PARALLEL A-STAR

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1 Introduction

Implementation of the A-Star algorithm both parallel and sequential versions on large and weighted benchmark graphs. Study on performance and comparison between the 2 implementations.

The project implies:

- reading of large weighted benchmark graphs
- run of A-Star parallel, sequential and standard Djkstra algorithm
- comparison considering computation time and memory usage

2 Reading

Starting from a .map file (standard format for maps rappresentation, using ascii characters to represent walls and passable terrain) the `graph_generator.py` python script is able to create a .txt with the format required by our A-Star implementation.
In the benchmark section we have:

- huge-graphs: graphs with millions of nodes, used for comparisions on large dimensions
- maze: graph with a small number of solutions (few path available from a point to another)
- street-maps: true city grid maps with different size
- small-graphs: generated by us used for testing

The weight of the edges can be randomized by the script in order to raise a level of difficulty in finiding a path (all the grids benchmark have only edge with weight 1)

3 Basic structures

The project started implementing all the basic structures needed by the algorithm. All the structures are as generic as possible to encourage reuse and are dynamically allocated and are implemented using lists to have no static limitations.
Each structure have a create fucntion for allocation and a destroy one for disallocation of the memory.

3.1 hash table

Is implemented with multiplicative modular method with golden ratio:

$$golden\_ratio = (\sqrt{5} - 1)/2 \tag{1}$$

$$P = 8191 \tag{2}$$

$$hash(key, module) = ((key * golden\_ratio)\%P)\%module \tag{3}$$

The structures re-allocates itself when reaches the 3/4 of the maximum capacity, in case of collisions concatenate the elements in a list (keeps in the first place the last inserted item).

3.2 heap

The heap structures uses hash table for faster addressing and is used as a priority queue with the possibility to have MAX or MIN priority as first element

3.3 queue

A generic list with Head and Tail pointers with a generic item. FIFO queue with head extraction and tail insertion

3.4 stack

LIFO implementation with both insertion and extraction on the head

3.5 graph

Generic Graph with possibility to be UNDIRECTED or DIRECTED, have a pointer to generic data (possibility to manipulate passing custom funcitons eg. 2d data).
Each vertex has a true_cost (the cost of the path from start to that vertex) and a heuristic_cost (exstimation of the cost from that node to the destination node). The graph also contains a Hash table of all the nodes used to efficiently find a node (a good improvement in the graph generation).

3.6 message queue

Is composed by a vector of queue, as long as the number of threads of the program. The receive and send method are protected by a mutex to avoid race conditions, and receive a Id to send a message to a specific queue. Have a function to check if all is empty used for the terminate detection.

4 A-Star Implementation

The A-Star algorithm is based on the use of a heuristic function which exstimates the cost from a point to a destination node.

Both implementations are based on two set, the OPEN and the CLOSE one. The first is implemented using a priority queue (our heap 3.2) and contains nodes that have been discovered but not expanded yet. The other one with a hash table 3.1 and contains node that have been expanded.

All vertex contains a link to a parent vertex which is used to keep trace of the path found by the algorithm, at the end the solution is inserted in a stack 3.4 pushing from the goal node and going backward.

4.1 Sequential

Starting from the pseudo-code taken from (insert bibliography)

```
Initialize OPEN to {s_0};
while OPEN $\neq$ 0; do
Get and remove from OPEN a node n with a smallest f(n);
Add n to CLOSED;
if n is a goal node then
  Return solution path from $s\_0$ to n;
for every successor n' of n do
  $g_1$ = g(n) + c(n; $n'$);
  if n' $\in$ CLOSED then
      if g_1 < g(n') then
          Remove n' from CLOSED and add it to OPEN;
      else
          Continue;
  else
      if n' $\notin$ OPEN then
          Add $n'$ to OPEN;
      else if $g_1$ $\geq$ g($n'$) then
          Continue;
  Set g($n'$) = g_1;
  Set f($n'$) = g($n'$) + h($n'$);
  Set parent($n'$) = n;
Return failure (no path exists);
```

Where

- s_0 : is the starting node
- $g(n)$: is the best known cost of the path from s_0 to n
- $h(n)$: is the heuristic function
- $f(n)$: is the sum $g(n) + h(n)$ is used in the OPEN set to calculate the priority

4.2 Parallel

Implementation of the decentralized AStar algorithm, where each thread has its own CLOSED and OPEN set, when a thread discover a neighbor node chose the thread that will expand it. When a thread find a solution compare the cost with the global one and if have a lower cost it just copies the cost (the global cost is protected with a lock).

