github.com/SilvioBaratto/Lab-1

Report Lab 1

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Indice

1 PERF (I)

1.1 Definition profiler

A profiler in software engineering, is a form of dynamic program analysis that measures, for example, the space (memory) or time complexity of a program, the usage of particular instructions, or the frequency and duration of function calls. Most commonly, profiling information serves to aid program optimization, and more specifically, performance engineering. Profilers, which are also programs themselves, analyze target programs by collecting information on their execution. Based on their data granularity, on how profilers collect information, they are classified into event based or statistical profilers.

1.2 Code explanatin for benchmarking

The code given to do some performance analysis using perf as a profiler consist in a simple function that initialize a matrix of dimension 2000×2000 and fill all the matrix with a value equal to 1. The program repeat this operation 100 times.

1.3 Performance analysis tool (perf)

We are interested in see how the program behaves with different optimizers and code optimizations using perf to check the performance results. To do that with this instructions we want to look at:

a. CPU clock cycles at user level

b. Machine code instructions at user level

c. First-level data cache load hitst at user level

d. First-level data cache load misses at user level

e. First-level data cache store hits at user level

f. First-level data cache store misses at user level

g. Last-level cache load hits at user level

h. Last-level cache load misses at user level

i. Last-level cache store hits at user level

j. Last-level cache store misses at user level

The way how we obtain the following benchmark results is from this terminal command:

```
$ sudo perf stat -e cycles:u -e instructions:u \
                      -e L1-dcache-loads:u -e L1-dcache-load-misses:u \
                      -e L1-dcache-stores:u -e L1-dcache-store-misses:u \
                      -e LLC-loads:u -e LLC-load-misses:u \
                      -e LLC-stores:u -e LLC-store-misses:u ./task1
```

From the first run of the code we obtain the following results:

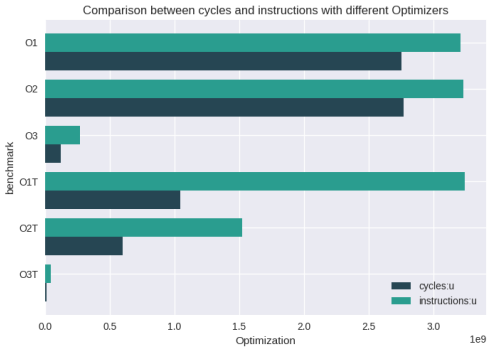
```
CPU = 5.893150 ms

 Performance counter stats for './task1':

     2,743,735,005      cycles:u                  (32.74%)
     3,199,246,694      instructions:u            (44.26%)
       402,366,995      L1-dcache-loads           (55.79%)
       803,099,963      L1-dcache-load-misses     (67.31%)
       799,527,269      L1-dcache-stores          (67.46%)
   <not supported>      L1-dcache-store-misses
         1,628,527      LLC-loads                 (67.46%)
             1,094      LLC-load-misses           (44.21%)
         2,479,174      LLC-stores                (21.69%)
               258      LLC-store-misses          (21.69%)

       0.590644181 seconds time elapsed

       0.590584000 seconds user
       0.000000000 seconds sys
```

Changing the code in such way that array is now traversed by rows instead of by columns, hence taking advantage of both the row major order used in C and the cache hierarchy we obtain the following results:

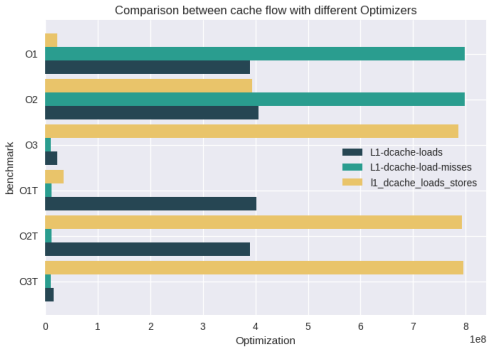
```
CPU = 1.423880 ms

 Performance counter stats for './task1':

       648,114,804      cycles:u                  (32.97%)
     1,624,440,721      instructions:u            (44.14%)
       396,820,828      L1-dcache-loads           (55.31%)
        12,204,130      L1-dcache-load-misses     (66.48%)
       383,946,246      L1-dcache-stores          (66.48%)
   <not supported>      L1-dcache-store-misses
             1,680      LLC-loads                 (66.48%)
                40      LLC-load-misses           (44.69%)
         6,988,534      LLC-stores                (22.35%)
                67      LLC-store-misses          (22.35%)

       0.143955657 seconds time elapsed

       0.135983000 seconds user
       0.007999000 seconds sys
```

