Particle Swarm Optimization

A parallelized approach

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December 14, 2022

Introduction

Particle Swarm Optimization

Particle Swarm Optimization is an optimization algorithm for nonlinear functions based on bird swarms.

In PSO, a particle is characterized by:

- position x;
- velocity v;
- performance measure $f(x)$;
- personal best y;
- global best position z.

The solution is achieved by perturbing each particle according to the neighbors:

1. $v' = w \cdot v + \phi_1 U_1 \cdot (y - x) + \phi_2 U_2 \cdot (z - x)$
2. $x' = x + v'$

Particle Swarm Optimization

Easom function

$$f(x) = -\cos(x_1)\cos(x_2)\exp(-(x_1-\pi)^2-(x_2-\pi)^2)$$

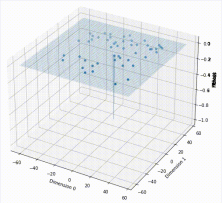

Figure 1: PSO start

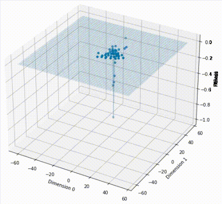

Figure 2: PSO mid

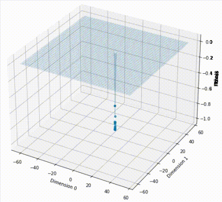

Figure 3: PSO end

DevOps

Pipeline

The proposed solution is provided with a pipeline for containers creation and usage suitable for a cluster environment.

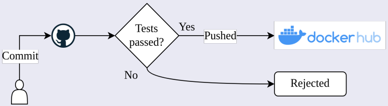

Figure 4: Container creation

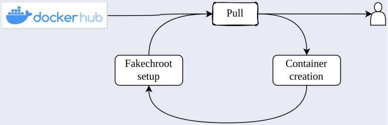

Figure 5: Container pull

Analyzing the program behavior

In order to know each process and thread state and visualize a thread-safe logging library has been employed: The logs follows a common pattern so as to be easily processed.

```
15:27:58 DEBUG : PSODATA    :: problem dimension :: 2
...
15:27:58 DEBUG : New best global solution found
...
15:27:58 INFO  : COMPUTING  :: iteration 10/10
Best fitness 4.690962
```

To recover the particles' positions during the entire program execution, we have stored each particle position at each iteration within a SQLite database.

Serial version of the algorithm

Algorithm 1 Particle Swarm Optimization (Nearest Neighbors)

```
function PSO(S, D, MAX_IT, n, f, v, x, x_min, x_max, v_max)
    INITIALIZE(S, D, f, v, x, x_min, x_max, v_max)
    it = 0
    repeat
        for each particle i ∈ S do
            if f(x_i) < f(pb_i) then
                pb_i ← x_i
            end if
        end for
        S' = COPY(S)
        for each particle i ∈ S do
            S' = SORT(S', i)
            for each particle j ∈ S' do
                if f(x_j) < f(gb_i) then
                    gb_i ← x_j
                end if
            end for
        end for
        for each particle i ∈ S do
            for each dimension d ∈ D do
                v_{i,d} = v_{i,d} + C_1 · Rnd(0,1) · [pb_{i,d} − x_{i,d}] + C_2 · Rnd(0,1) · [gb_d − x_{i,d}]
                x_{i,d} = x_{i,d} + v_{i,d}
            end for
        end for
        it ← it + 1
    until it < MAX_ITERATIONS
    return x
end function
```

We propose an all-to-all parallel computational solution using `MPI_Allgather`.

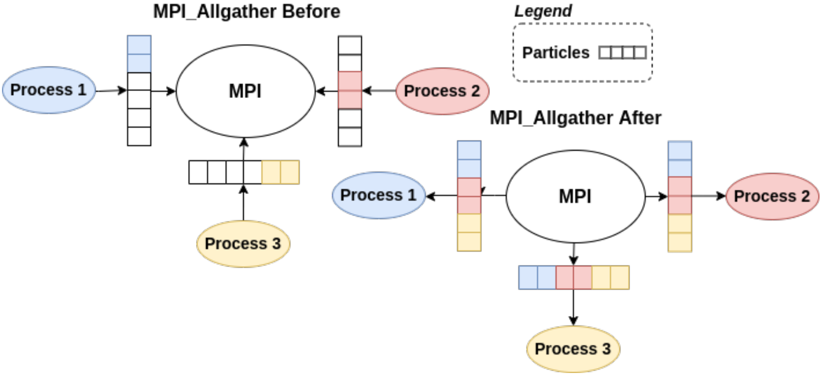

Figure 6: Parallel Architecture

Once each process knows everything about the others, PSO considers the neighbor contributions.

To compute the particle's neighboring positions we have employed the quicksort algorithm.

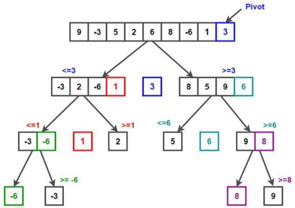

Figure 7: Parallel Quicksort

Finally, the algorithm evolves by updating velocity and position.

Benchmarking, first conclusions

The problem we have decided to address consists in solving the sphere function $\left(f(x_1, x_2, \ldots, x_n) = \sum_{i=1}^{n} x_i^2 \right)$ with:

- 50 particle dimensions;
- 500 iterations;
- 5000 particles.