4.2.1 Pseudo-code

```
 1 Initialize OPENp for each thread p;
 2 Initialize incumbent.cost = $\infty$;
 3 Add s0 to OPENComputeRecipient(s0);
 4 In parallel, on each thread p, execute 5-31;
 5 while TerminateDetection() do
 6   while BUFFERp $\neq$ 0 ; do
 7       Get and remove from BUFFERp a triplet (n0; g1; n);
 8       if n0 2 CLOSEDp then
 9           if g1 < g(n0) then
10               Remove n0 from CLOSEDp and add it to OPENp;
11              else
12                   Continue;
13       else
14           if n0 =2 OPENp then
15               Add n0 to OPENp;
16           else if g1  g(n0) then
17               Continue;
18       Set g(n0) = g1;
19       Set f(n0) = g(n0) + h(n0);
20       Set parent(n0) = n;
21   if OPENp = ; or Smallest f(n) value of n 2 OPENp $\geq$ incumbent.cost then
22       Continue;
23   Get and remove from OPENp a node n with a smallest f(n);
24   Add n to CLOSEDp;
25   if n is a goal node then
26       if path cost from s0 to n < incumbent:cost then
27           incumbent = path from s0 to n;
```

```
            incumbent.cost = path cost from s0 to n;
 for every successor n0 of n do
     Set g1 = g(n) + c(n; n0);
     Add (n0; g1; n) to BUFFER ComputeRecipient(n);
if incumbent:cost = 1 then
 Return failure (no path exists);
else
 Return solution path from s0 to n;
```

Where

- $BUFFER$: is the structure for thread communication 4.2.3
- *incumbent* : the shared best known path
- $TerminateDetection$: function to check if the path search is completed 4.2.4
- $ComputeRecipient$: function to chose the thread that will expand the node 4.2.2

4.2.2 Compute recipient

A Funciton to map the nodeId into a thread identifier we have 2 implementaitons. The basic module computed as $node\_id \; \% \; number\_of\_threads$. A implementation of multiplicative hashing:
$h(node\_id) = ((a * node\_id \; + \; b) \; \% \; p) \; \% \; number\_of\_threads$
where:

- p: prime large number (we used INT_MAX = $2^{31} - 1$)
- a: random integer [1,p-1]
- b: random integer [0,p-1]

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4.2.3 Thread communication

A message queue 3.6 structure is used to allows threads to communicate: a thread compute the recipient and send a message using the thread destinaiton with the node and cost.

4.2.4 Terminate condition

When a thread has his OPEN set empty or there isn't elements that will improve the cost of the path sets his termiantion_flag. A thread waits on his condition variable if have no message pending and his termiantion flag is set, if all other threds are waiting the program terminates instead.

```
lock_mutex
while termination_flags[this_thread] and
BUFFER(this_thread) = 0 and not program_terminated
  if(counter  $\geq$  n_threads - 1 and all buffer empty
      program_terminated = 1
      signal all condition variables
  else
      counter++
      wait on cv of this_thread
      counter--
mutex unlock
if(program_terminated)
 return true
else
 return false
```

Where

- *termination_flags*: array of flags setted by a thread when the OPEN set is empty or doesn't have node with a minor cost then the acutal path
- *program*$_t$*erminated*: flag setted by last thread awake when detects termination of the program
- *counter*: counter of sleeping threads
- *mutex*: one mutex to protect all condition variables
- *BUFFER*: message queue of each thread

5 Experimental evaluation

Here we report all the test executed to compare the performance between the sequential and parallel version of the A-Star implementation. All the test are performed on a Linux environment.

5.1 performance

5.1.1 Grid Milan

The graph generated from the grid of Milan (1024x1024) has around 800k nodes and has random generated weights to increase the difficulty to find the path with the best cost.

Looking at the Figure 2, and considering that we choosed the best efficient number of threads for the parallel A*, we can notice a better performance compare to the sequential A* and the Dijkstra algorithms. To find the best result we tried the parallel A* changing the number of threads and the compute recipient