1.4 Conclusion

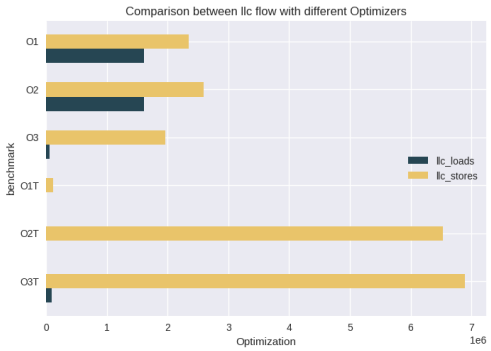
From the following graphs we can see the results of the different optimization methods and the comparison between normal matrix calcuation and row-major-ordering used in C. As can be shown, the cycles and instructions are much smaller in the when using both optimization approaches in comparison to the initial approach.
We observe similar results in the usage of L1-cache with an exception of the load misses, which are less frequent in row-major-version of the program in general.
Looking at llc_flow behaviour, we see an improvement in llc_loads with row-major-ordering, however llc_stores are increased.



(a)



(b)



(c)

2 PERF (II)

The program given initializes two random matrices. The first part performs simple matrix multiplication without taking advantage of the row-major order used in C and the cache hierarchy. We analyze the performance of this approach:

2.1 Program without optimization

```
CPU = 655.932007 ms Mul1

 Performance counter stats for './task2':

     6,065,174,592      cycles:u                  (33.25%)
    18,111,358,969      instructions:u            (44.57%)
     4,031,509,126      L1-dcache-loads           (55.85%)
     2,034,376,280      L1-dcache-load-misses     (66.88%)
     2,017,118,230      L1-dcache-stores          (66.88%)
   <not supported>      L1-dcache-store-misses
           708,795      LLC-loads                 (66.89%)
             3,761      LLC-load-misses           (44.15%)
           429,307      LLC-stores                (22.08%)
            53,142      LLC-store-misses          (22.07%)

      1.413953736 seconds time elapsed
```

```
       1.409785000 seconds user
       0.004005000 seconds sys
```

Afterwards we apply said optimization towards more beneficial calculation order (and check for correctness, of course) and run the performance analysis again:

2.2 Program with optimization

```
CPU = 664.648987 ms Mul1

 Performance counter stats for './task2':

     6,148,114,191      cycles:u                  (33.03%)
    18,299,920,676      instructions:u            (44.29%)
     4,060,471,919      L1-dcache-loads           (55.58%)
     2,035,551,933      L1-dcache-load-misses     (66.82%)
     2,010,732,108      L1-dcache-stores          (67.10%)
   <not supported>      L1-dcache-store-misses
           563,053      LLC-loads                 (67.10%)
             4,433      LLC-load-misses           (44.42%)
           468,321      LLC-stores                (21.93%)
            65,307      LLC-store-misses          (21.93%)

       1.350588624 seconds time elapsed

       1.346580000 seconds user
       0.004007000 seconds sys
```

Overall, no significant improvement can be seen (1.41s versus 1.35s). The main difference can be observed in LLC-loads.

3 GPROF

3.1 self-explained "profile" file

This file provide benchmarks of all the function runned by the program `algi.c`, giving the the percentage of the total running time of the time program used by one function, the number of seconds accounted for by one function alone and the average number of milliseconds spent in this ms/call function per call.

3.2 Bottlenecks and best candidates to parallelized

a Functions with high "self ms/call" (shown in green) values and a big percentage of running time are considered our bottlenecks. The cannot be divided into smaller pieces and therefore not be parallelized.

b In contrast, functions with low "self ms/call" (shown in blue) values and frequent calls are already divided up in small, very managable chunks and can therefore be parallelized. In this case we divide the matrices in chunks and loop over them seperately in parallel (for example domain decomposition).

