598	0.7615914685377598
Parallel	2	0.0016804055555555556	0.004773049645390071	0.00022602739726027398	0.0029999999999999996	0.8772412396269956	0.438620619813478
Parallel	4	0.0020522758620689654	0.008867132867132869	0.0010738255033557048	0.004	0.7182860159674004	0.1795715039918501
Parallel	8	0.0018681941176470589	0.015135483870967742	0.0002905027932960894	0.0024906832298136647	0.7890620352065961	0.09863275440082452
Parallel	16	0.006742785714285715	0.014345323741007193	0.01235	0.01	0.21862196354667007	0.013663872721666688
Parallel	32	0.006172013605442177	0.014081967213114756	0.009821138211382113	0.008000000000000002	0.23883956628542946	0.007463736446419671



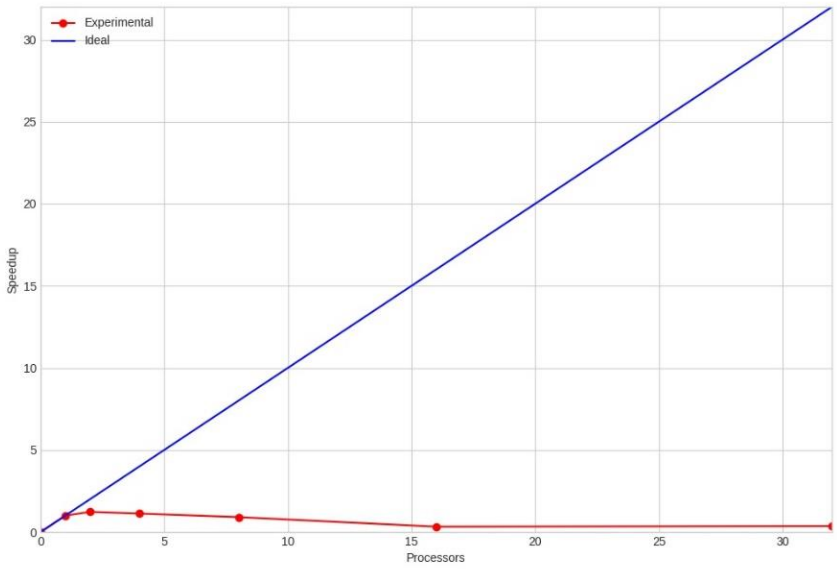
Size-5000-Max-100000-O2

Version	Threads	TimeInt	User	Sys	Real	Speedup	Efficiency
Serial	1	0.0017765123456790124	0.0029813084112149534	0.00015151515151515152	0.0029999999999999996	1.0	1.0
Parallel	1	0.0017773809523809522	0.003	0.0	0.0029999999999999996	0.9995112996452583	0.9995112996452583
Parallel	2	0.0016001122994652407	0.004859375000000001	0.00013333333333333334	0.0029999999999999996	1.1102422912896633	0.5551211456448165
Parallel	4	0.0019194831460674156	0.008349315068493152	0.0010136986301369864	0.004	0.9255159907596386	0.23137899768990966
Parallel	8	0.0018411193181818184	0.01431875	0.00044943820224719103	0.002429447852760737	0.9649088617642619	0.12061360772053274
Parallel	16	0.0066595364238410580	0.014047297297297295	0.012592857142857142	0.01	0.2667621637024343433	0.016672635231402146
Parallel	32	0.0061214430379746830	0.013201550387596898	0.010750000000000001	0.008000000000000002	0.2902113659570672 6	0.009069105186158352



