COMP30250 - Assignment 4
Parallel Programming with OpenMP

November 28, 2021

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1 Introduction

The variants for this assignments are the following:

1. Compute the norm in two successive steps: parallelisation of matrix multiplication, then parallelisation of matrix norm computation
2. Left matrix is horizontally partitioned
3. Compute 1-norm (maximum absolute column sum norm)

Command `cat /proc/cpuinfo` displays 16 processors, therefore `p` will be 16 for the parallel programs.

[15]:
```python
import pandas as pd
import matplotlib.pyplot as plt
import matplotlib as mpl
import numpy as np
import matplotlib.gridspec as gs

plt.style.use('ggplot')
```

2 Code explanation

First, we get the number of processors of the computers with this function

```c
// line 47
nb_thrds = omp_get_num_procs();
```

Then we set the numbers of threads to create for the following OpenMP directives

```c
// line 69
omp_set_num_threads(nb_thrds);
```

This part compute the product of matrix `a` and `b` and store the result in matrix `c`. I combine a `parallel` and `for` directives to launch a team of thread to execute the foor loop in parallel. I choose to parallelize the `i` loop in order to partition horizontally the matrix `a`. I create three different programs to test the different schedule (`static`, `dynamic` and `guided`). Matrix `a`, `b`, `c` and their size are `shared` across the threads and only read. The `sum`, `j`, `k` are local to each thread and instances of these variable are created in all threads thanks to the `private` directive.

```
// line 74
#pragma omp parallel for schedule(dynamic, chunk_size) shared(a, b, c, m_size) private(sum, j, k
for (i = 0; i < m_size; i++)
{
    for (j = 0; j < m_size; j++)
    {
        sum = 0.0;
        for (k = 0; k < m_size; k++)
        {
            sum += a[i*m_size+k] * b[k*m_size+j];
        }
        c[i*m_size+j] = sum;
    }
}
```

This part compute the 1-norm of matrix `c`. I choose to parallelize the `j` loop in order to create vertical partition of the matrix `c` since 1-norm need the sum of columns. The `reduction` directive creates private `norm` variables for every thread. When threads are joined, it will update the outside `norm` variable by computing the `max` of all the private `norm` variables.

```
// line 89
norm = 0.0;
#pragma omp parallel for schedule(dynamic, chunk_size) shared(c, m_size) private(i, sum) reducti
for (j = 0; j < m_size; j++)
{
    sum = 0.;
    for (i = 0; i < m_size; i++)
    {
        sum +=  c[i*m_size+j] > 0. ?  c[i*m_size+j] : -c[i*m_size+j];
    }

    norm = (norm < sum) ? sum : norm;
}
```

3 Benchmarks of parallel and serial programs for difference matrix size

3.1 Benchmark of parallel programs (static schedule)

	matrix_size	schedule	chunk size	timing
0	128	static	2	0.019354
1	128	static	4	0.019726
2	128	static	8	0.018323
3	128	static	16	0.017857
4	128	static	32	0.018945
..	...	...	...	...

92	2048	static	32	45.575052
93	2048	static	64	49.536260
94	2048	static	128	47.112740
95	2048	static	256	45.876026
96	2048	static	512	46.193746

[97 rows x 4 columns]

3.2 Benchmark of parallel programs (dynamic schedule)

	matrix_size	schedule	chunk size	timing
97	128	dynamic	2	0.023181
98	128	dynamic	4	0.023250
99	128	dynamic	8	0.022289
100	128	dynamic	16	0.022658
101	128	dynamic	32	0.024076
..	...	...	...	...
189	2048	dynamic	32	42.714066
190	2048	dynamic	64	44.126901
191	2048	dynamic	128	44.098373
192	2048	dynamic	256	57.887055
193	2048	dynamic	512	74.683294

[97 rows x 4 columns]