Time %	cumulative seconds	self seconds	calls	self ms/call	total ms/call	name	total time ms
8.14	0.5	0.07	1	70	90.54	Label_Binary_Image	70
6.98	0.68	0.06	1	60	173.39	Binary_Dilation	60
6.98	0.62	0.06	2	30	30	BMP_Read_Color_Image	60
3.49	0.82	0.03	1	30	61.07	Or_Gray_Images	30
3.49	0.79	0.03	2	15	15	BMP_Write_Gray_Image	30
3.49	0.76	0.03	3	10	30.53	Binarize_Gray_Image	30
1.16	0.86	0.01	1	10	10	BMP_Write_Color_Image	10
5.81	0.73	0.05	7	7.14	7.14	BMP_Create_Gray_Image	49.98
1.16	0.85	0.01	2	5	35	Color_Image_to_Gray	10
22.09	0.19	0.19	234249700	0	0	BMP_Read_Gray_Pixel	0
9.3	0.27	0.08	103980960	0	0	BMP_Write_Gray_Pixel	0
9.3	0.35	0.08	51966720	0	0	BMP_Read_Color_Pixel	0
9.3	0.43	0.08	0	0	0	_init	0
6.98	0.56	0.06	13014556	0	0	BMP_Write_Color_Pixel	0
1.16	0.83	0.01	12991680	0	0	Read_Label	0
1.16	0.84	0.01	296827	0	0	Update_Lookup	0
0	0.86	0	1187308	0	0	Minimum_Label_Neighbor	0
0	0.86	0	1187308	0	0	Update_Lookup_Neighbor	0
0	0.86	0	296827	0	0	Label_Pixel	0
0	0.86	0	296827	0	0	Minimum_Label	0
0	0.86	0	7	0	0	BMP_Free_Gray_Image	0
0	0.86	0	3	0	0	BMP_Free_Color_Image	0
0	0.86	0	1	0	99.89	Add_Color_Images	0
0	0.86	0	1	0	0	BMP_Create_Color_Image	0
0	0.86	0	1	0	213.67	Binary_Closing	0
0	0.86	0	1	0	33.13	Binary_Erosion	0
0	0.86	0	1	0	0	Create_Label_Array	0
0	0.86	0	1	0	0	Destroy_Label_Array	0
0	0.86	0	1	0	0	Readjust_Lookup	0

4 OpenMP (Compilation and basic directives)

4.1 CPU information from the Linux kernel

```
model name      : 11th Gen Intel(R) Core(TM) i7-1165G7 @ 2.80GHz

processor       : 0, physical id 0
processor       : 1, physical id 0
processor       : 2, physical id 0
processor       : 3, physical id 0
processor       : 4, physical id 0
processor       : 5, physical id 0
processor       : 6, physical id 0
processor       : 7, physical id 0

cpu cores       : 4
siblings        : 8

processor       : 0, physical id:       0, core id: 0
processor       : 1, physical id:       0, core id: 1
processor       : 2, physical id:       0, core id: 2
processor       : 3, physical id:       0, core id: 3
processor       : 4, physical id:       0, core id: 0
processor       : 5, physical id:       0, core id: 1
processor       : 6, physical id:       0, core id: 2
processor       : 7, physical id:       0, core id: 3
```

4.2 Number of cores and threads from internet

In the intel website we can find the same information:

Especificaciones de la CPU

Cantidad de núcleos	4
Cantidad de subprocesos	8
Frecuencia turbo máxima	4,70 GHz
Caché	12 MB Intel® Smart Cache

4.3 Program explanation

Task1 is a simple for loop iterating 2 billion times and counting up two variables, j as a long datatype and k as a double datatype. In accordance with the task description we run the program under different conditions: 1 thread, 2 threads, 2 threads but limited to one CPU, 4 threads.

4.4 Benchmarks with multiple threads

Analyzing the behaviour with gnome system monitor we can see spikes in utilization of the cores, depending on usage. With altering the number of threads we allow the program to

run on more than one CPU, resulting in significant speedup of the total execution time (see SpeedUp in table and blue line in graph. What can also be observed on the other hand is actually a decrease in efficiency with an increase of speedup, due to CPU timing, coordination and communication between processing units.

