Report Common Assignment: Parallel Tarjan

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Problem description

The requirement was to provide a parallell version of the Tarjan's algorithm to find Strongly Connected Components in a Graph. The implementation is an hibrid of message passing / shared memory paradigm implemented by using MPI and openMP.

There are no constraints on the graph structure and allocation type.

Solution

In the proposed solution the graph is read from a text file and splitted into subgraphs each of which is sent to an MPI process.

After that a reduction mechanism was implemented; one half of the processes elaborates the partial graph and forwards the result to the others, the mechanism continues until the whole graph converges to process 0. The library used for the comunication between processes is MPI (Message Passing Interface).

In our solution there are two versions provided for the parallel program with 2 different communication systems: in the first case, communication was via the functions MPI_Send() and MPI_Recv () by sending the fields separately, in the second case, data were sent after encapsulation via MPI_Pack().

In addition, a second level of parallelization was added via OpenMP trying to make the loops more efficient.

Initially, measurements were made with MPI and later with the addition of OpenMP.

Experimental setup

Hardware

Architecture: x86_64

CPU op-mode(s): 32-bit, 64-bit

Address sizes: 39 bits physical, 48 bits virtual

Byte Order: Little Endian

CPU(s): 8

On-line CPU(s) list: 0-7

Vendor ID: GenuineIntel

Model name: Intel(R) Core(TM) i7-10510U CPU @ 1.80GHz

CPU family: 6

Model: 142

Thread(s) per core: 2

Core(s) per socket: 4

Socket(s): 1

Stepping: 12

CPU(s) scaling MHz: 39%

CPU max MHz: 4900.0000

CPU min MHz: 400.0000

BogoMIPS: 4599.93

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 n

onstop_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 3dnowprefet

ch cpuid_fault epb invpcid_single ssbd ibrs ibpb stibp ibrs_enhanced tpr_shadow vnmi flexpriority ept vpid ept_ad fsgsbase tsc_adjust sgx bmi1 avx2 smep bmi2 erms invpcid mpx rdseed adx smap clflushopt intel_pt xs

aveopt xsavec xgetbv1 xsaves dtherm ida arat pln pts hwp hwp_notify hwp_act_window hwp_epp md_clear flush_l1d arch_capabilities

Memory Device

Array Handle: 0x1000

Error Information Handle: Not Provided

Total Width: 64 bits

Data Width: 64 bits

Size: 8 GB

Form Factor: Row Of Chips

Set: None

Locator: MotherBoard

Bank Locator: BANK 0

Type: LPDDR3

Type Detail: Synchronous

Speed: 2133 MT/s

Manufacturer: Samsung

Serial Number: 55000000

Asset Tag: 01000000

Part Number: K4EBE304EC-EGCG

Rank: 2

Configured Memory Speed: 2133 MT/s

Minimum Voltage: Unknown

Maximum Voltage: Unknown

Configured Voltage: 1.2 V

Memory Technology: DRAM

Memory Operating Mode Capability: Volatile memory

Firmware Version: 55000000

Module Manufacturer ID: Bank 1, Hex 0xCE

Module Product ID: Unknown

Memory Subsystem Controller Manufacturer ID: Unknown

Memory Subsystem Controller Product ID: Unknown

Non-Volatile Size: None

Volatile Size: 8 GB

Cache Size: None

Logical Size: None

Software

OS: Linux fedora 6.1.6-200.fc37.x86_64

GCC: gcc (GCC) 12.2.1 20221121 (Red Hat 12.2.1-4)