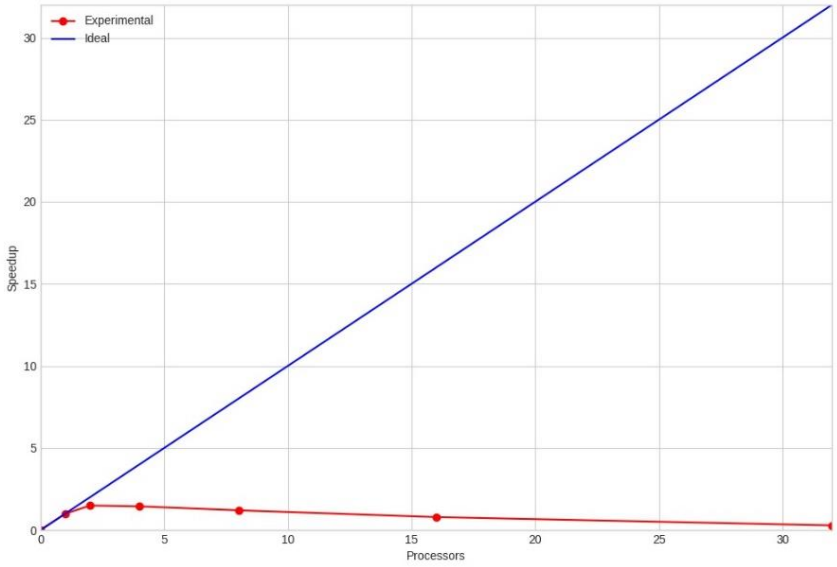
Size-5000-Max-100000-O3

Version	Threads	TimeInt	User	Sys	Real	Speedup	Efficiency
Serial	1	0.0013752539682539684	0.0030000000000000005	0.0	0.003	1.0	1.0
Parallel	1	0.0013778944444444443	0.0030000000000000005	0.0	0.003	0.9980836876140099	0.9980836876140099
Parallel	2	0.0011224333333333333	0.0037887323943661976	0.00021126760563380283	0.003	1.2252433417758755	0.6126216708879377
Parallel	4	0.0012257640449438202	0.0063404255319148934	0.0004460431654676259	0.003	1.1219565249338013	0.2804891312334503
Parallel	8	0.0015180176470588238	0.0096994219653179190	0.0009064327485380117	0.002787356321839081	0.9059538740663117	0.1132442342582896
Parallel	16	0.0042380145985540146	0.0096640625	0.012289062500000003	0.007000000000000001	0.3245043017850144 4	0.0202815188615634 02
Parallel	32	0.0038110138888888889	0.0100593220338983 02	0.0098034188034188803	0.005999999999999999	0.3608630166013190 3	0.0112769692687912 2



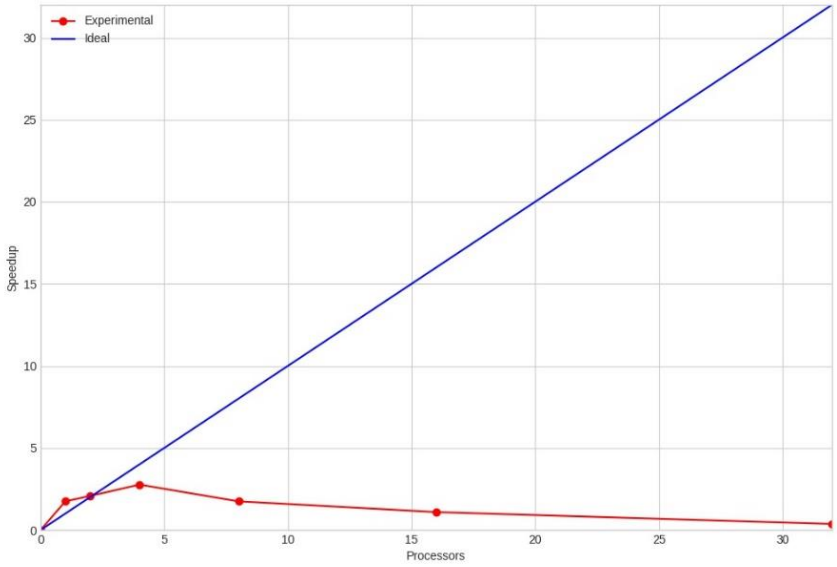
Size-100000-Max-100000-O0

Version	Threads	TimeInt	User	Sys	Real	Speedup	Efficiency
Serial	1	0.0025046187845303865	0.005	0.0	0.005	1.0	1.0
Parallel	1	0.0025164682080924855	0.0050377358490566035	0.0	0.005011560693641618	0.9952912484552782	0.9952912484552782
Parallel	2	0.0016828516483516484	0.005988636363636363	2.27272727272727e-05	0.004000000000000001	1.4883182287539476	0.7441591143769738
Parallel	4	0.0017404100719424467	0.009836477987421382	0.0002138728323699422	0.004202531645569621	1.4390969260106719	0.35977423150266796
Parallel	8	0.0020862905027932960	0.018840490797546010	0.0003505747126436781	0.004999999999999999	1.2005129588506485	0.15006411985633106
Parallel	16	0.0031810197368421052	0.013222222222222224	0.0022325581395348836	0.005999999999999999	0.7873634845839711	0.049210217786498194
Parallel	32	0.0089681939393939393	0.027967479676479676	0.009879999999999998	0.014179190751445088	0.2792779462014674	0.008727435818795856