Repetition	1 Thread		2 Threads		2 Threads (CPU locked)		4 Threads	
	CPU Time	Wall Time	CPU Time	Wall Time	CPU Time	Wall Time	CPU Time	Wall Time
1	1001	1000	1047	524	1020	1020	1301	327
2	996	996	1078	540	1016	1015	1340	335
3	996	996	1106	554	1018	1017	1299	324
4	996	995	1048	543	1022	1021	1319	332
5	999	999	1066	534	1073	1073	1337	336
6	1034	1033	1084	544	1020	1020	1304	326
7	1058	1057	1081	541	1019	1019	1300	326
8	1002	1001	1080	540	1009	1009	1298	327
9	1008	1007	1077	540	1015	1015	1302	328
Average	1010	1009	1074	540	1024	1023	1311	329
	S(1)		S(2)		S(2L)		S(4)	
SpeedUp	1		1.86913580246914		0.98642632207623		3.06788247213779	
Efficiency	1		0.93456790123457		0.98642632207623		0.76697061803445	

4.5 Speedup and Efficiency

4.6 Task 2 program explanation

The program task 2 creates a big random number ”limit” and iterates ”limit” times to increase the variable j by 1 for each loop in a parallel environment.The output of the program gives us the value of j for each thread used.

4.7 Program behaviour

We observe that the the order of the execution of the threads as well as the starting thread PID is not constant but changes every execution. This does not change when setting the PID variable to private, even though, now every thread used it's own private copy of the variable. The reason for this is, that in the given program the PID variable is not actually being used for anything but giving the overview.

4.8 Changing from "private" to "firstprivate"

Now we take a look at the initialization of the "limit" variable. In the master thread the variable is initally set to -1, however, with being set to private in the parallel part, it is re-initialized for every parallel thread to 0. Changing the variable to firstprivate results in the initial value being kept even in the parallel threads.

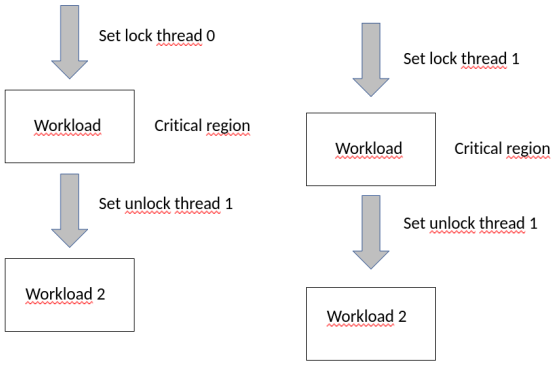
5 Optional assignment

5.1 Program task 3 explanation

The program task 3 creates a parallel enviroment with 2 threads. The program has two workloads that behave in the same way (1000 loops, count up everz 10th loop, looped 10 times).

5.2 Behaviour semaphores

As shown in the image with the semaphores the thread that arrives first has the precedence and the other must wait the execution of the first one. When the first thread ends its task the second one can execute the workload. This is the reason why they run alternately.

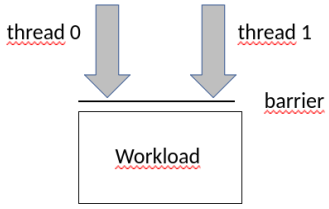


5.3 Comment omp lock and omp unlock

If we comment the omp_set_lock and omp_set_unlock the program doesn't behave in the same way because we remove the "precedence" we create before using sempahores. So every thread execute could execute the workload in the same moment.
If we use the command "#pragma omp critical" we obtain the same results as using sempahores. A critical region behaves as semaphores, creating precedence between threads and so the workload can not be execute in the same moment by different threads.

5.4 Inserting barrier synchronization

Barrier block everythread before the workload and decide who goes first as shown in this picture. If we comment omp_unset_lock we remove the option for the lock to be opened



again, resulting in the program being stuck after the first iteration of the first thread.
A similar problem arises with the use of the barrier inside of the lock. As the barrier waits

for all threads to be finished with the current task, the program gets stuck, because the semaphore does not allow the second thread to enter into the workload.

5.5 task 4

The result of the calculation is wrong because both threads are trying to increase the shared variable k at the same the. This results in the variale being increased by 1 twice for each time the loop runs, thus making the result only half of the correct answer.
Introducing the reduction clause splits the workload to two separate private variables and combines them after the loop is done, resulting in the correct answer.