Cooperative Vs Non-Cooperative Parallelization Strategies for Variable Neighborhood Search metaheuristic: A case study on the Capacitated Vehicle Routing Problem

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Publications

List of publications derived from this thesis:

- Kalatzantonakis P., Sifaleras A., and Samaras N., *"Cooperative Vs Non-Cooperative Parallel Variable Neighborhood Search Strategies: A case study on the Capacitated Vehicle Routing Problem"*, re-submitted to *Journal of Global Optimization*, Springer, 2019 (minor revision).
- Kalatzantonakis P., Sifaleras A., and Samaras N., *"On a cooperative VNS parallelization strategy for the capacitated vehicle routing problem"*, to appear in N. Matsatsinis, Y. Marinakis, and P. M. Pardalos (Eds.), *Learning and Intelligent Optimization*. LION13. Lecture Notes in Computer Science, 27-31 May, Chania, Crete, Greece, 2019.
- Kalatzantonakis P., Sifaleras A., Samaras N., Migdalas Ath., *"Parallel Variable Neighborhood Search for the Capacitated Vehicle Routing Problem"*, presented at the 6th *International Conference on Variable Neighborhood Search*. ICVNS, Sithonia, Halkidiki, Greece, October 4-7, 2018, p. 32 (book of abstracts).

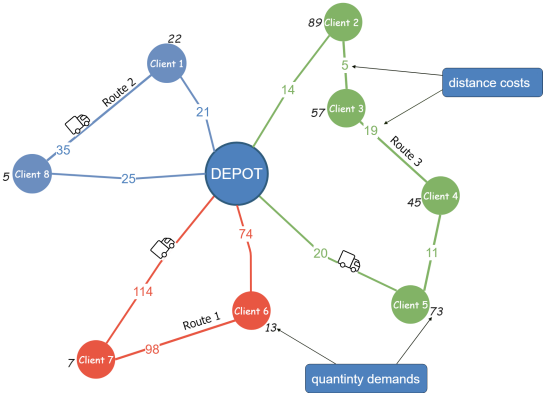
Outline

Objectives

The objectives of this thesis are as follows:

- To survey recent successful parallel implementations of the VNS metaheuristic regarding several variants of vehicle routing problems.
- To present three parallelization strategies using the General VNS variant to tackle the CVRP, in which we examine different approaches of exchanging solutions among parallel executions.
- To experimentally evaluate how the level of cooperation can affect the performance between non-cooperative and cooperative models.
- To improve the quality of the solutions by creating a new parallel model that filters communication based on the tests performed.

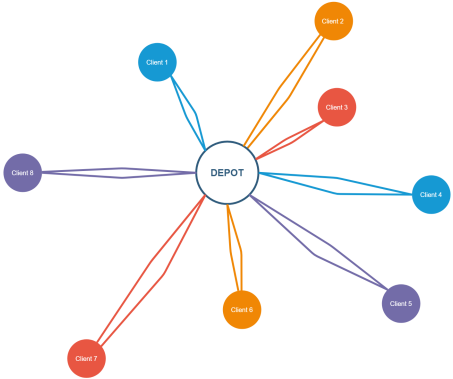
Capacitated Vehicle Routing Problem (CVRP)



CVRP was introduced in:

Dantzig, G. B. and J. H. Ramser (1959).
The truck dispatching problem.
Management Science 6(1),80–91.

Clarke and Wright construction heuristic (1/2)

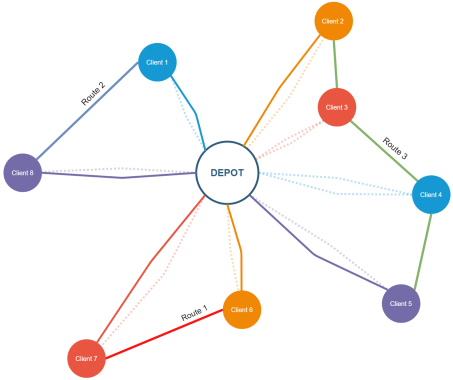


Clarke and Wright heuristic was introduced in:

Clarke, G. and J. W. Wright (1964). *Scheduling of vehicles from a central depot to a number of delivery points*. Operations Research 12 (4), 568–581.

- The algorithm starts with one route for every customer.

Clarke and Wright construction heuristic (2/2)



- In every iteration the number of vehicles is reduced unifying two routes that give max savings.

Variable Neighborhood Search (VNS)

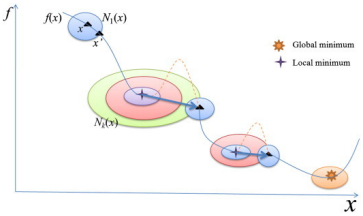


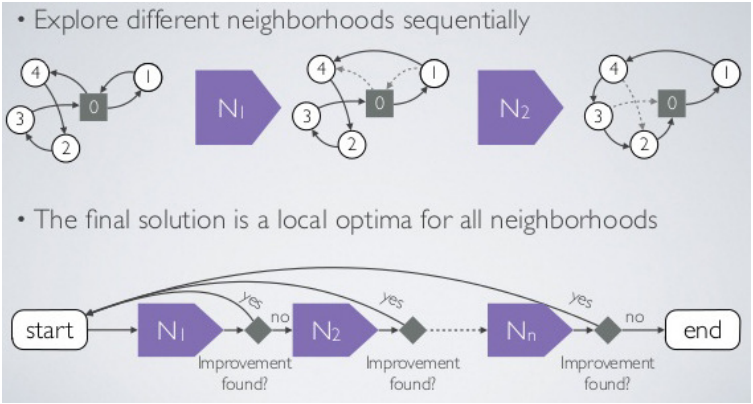
Figure: Systematic neighborhood changes.