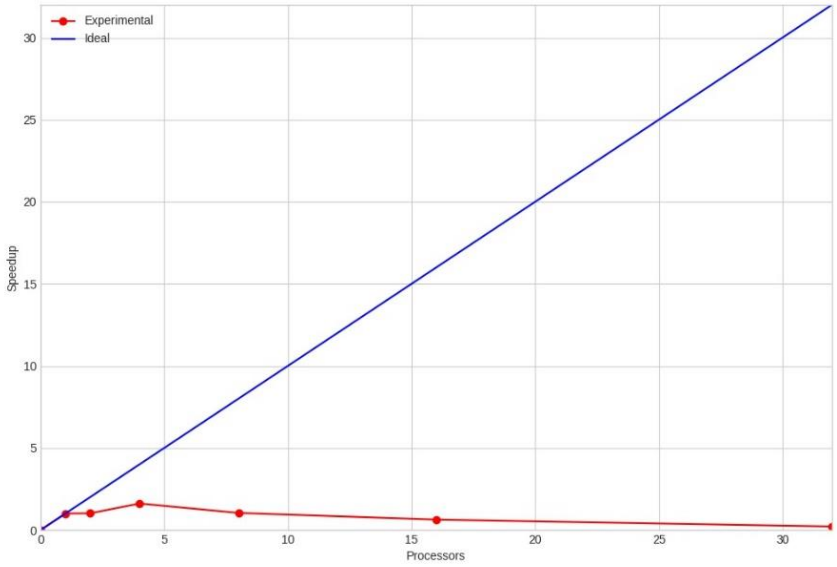
Size-100000-Max-100000-O1

Version	Threads	TimeInt	User	Sys	Real	Speedup	Efficiency
Serial	1	0.002387529411764706	0.005676136363636364	1.2820512820512822e-05	0.006943661971830986	1.0	1.0
Parallel	1	0.001367560846560847	0.004000000000000001	0.0	0.004	1.7458304818896246	1.7458304818896246
Parallel	2	0.001150851063829785	0.005013793103448277	0.0001097560975609756	0.003702127659574468	2.075958899488312	1.037979449744156
Parallel	4	0.000863458563535911 5	0.005909638554216868	9.036144578313253e-05	0.002999999999999996	2.765076996848162	0.6912692492120405
Parallel	8	0.001367451086956521 8	0.013378881987577641	0.0001212121212121212121	0.004000000000000001	1.745970612432309 6	0.2182463265540387
Parallel	16	0.002189978723404255 7	0.009847560975609754	0.0012606060606060606 08	0.004999999999999999	1.090206670160413	0.0681379168850258 1
Parallel	32	0.006466113475177305	0.017420634920634 92	0.010370689655172415	0.012	0.369237165560141 7	0.0115386614237544 28