Swap: 8GB

Performance, SpeedUp & Efficiency

Case study 1: No OpenMP

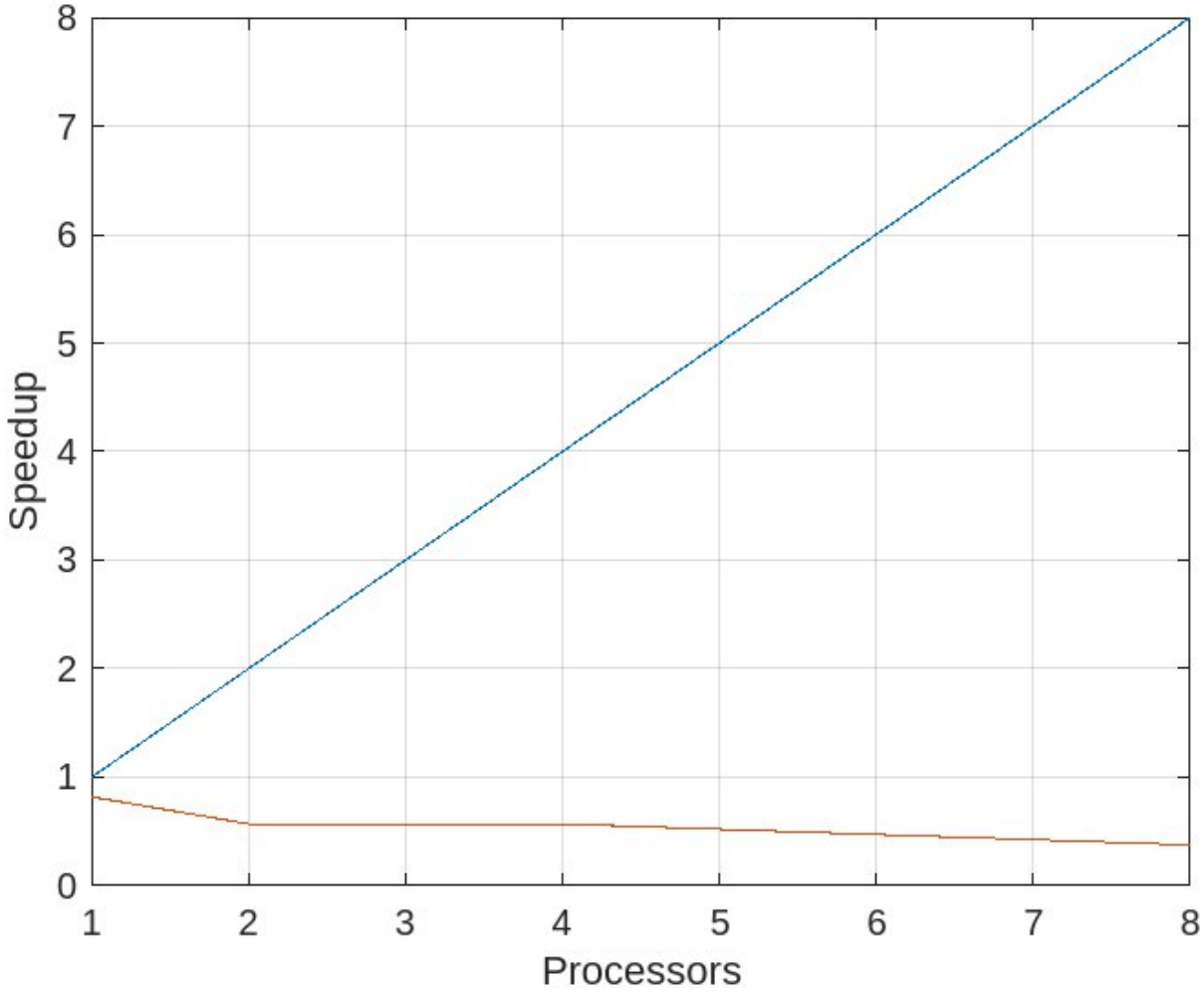
In the first case study, communication was implemented using MPI_Send() and MPI_Recv() without encapsulating the data, thus sending them separately. In this version, our solution has been implemented without using openMP.

Both sequential and parallel compilation were done with the -O3 gcc optimization and measurements were performed with 1, 2, 4 and 8 MPI processes. Note that the source code is the same, but it has been compiled without “-fopenmp” in order to ignore the #pragma directives.

The graph used has 6000 vertices and 150 edges for the first measurement, 250 for the second and 400 for the third.