3.3 Benchmark of parallel programs (guided schedule)

	matrix_size	schedule	chunk size	timing
194	128	guided	2	0.019024
195	128	guided	4	0.020568
196	128	guided	8	0.019301
197	128	guided	16	0.020062
198	128	guided	32	0.019772
..	...	...	...	...
286	2048	guided	32	43.208950
287	2048	guided	64	41.282658
288	2048	guided	128	42.201588
289	2048	guided	256	54.907581
290	2048	guided	512	70.753524

[97 rows x 4 columns]

3.4 Benchmark of serial programs

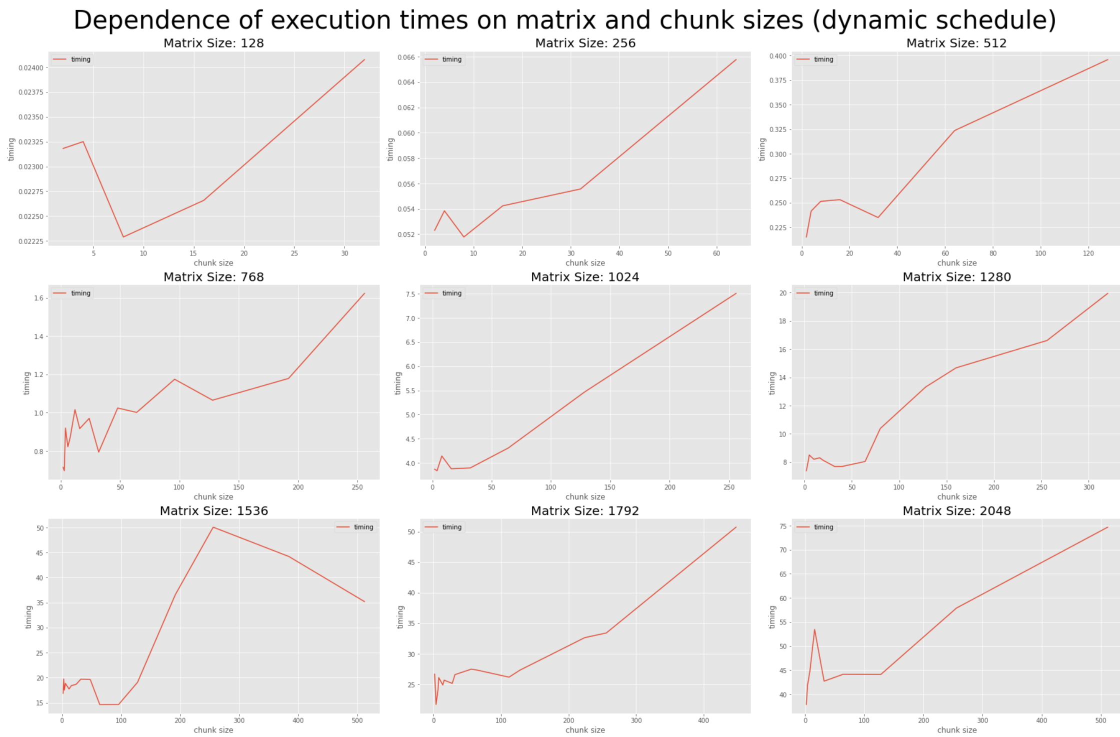
	matrix_size	timing
0	128	0.010308
1	256	0.105016
2	512	0.850544
3	768	2.940415
4	1024	24.621667
5	1280	43.775354
6	1536	83.561879
7	1792	167.386475
8	2048	242.297539