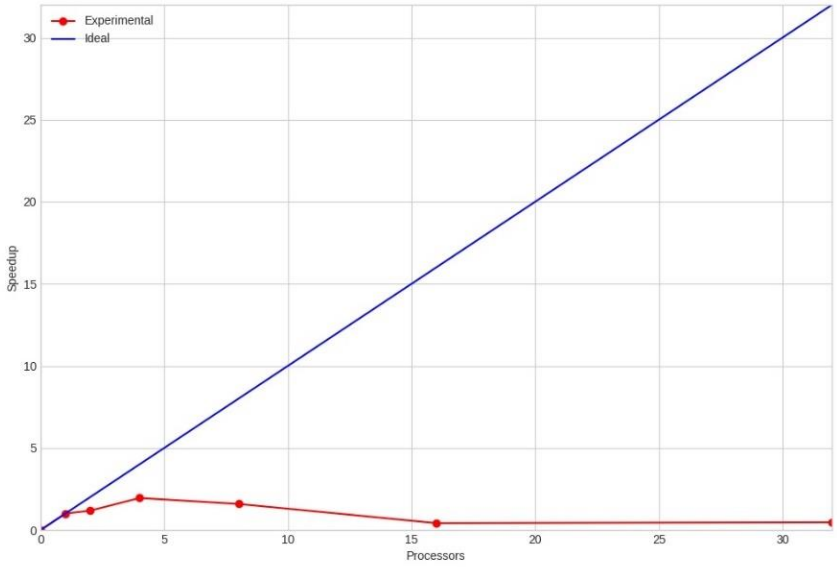
Size-100000-Max-100000-O2

Version	Threads	TimeInt	User	Sys	Real	Speedup	Efficiency
Serial	1	0.0014049555555555556	0.003988235294117648	0.0	0.004005524861878454	1.0	1.0
Parallel	1	0.0013978994708994706	0.004000000000000001	0.0	0.004	1.0050476338270196	1.0050476338270196
Parallel	2	0.0013840769230769232	0.006303030303030303	0.00013714285714285713	0.005	1.0150848786873907	0.5075424393436954
Parallel	4	0.0008717142857142857	0.005994152046783626	8.187134502923977e-05	0.0029999999999999996	1.611715648785462	0.4029289121963655
Parallel	8	0.0013517460317460320	0.013089171974522291	0.00012578616352201257	0.004000000000000001	1.0393635509628931	0.12992044387036164
Parallel	16	0.0022136496350364967	0.009933734939759034	0.0013431952662721896	0.005	0.6346783760711943	0.03966739850444964
Parallel	32	0.0066465864197530870	0.017847328244274811	0.010196581196581195	0.011803680981595509	0.2113800177757634 8	0.006605625555492609



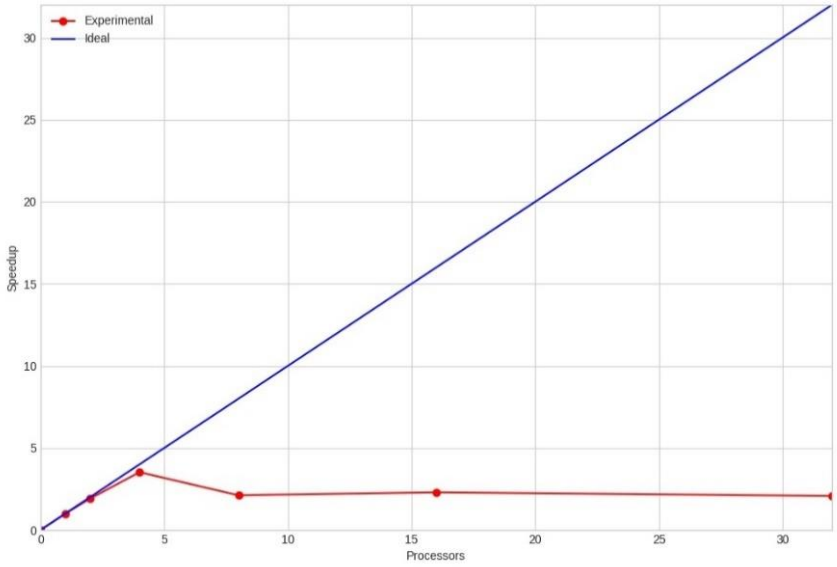
Size-100000-Max-100000-O3

Version	Threads	TimeInt	User	Sys	Real	Speedup	Efficiency
Serial	1	0.0012084082840236685	0.0040143884892086335	0.0	0.004000000000000001	1.0	1.0
Parallel	1	0.001207	0.003994252873563219	0.0	0.004	1.0011667638969914	1.0011667638969914
Parallel	2	0.001027513966480447	0.004964497041420118	0.0	0.004000000000000001	1.1760504707910109	0.5880252353955054
Parallel	4	0.000620010989010989	0.005011976047904191	3.59281437125748e-05	0.003	1.9490110747089529	0.4872527686772382
Parallel	8	0.000761268456375839	0.008832298136645962	0.00019631901840490797	0.003	1.5873615593854005	0.19842019492317506
Parallel	16	0.00288492700729927	0.010351999999999998	0.00785263157894737	0.008405797101449276	0.41886962164596403	0.026179351352872752
Parallel	32	0.002572394 1176470587	0.0085	0.0074745762711864415	0.005999999999999999	0.4697601645617922	0.014680005142556006