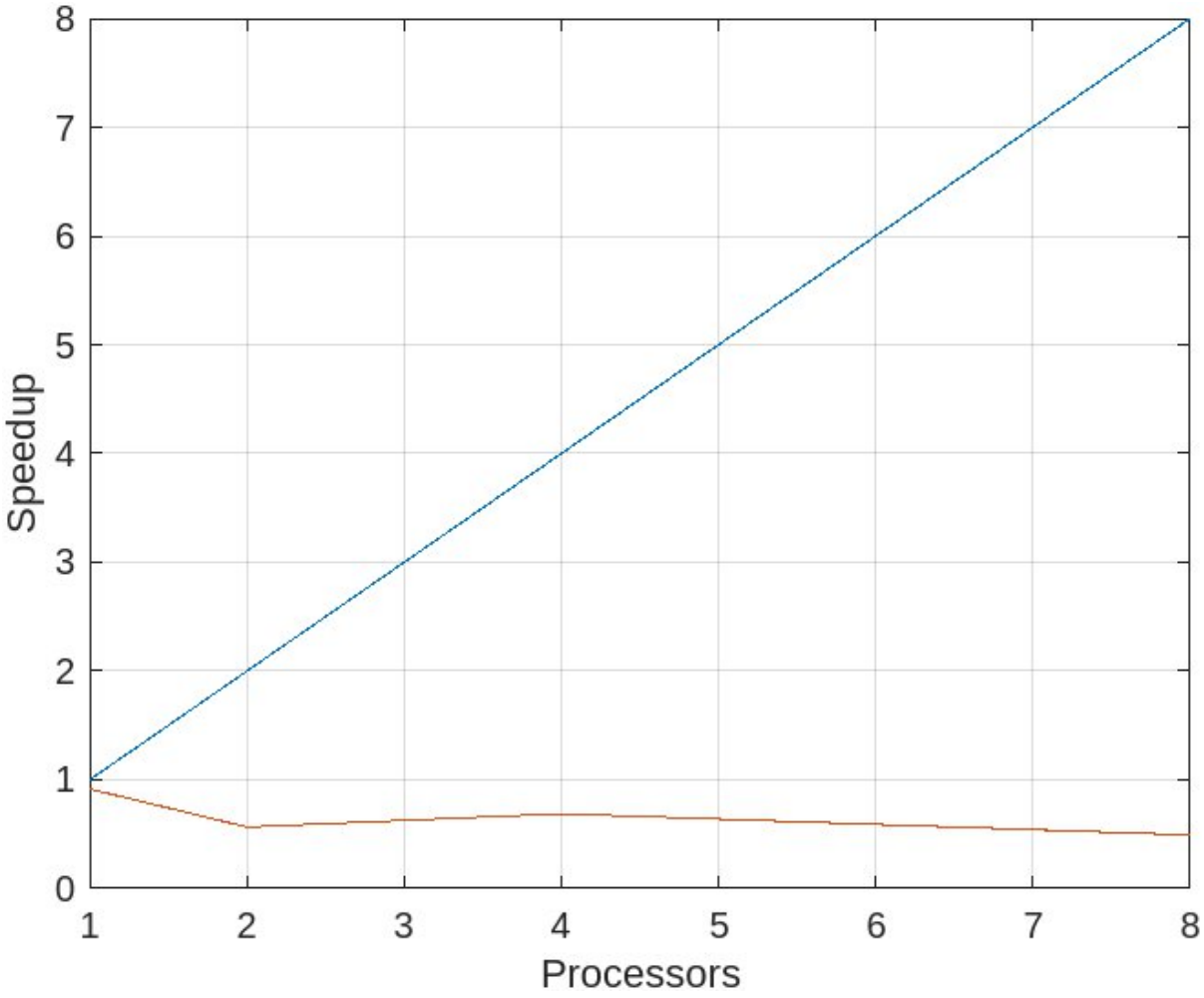
6000 vertices and 150 edges

Version	Processes	Real	User	System	Speedup	Efficency
Sequential	1	3.754	3.345	0.403	1	1
Parallel	1	4.583	1.789	0.598	0.819114	0.819114
Parallel	2	6.585	6.019	1.293	0.570084	0.285042
Parallel	4	6.597	10.112	2.985	0.569047	0.142262
Parallel	8	9.96	10.595	31.205	0.376908	0.047113



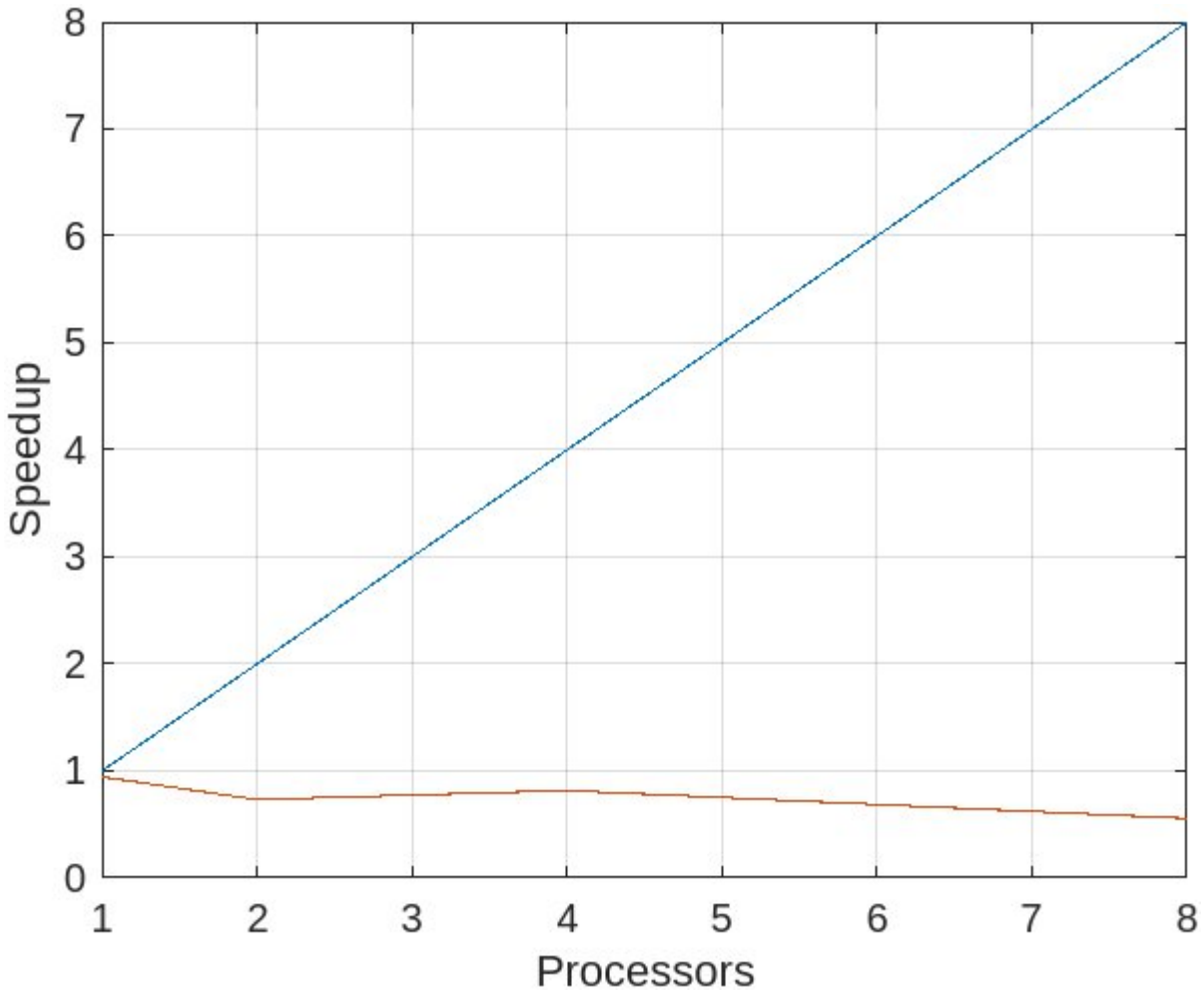
6000 vertices and 250 edges

Version	Processes	Real	User	System	Speedup	Efficency
Sequential	1	5.756	5.316	0.424	1	1
Parallel	1	6.289	2.608	0.613	0.915249	0.915249
Parallel	2	8.763	9.451	1.342	0.656853	0.328426
Parallel	4	8.374	14.03	3.071	0.687366	0.171841
Parallel	8	11.683	14.679	34.686	0.492682	0.061585