4 Dependence of the execution time of the program on the matrix size n

4.1 Static schedule

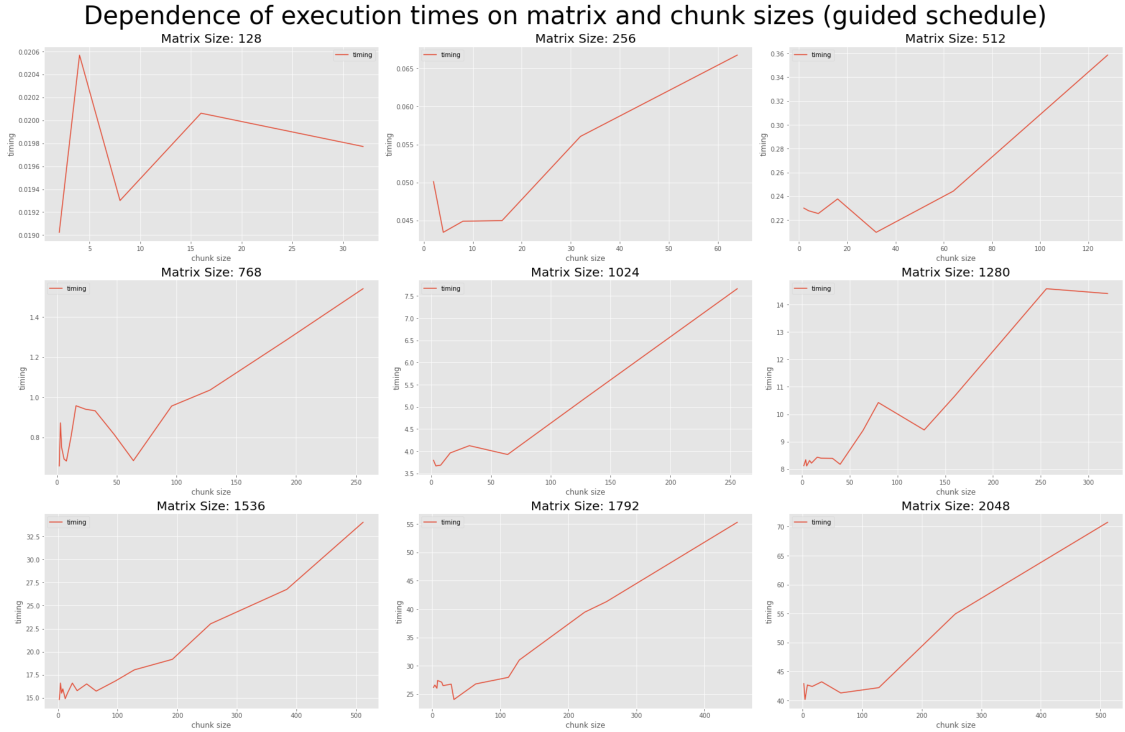
The variation are erratic when we change the value of chunk size. The graphs don't seem to follow any general trend. For instance, for matrix of size 1536, the timing constantly vary between 14 and 16s without clearly indicating whether the performance are better or not.

4.2 Dynamic schedule



The graphs generally follow a linear evolution for dynamic schedule. It seems that choosing small chunk size gives better result in general.

4.3 Guided schedule



Guided schedule gives result similar to the dynamic one. Evolution is mostly linear and small chunks give better results overall.

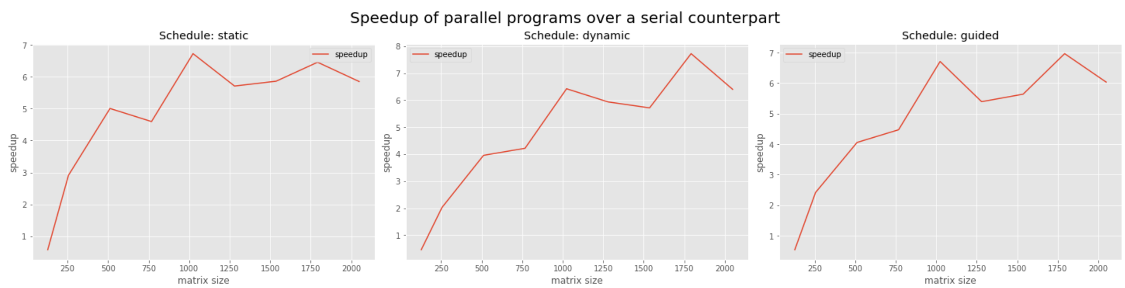
5 Speedup over a serial counterpart of the program

Speedup is calculated as follows:

$$S(m) = \frac{T_{serial}(m)}{T_{parallel}(m)}$$

where m is matrix size

For each matrix size m, the speedup is calculated using the chunk size giving the best performance



Parallel programs outperforms for matrix for a size $m > 200$.