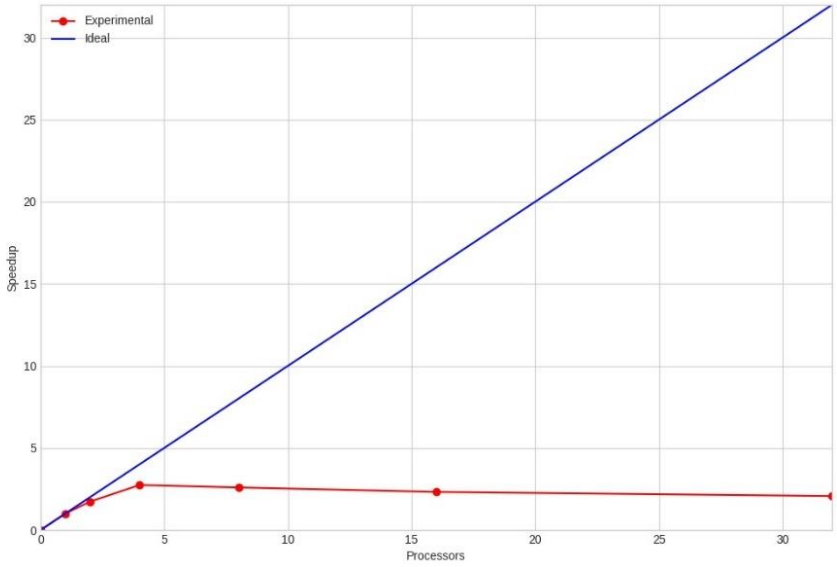
Size-10000000-Max-100000-O0

Version	Threads	TimeInt	User	Sys	Real	Speedup	Efficiency
Serial	1	0.07063460989010988	0.25408270676691735	0.009272727272727273	0.2627880434782609	1.0	1.0
Parallel	1	0.07054185245901638	0.2542	0.008085714285714286	0.2625128205128205	1.0013149276331719	1.0013149276331719
Parallel	2	0.03690498453608247	0.2581351351351351	0.009290816326530614	0.2291550802139038	1.9139585283134184	0.9569792641567092
Parallel	4	0.02005649723756905 8	0.2667988826815642 6	0.009421383647798744	0.2125449438202247	3.5217819469393614	0.8804454867348404
Parallel	8	0.03339481196581197	0.4438812499999999	0.008782894736842106	0.2255051020408163	2.1151372243815074	0.2643921530476884
Parallel	16	0.03074752083333333 3	0.3595571428571428	0.010433333333333333	0.2228496732026144	2.2972456957744383	0.1435778559859024
Parallel	32	0.034059	0.3698709677419354 5	0.013766666666666667	0.2268518518518518 6	2.0738897175521 85	0.0648090536735 0578