6000 vertices and 400 edges

Version	Processes	Real	User	System	Speedup	Efficency
Sequential	1	9.233	8.79	0.419	1	1
Parallel	1	9.762	4.285	0.634	0.94581	0.94581
Parallel	2	12.594	15.12	1.451	0.733127	0.366563
Parallel	4	11.278	20.789	3.335	0.818674	0.204668
Parallel	8	16.559	21.307	51.786	0.557582	0.069698



Case study 2: send without pack

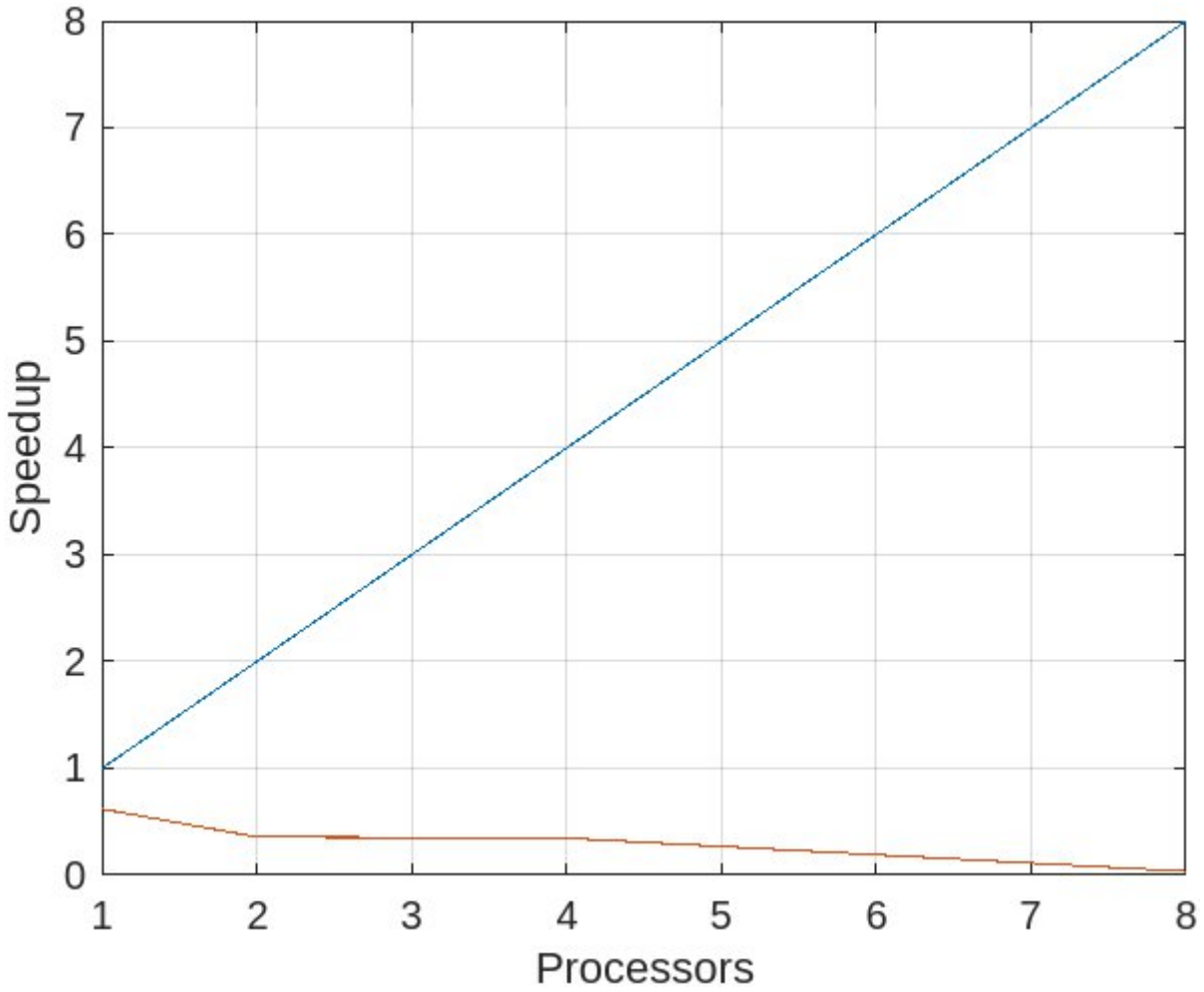
In the second case study, communication was implemented by means of MPI_Send() and MPI_Recv() without encapsulating the data, thus sending them separately.

Both sequential and parallel compilation were done with the -O3 gcc optimization and measurements were performed with 1, 2, 4 and 8 MPI processes and 4 OpenMP threads.

The graph used has 6000 vertices and 150 edges for the first measurement, 250 for the second and 400 for the third.