6 Dependence of the execution time on chunk sizes in schedule

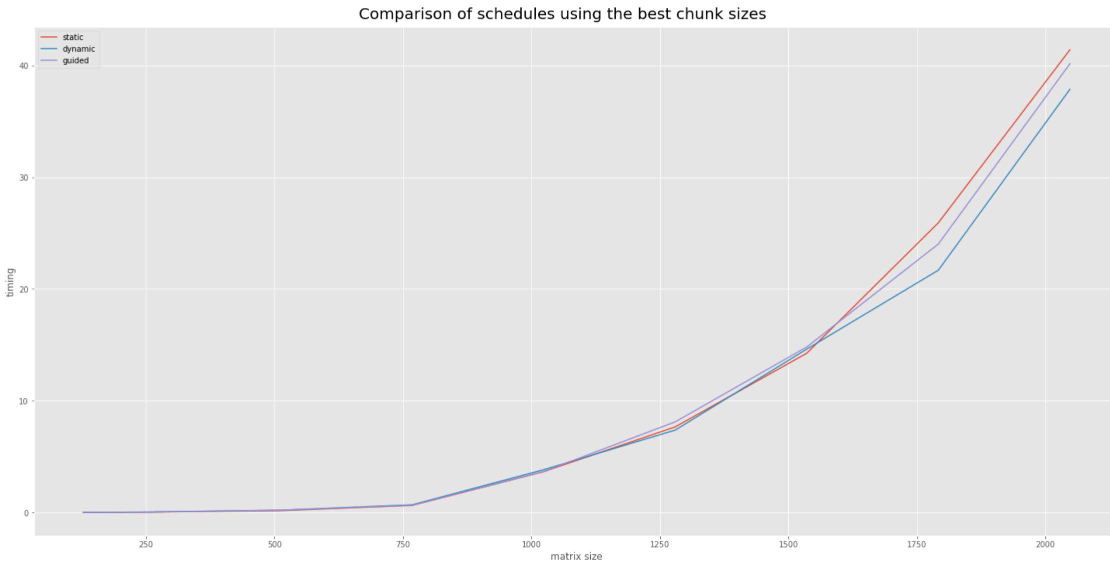
	matrix_size	schedule	chunk size	timing	speedup
0	128	static	16	0.017857	0.577275
1	256	static	64	0.036048	2.913216
2	512	static	16	0.169869	5.007057
3	768	static	8	0.639648	4.596926
4	1024	static	64	3.660362	6.726566
5	1280	static	16	7.665756	5.710507
6	1536	static	256	14.255738	5.861631
7	1792	static	8	25.923004	6.457063
8	2048	static	8	41.396349	5.853114

6.1 Best chunk size for dynamic schedule

	matrix_size	schedule	chunk size	timing	speedup
0	128	dynamic	8	0.022289	0.462488
1	256	dynamic	8	0.051782	2.028033
2	512	dynamic	2	0.214986	3.956275
3	768	dynamic	3	0.697145	4.217795
4	1024	dynamic	4	3.834977	6.420291
5	1280	dynamic	2	7.378175	5.933087
6	1536	dynamic	64	14.626963	5.712866
7	1792	dynamic	4	21.682705	7.719815
8	2048	dynamic	2	37.864137	6.399130

6.2 Best chunk size for guided schedule

	matrix_size	schedule	chunk size	timing	speedup
0	128	guided	2	0.019024	0.541863
1	256	guided	4	0.043434	2.417820
2	512	guided	32	0.209620	4.057551
3	768	guided	2	0.657356	4.473093
4	1024	guided	4	3.668877	6.710955
5	1280	guided	5	8.116453	5.393409
6	1536	guided	2	14.818655	5.638965
7	1792	guided	32	24.024544	6.967311
8	2048	guided	4	40.147863	6.035129



For large matrix, guided schedule seems to be better than dynamic (difference of ~3s) and dynamic is better than static (difference ~1s)