We have run around 1280 tests considering every possible combination of different parameters:

- processes: `[1 2 4 8 16 32 64]`;
- threads: `[1 2 4 8 16 32 64]`;
- chunks: `[1 2 3 4 5]`;
- places: `[pack scatter pack:excl scatter:excl]`.

Benchmarking, time exceed

Many of the submitted experiments failed due to time exceeded errors. At a first sight, it seems that the failure rate is correlated with the increasing number of processes used for the computation.

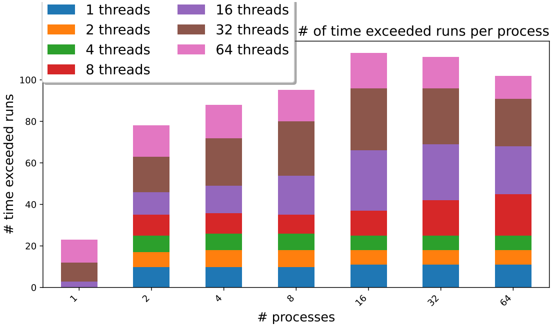

Figure 8: Number of failed run per process

Benchmarking, threads fault

A more depth analysis highlights that the problem is related to threads' overhead.

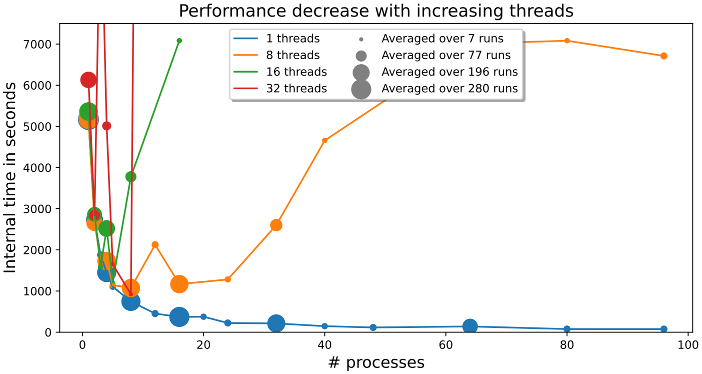

Figure 9: Thread and time exceeded correlation

Benchmarking, single thread solution

- The time required for the execution decreases if the number of processes is increased;
- The proposed solution is influenced neither by the network overhead nor exclusive nodes.

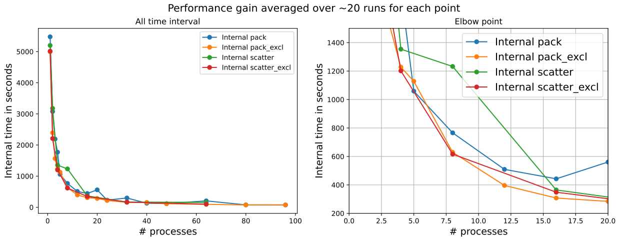

Figure 10: Processes performance

State of the Art Analysis

Ref.	Year	Type	Code	Note
Kennedy et al. (1995)	1995	Serial	No	-
toddguant (2019)	2019	Serial	Yes	1
souusouho (2019)	2019	Serial	Yes	1
kkentzo (2020)	2020	Serial	Yes	1
fisherling (2020)	2020	Serial	Yes	1
Moraes et al. (2015)	2014	MPI	No	-
Nedja et al. (2017)	2017	MPI/MP	No	-
abhi4578 (2019)	2019	MPI/MP,CUDA	Yes	1
LaSEEB (2020)	2020	OpenMP	Yes	2
pg443 (2021)	2021	Serial,OpenMP	Yes	1

only global neighborhood (1) no distance-based implementation (2)

Benchmarking, final remarks

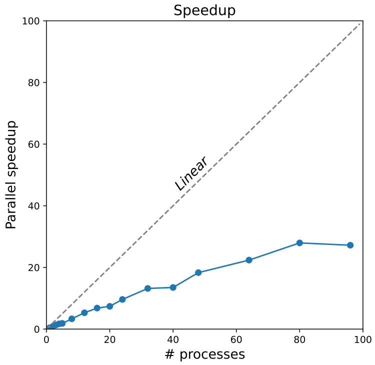

Figure 11: Speedup

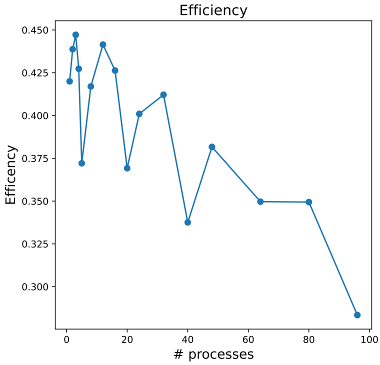

Figure 12: Efficiency

Conclusion and future work

Up until this point, we produced a hybrid OpenMP-MPI algorithm to solve complex continuous optimization problems.

From the benchmarking analysis we claim:

- thread parallelization does not fit well our solution;
- benchmarking the algorithm is far from being trivial;
- the program provides its best result when the number of processes is limited.

As a future work, it would be interesting to:

- complement the already present architecture with different types of neighborhoods;
- analyze which configuration brought the best results.

References I

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