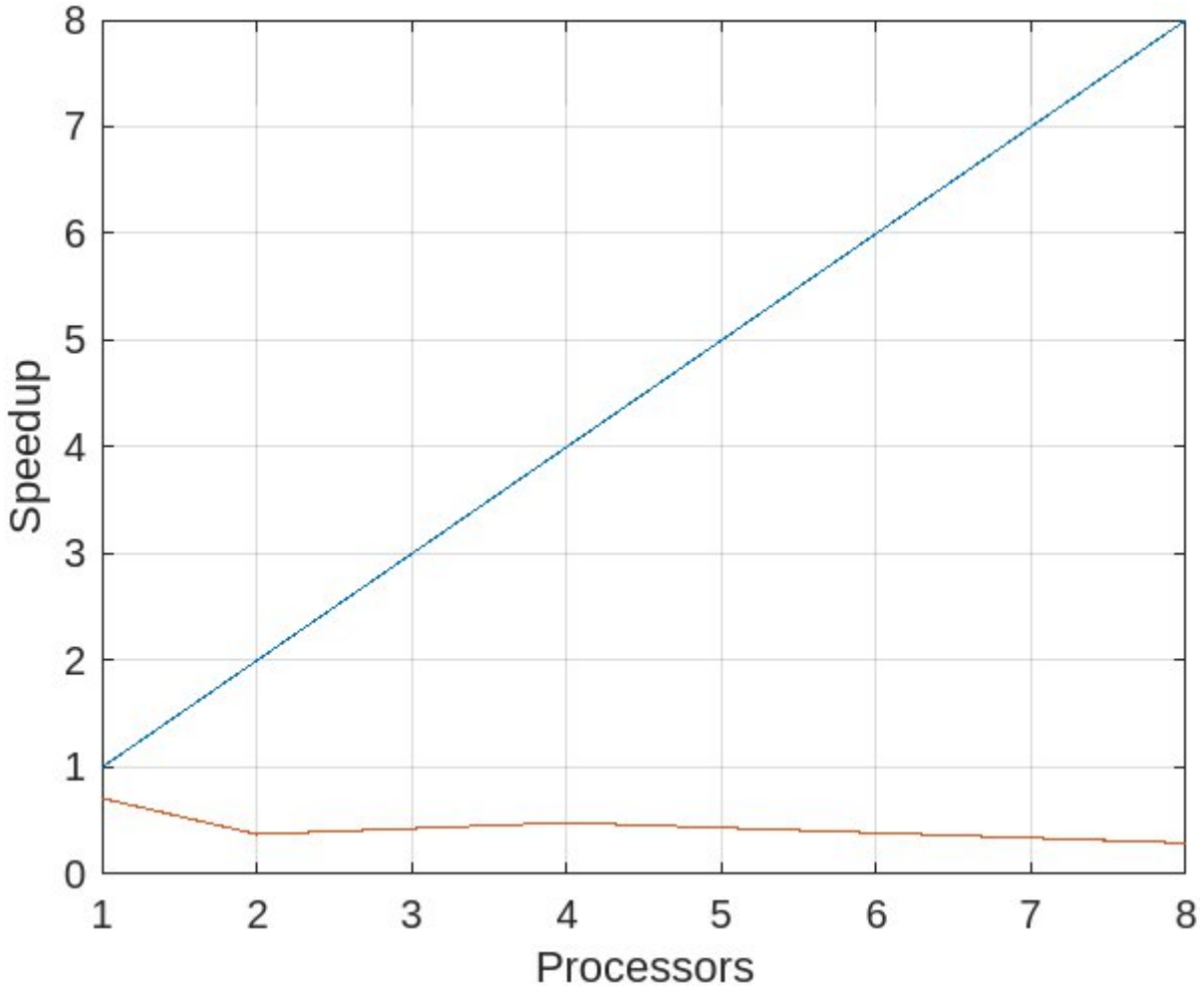
6000 vertices and 150 edges

Version	Processes	Real	User	System	Speedup	Efficency
Sequential	1	3.754	3.345	0.403	1	1
Parallel	1	6.04	3.331	0.834	0.621523	0.621523
Parallel	2	10.459	12.632	1.715	0.358925	0.179463
Parallel	4	8.572	17.432	3.848	0.437937	0.109484
Parallel	8	12.589	18.969	36.301	0.298197	0.037275