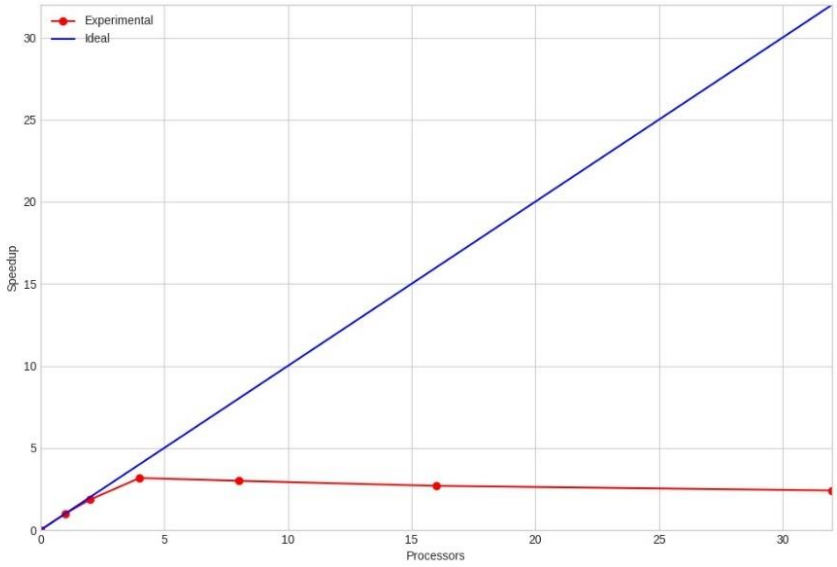
Size-10000000-Max-100000-O1

Version	Threads	TimeInt	User	Sys	Real	Speedup	Efficiency
Serial	1	0.022356548387096775	0.2009851851851852	0.007800000000000005	0.20891145833333336	1.0	1.0
Parallel	1	0.022219653846153847	0.19991240875912408	0.008114285714285715	0.20831111111111109	1.0061609664079723	1.0061609664079723
Parallel	2	0.012940113636363637	0.2054671052631579	0.008137931034483276	0.19951336898395725	1.7276933584471437	0.8638466792235718
Parallel	4	0.008158505681818182	0.2158431372549019	0.008058823529411766	0.19537777777777773	2.7402749056018862	0.6850687264004716
Parallel	8	0.008624346938775512	0.2568987341772152	0.009875776397515527	0.19522051282051282	2.5922598598834856	0.3240324824854357
Parallel	16	0.009632547445255475	0.2392675159235668	0.009850931677018634	0.19609895833333332	2.3209383098453 9	0.1450586443653369
Parallel	32	0.010811264705882354	0.2407021276595744	0.014074074074074	0.19763589743589 74	2.0678939046726597	0.0646216845210 2061



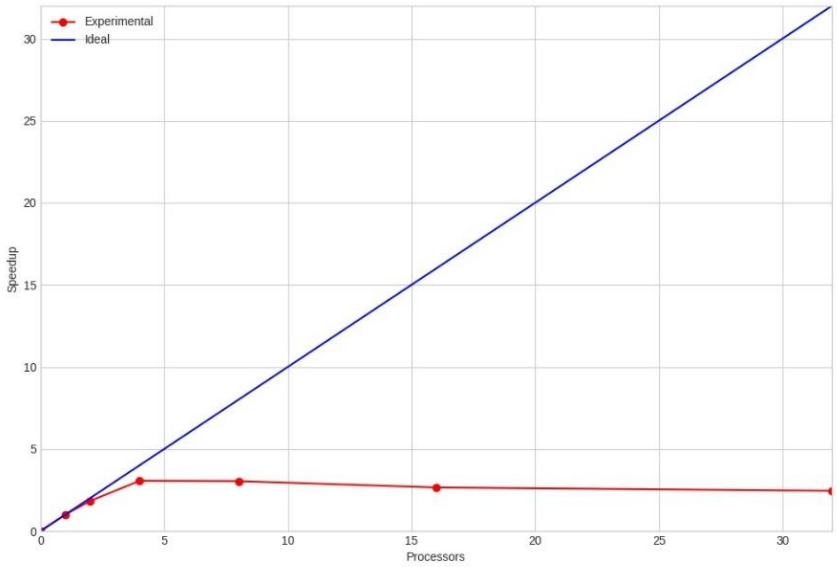
Size-10000000-Max-100000-O2

Version	Threads	TimeInt	User	Sys	Real	Speedup	Efficiency
Serial	1	0.029094779661016944	0.21042857142857144	0.008993630573248408	0.21820744680851065	1.0	1.0
Parallel	1	0.029006909604519772	0.2098661971830986	0.007887323943661973	0.2179175257731959	1.003029280185142	1.003029280185142
Parallel	2	0.015718341836734696	0.2136689189189189	0.007478260869565217	0.20469518716577537	1.8510082019606369	0.9255041009803184
Parallel	4	0.009186926701570680	0.2212797619047619	0.008349315068493153	0.19807486631016047	3.1669763573973695	0.7917440893493424
Parallel	8	0.009708140703517588	0.2683978494623656	0.009314102564102563	0.19889847715736045	2.9969466398931486	0.3746183299866436
Parallel	16	0.010821620437956205	0.2499659863945578	0.009968152866242037	0.19999999999999998	2.688578834179833	0.16803617713623956
Parallel	32	0.012069496350364963	0.2514296296296296	0.013938931297709924	0.20117676767676773	2.4106042883999184	0.07533138401249745



Size-10000000-Max-100000-O3

Version	Threads	TimeInt	User	Sys	Real	Speedup	Efficiency
Serial	1	0.024414401129943503	0.2047462686567164	0.008244897959183674	0.21334946236559144	1.0	1.0
Parallel	1	0.024362907103825136	0.20561428571428572	0.007643835616438357	0.21346486486486485	1.0021136240391156	1.002113624039156
Parallel	2	0.013353108808290154	0.20816107382550336	0.008161073825503356	0.20234391534391538	1.8283683208502013	0.9141841604251006
Parallel	4	0.007991420689655172	0.21602083333333333	0.007964788732394368	0.19669230769230772	3.0550764473640766	0.7637691118410191
Parallel	8	0.008039723404255319	0.2551656804733728	0.009232558139534884	0.197	3.036721526641238	0.3795901908301548
Parallel	16	0.009203506666666667	0.2410974025974026	0.009626506024096388	0.19815736040609142	2.652728140934435	0.16579550880839647
Parallel	32	0.009957936619718308	0.2425174825174825	0.013297101449275362	0.19907614213197972	2.4517530149367572	0.07661728171677366