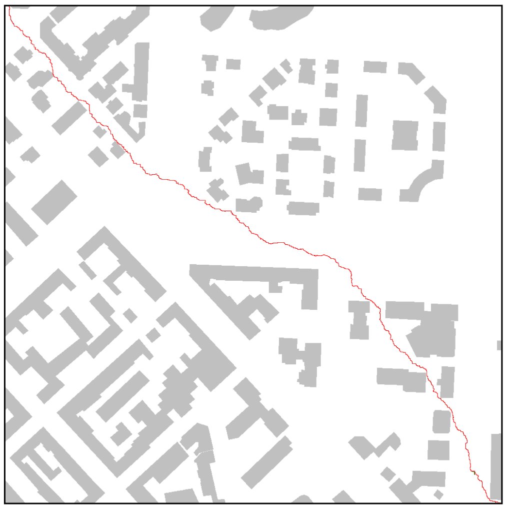


Figure 1: Milan map with path found

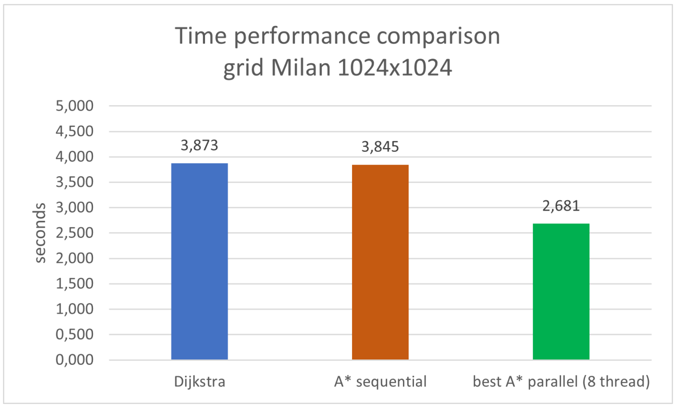
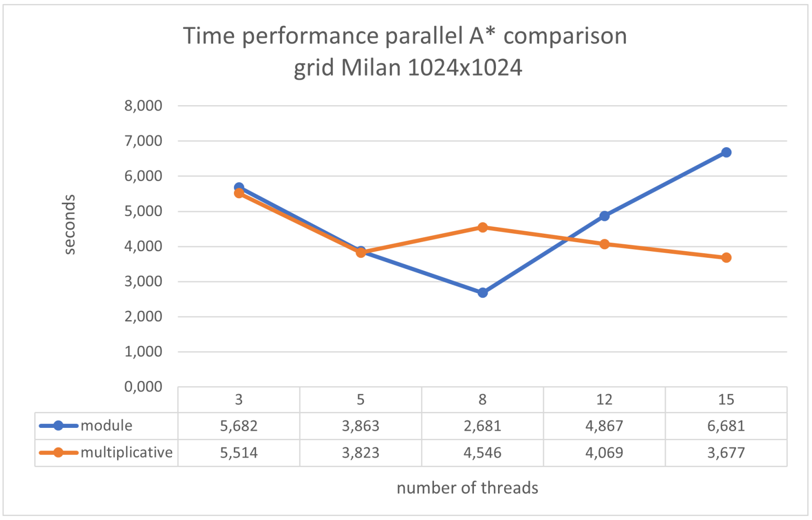


Figure 2: Performance comparison on different algorithms



	3	5	8	12	15
module	5,682	3,863	2,681	4,867	6,681
multiplicative	5,514	3,823	4,546	4,069	3,677

Figure 3: Performance comparison on different thread number and compute recipient function

function, the Figure 3 shows all the experimental results of the tests. Comparing the two compute recipient functions (simple module and multiplicative hash 4.2.2) on this relative small graph, the performance are comparable except on a big number of threads.

5.1.2 Big Map

To test more our algorithm we used a bigger graph, always with random weights, with about 4 Millions nodes.

5.2 memory occupation

6 Summary

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References

7 Appendix

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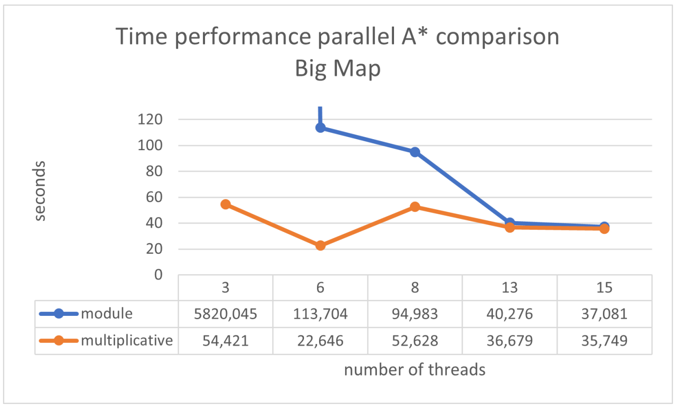

	3	6	8	13	15
module	5820,045	113,704	94,983	40,276	37,081
multiplicative	54,421	22,646	52,628	36,679	35,749

Figure 4: TODO