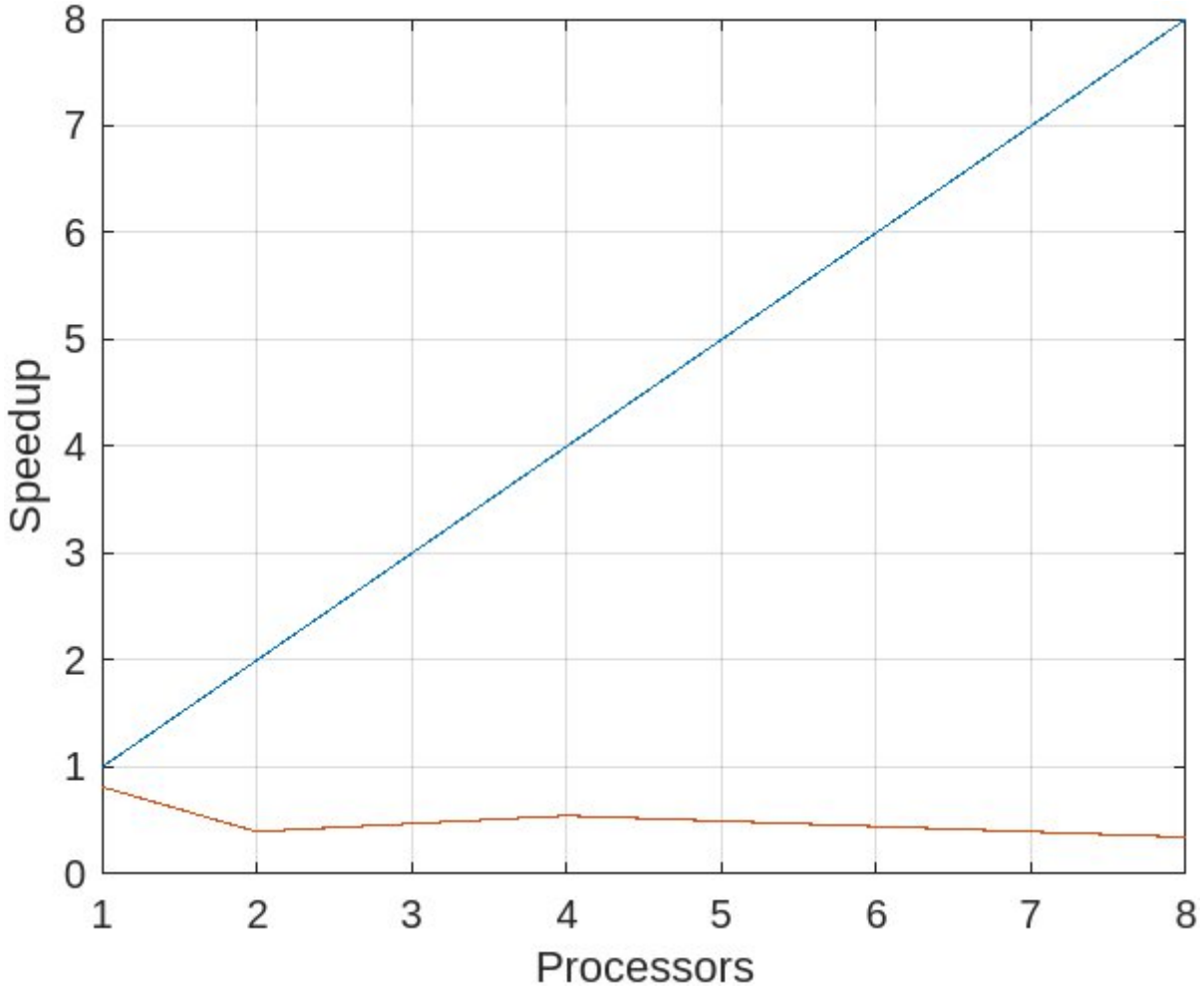
6000 vertices and 250 edges

Version	Processes	Real	User	System	Speedup	Efficency
Sequential	1	5.756	5.316	0.424	1	1
Parallel	1	8.077	5.443	0.819	0.712641	0.712641
Parallel	2	15.33	20.332	1.804	0.375473	0.187736
Parallel	4	11.897	25.324	4.129	0.483819	0.120955
Parallel	8	19.605	25.157	68.549	0.293599	0.0367



6000 vertices and 400 edges

Version	Processes	Real	User	System	Speedup	Efficency
Sequential	1	9.233	8.79	0.419	1	1
Parallel	1	11.288	8.639	0.814	0.817948	0.817948
Parallel	2	23.174	32.315	2.019	0.398421	0.19921
Parallel	4	16.871	37.109	4.781	0.54727	0.136818
Parallel	8	26.437	36.029	85.321	0.349245	0.043656



Case study 3: send with pack

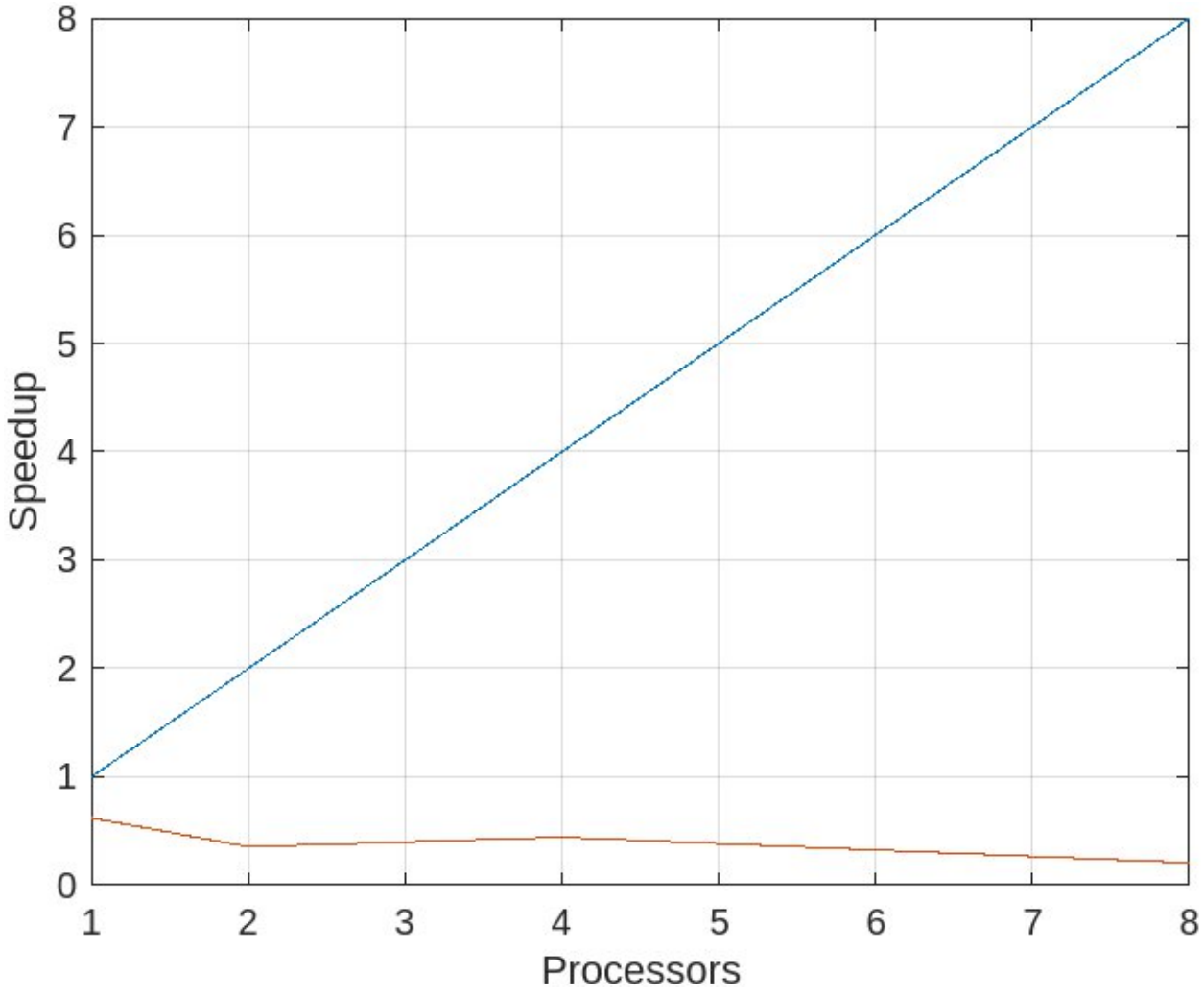
In the last case study, the submitted vertex fields were first encapsulated with MPI_Pack() and then submitted with MPI_Send(), so the number of submissions was reduced by 1/3.