Considerations

Case Study 1

From these measures it is clear that the parallel program is inefficient with low load (size up to 5000).
Increasing the size of the array to be ordered, the relative speedup of the parallel program in on average 1.6.
It can be seen that at high load(size up 10000000), the program is more performing up to a speedup of 2.6.
From this analysis we can affirm that the Counting Sort algorithm doesn't lend itself very well to being performed in parallel, in fact using the sequential algorithm and adding only the OPENMP directives, it is not possible to parallelize a part of the program, that is the one that actually does the sorting!
With low load the speedup of the parallel program is slightly larger than 1 and only with high load(size 10000000) we can reach a speedup of 2.6 both with gcc optimizations and without.
In each measure we can observer that the relative efficiency decreases as the number of threads increases and this is due to the overhead introduced by OPENMP.
The execution time of the Counting Sort algorithm in the sequential version increases as the size of the problem increases. The parallel algorithm, as the number of threads increases, the execution time decreases(look at timeInt that is the time of Counting Sort function).
At low load(size up to 100000), the first parallelized version of the algorithm shows a speedup curve with a steeper descent, this means that the parallelized algorithm is less performing than the algorithm executed sequentially, and with the increased number of threads performance deteriorates because the system loses more time dividing the load between threads than when it sequentially executed by only one thread.
It means that the overhead introduced by OPENMP is greater that the cost of the algorithm executed sequentially.
At high load(size 10000000) the speedup improves and tends to stabilize. The result is that the parallel version of this algorithm is suitable for high load and the sequential version of this algorithm is suitable for low load.
With size 5000 with optimization gcc 03 the phenomenon of superlinear speedup occurs, that is, it is the case in which the relative speedup is greater than the number of processors.
There are different reasons that can lead to such a result, for example the effects of the cache, that is, as the number of processors increases, there is an increase in the total available memory. More memory can allow intermediate results to be saved and avoid having to recalculate them in later parts of the algorithm. This can reduce the number of calculations performed compared to running with fewer processors.
The parallel algorithm with the first version has an optimal setup in the following way:

- with a low load (up to 5.000) the optimal configuration is 2 threads and gcc O3
- with a medium load (100.000) the optimal configuration is 4 threads and gcc O2 or O3
- with an high load (10.000.000) the optimal configuration is up to 8 threads and gcc O2 or O3

Case Study 2

The Counting Sort algorithm implemented with the second version, that is the one in which the only non-parallelized part is the sum of previous occurrences, but the actual sorting is totally parallelized has better performances than the first version of the algorithm.
Parallel algorithm thus implemented, at low load(up to size 5000) reaches a speedup of 1.2 with gcc 03 optimization. Reached this maximum value, it decreases as the numbers of threads increases.
It can be seen that at high load (size 10000000), without gcc optimization, the speedup up to 4 threads is very close to the ideal speedup, reaching the value of 3.5, after which, as the number of threads increases, speedup decreases and stabilized at 2. Similar behavior even with the different optimizations.
With size 100000 with optimization gcc 01 the phenomenon of superlinear speedup occurs
The parallel algorithm with the first version has an optimal setup in the following way:

- With a low load (up to 5000) use gcc O3 and up to 4 threads.
- With a medium load (100.000) use gcc O1 or O3 and up to 4 threads.

- With an high load use gcc O2 and up to 8 threads or use gcc O0 up to 4 threads.

Since the reachable speedup is higher with the second implementation of Counting Sort algorithm we can say that this is better than the first implementation.

DOCUMENTATION

Function countingSort**:**

```
void countingSort(int *A, int n)
```

Parameters:

- **A** is pointer to the array to be sorted
- **N** is the size of A

Docs also available in the doxygenDocumentation folder.

HOW TO RUN

1. Create a build directory and launch cmake
   mkdir build
   cd build
   cmake ..
2. Generate executables with make
3. To generate measures (this takes a lot of time) run make generate_output
   Our measures are already included so you should skip this step
4. To extract mean time and speedup curves from then run make extract_measures

Results can be found in the measure directory, divided by problem size and the gcc optimization option used