Again, this was compiled with the gcc -O3 option, measurements were performed with 1, 2, 4 and 8 MPI processes and 4 OpenMP threads.

The datasets used to measure the performances of this parallel version are the same of the first two cases.

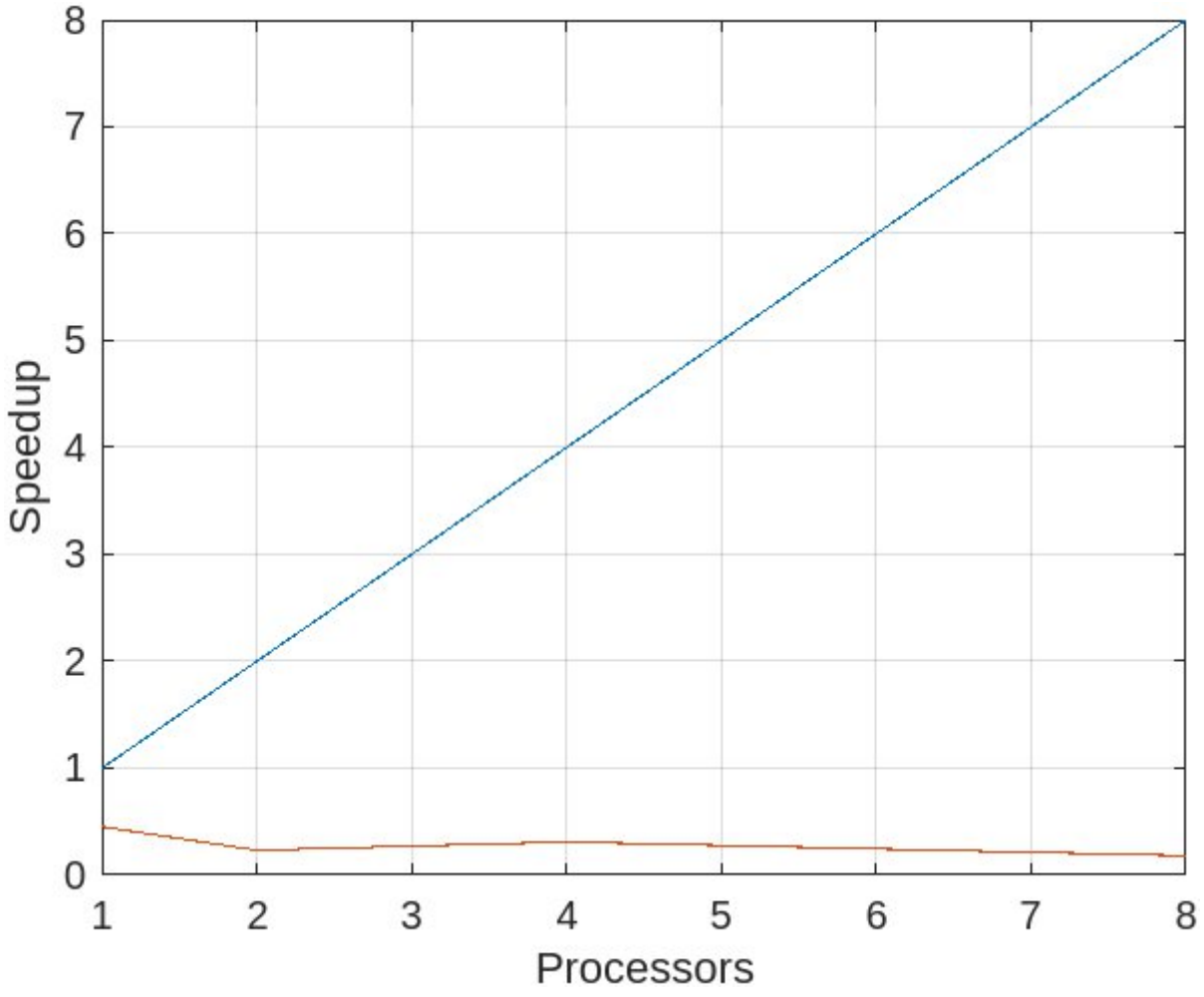
6000 vertices and 150 edges

Version	Processes	Real	User	System	Speedup	Efficency
Sequential	1	3.754	3.345	0.403	1	1
Parallel	1	6.043	3.331	0.834	0.621215	0.621215
Parallel	2	10.556	12.788	1.729	0.355627	0.177814
Parallel	4	8.457	17.49	3.749	0.443893	0.110973
Parallel	8	13.88	19.928	44.288	0.270461	0.033808



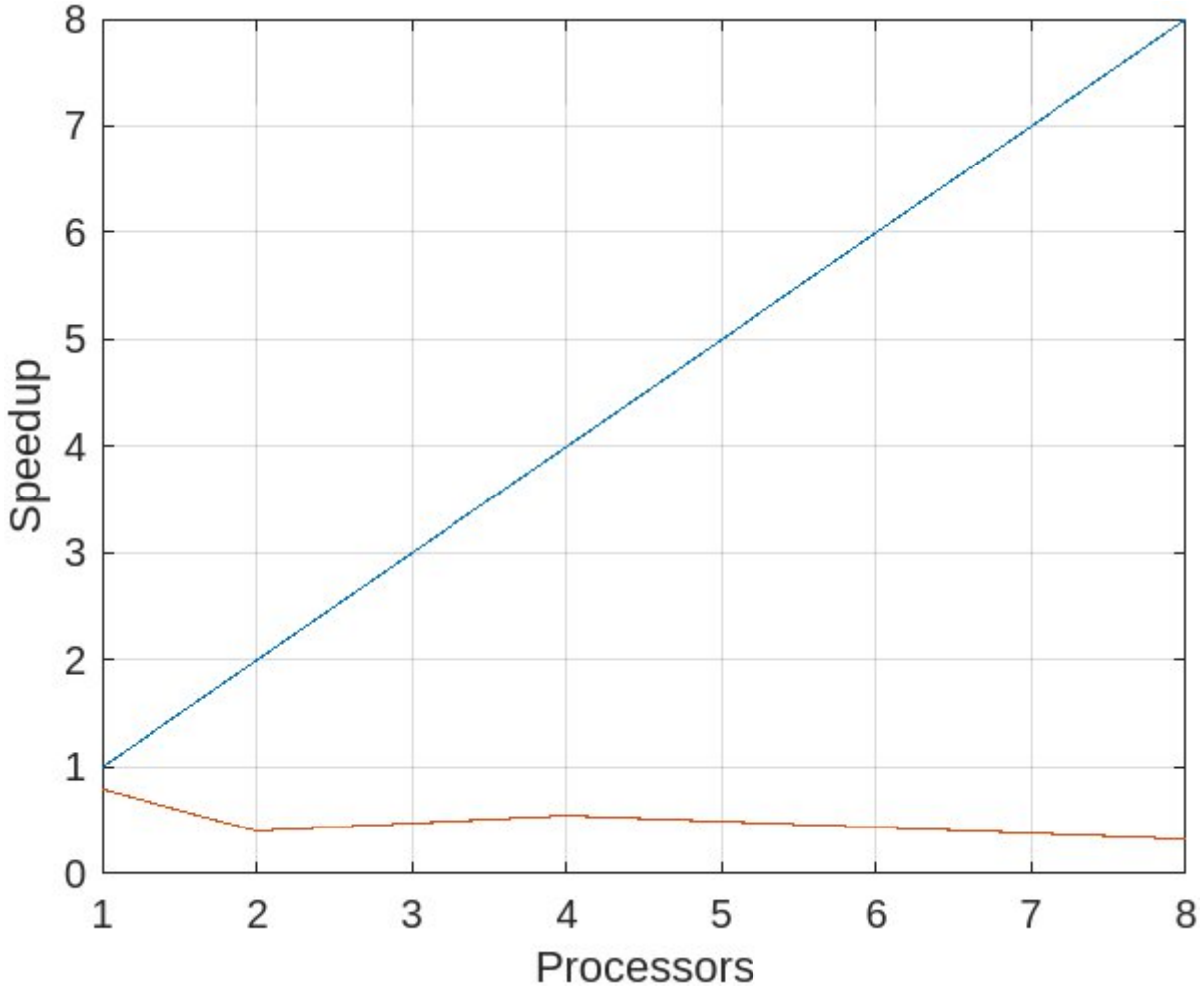
6000 vertices and 250 edges

Version	Processes	Real	User	System	Speedup	Efficency
Sequential	1	3.754	3.345	0.403	1	1
Parallel	1	8.285	5.658	0.78	0.453108	0.453108
Parallel	2	16.109	21.402	1.871	0.233037	0.116519
Parallel	4	12.065	25.627	4.247	0.311148	0.077787
Parallel	8	20.601	25.597	72.262	0.182224	0.022778



6000 vertices and 400 edges

Version	Processes	Real	User	System	Speedup	Efficency
Sequential	1	9.233	8.79	0.419	1	1
Parallel	1	11.552	8.8	0.807	0.799256	0.799256
Parallel	2	22.801	32.005	1.957	0.404938	0.202469
Parallel	4	16.775	36.95	4.546	0.550402	0.137601
Parallel	8	28.292	36.799	84.2	0.326347	0.040793



Final consideration

As expected, we can say that the Tarjan's Algorithm runs much better without parrallelization.
In fact, in the light of the data collected, we can see that the speedup of the parallel version is in each case much less than 1. This is due to the multiple execution of Tarjan on several graphs which, although smaller than the original graph, must still be reprocessed to combine the SCCs found on them.

Github repository: https://github.com/notprg/Parallel-Tarjan.git