VNS is a metaheuristic, or framework for building heuristics, proposed in:
Mladenović, N., Hansen, P.: *Variable neighborhood search*. Computers & Operations Research24(11), 1097–1100 (1997)

- **Fact 1** A local minimum w.r.t. one neighborhood structure is not necessary so with another;
- **Fact 2** A global minimum is a local minimum w.r.t. all possible neighborhood structures.

General Variable Neighborhood Search (GVNS)

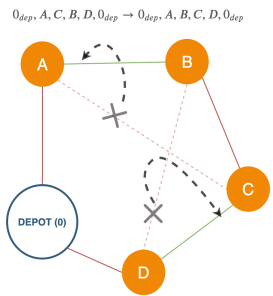
When the change of neighborhoods is performed in a deterministic way (Variable Neighborhood Descent) then a more generic VNS emerges, called **General Variable Neighborhood Descent** (GVNS).



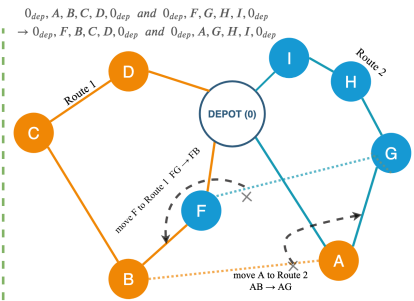
Neighborhood structures

Three operators were used:

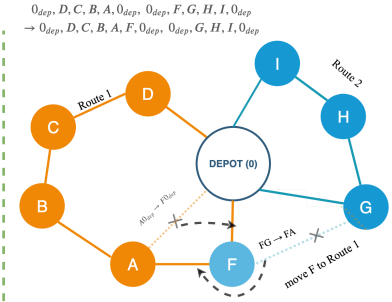
2-opt (Intra-route), Swap (Inter-route), Relocate (Inter-route)



Intra route 2-opt



Inter route swap



Inter route relocate

Computing environment

- We ran the experiments on a computer with the following characteristics:
  - Windows 10 64bit
  - Intel Core i9 CPU 7940X at 3.50 GHz with 20 MB Cache
  - 32GB DDR4 at 3333MHz
- The parallel implementation was done using:
  - Python 3.7 with the multiprocessing library
  - Cython for the compilation.

Benchmark instances

Tests were carried out using the CVRP benchmark instance library (CVRPLib) that can be found at: *http://vrp.galgos.inf.puc-rio.br/index.php/en/*

The sets A, B, E, M, *Golden* and X were used.

- All instances from the sets A,B,E and M have optimum values.
- Many instances from the Golden and the X set do not have an optimum value.

Stopping criteria

Our models are executed until one of the stopping criteria is met. The stopping criteria for this experiment are the following:

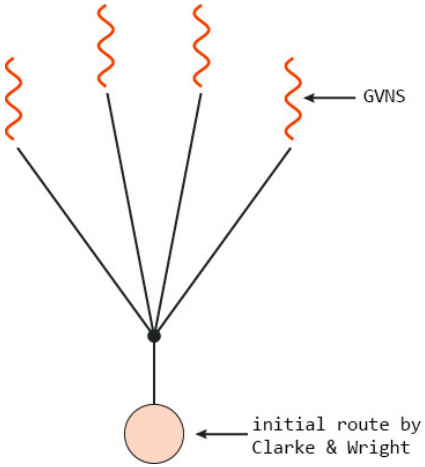
- the maximum execution time; set to 3600 seconds.
- the maximum number of GVNS iterations; set to 300.
- when the optimal value is reached, if it exist.

Parallel strategies

We propose three different strategies to parallelize GVNS:

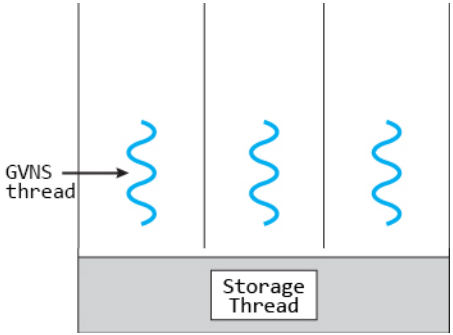
- The first one parallelizes the whole GVNS method while keeping every thread completely isolated.
- The second one parallelizes the whole GVNS, but all threads communicate the best solution through manager proxy, maintaining a dense communication.
- The third one parallelizes the whole GVNS. Communication is sparse and handled through a manager proxy. Solution exchange is based on a self-adaptive criterion called θ.

Parallel strategies, Non-cooperative model



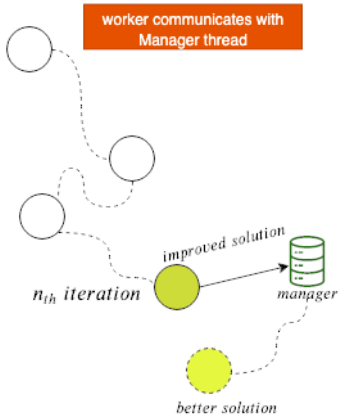
- Island-based design; every thread runs the GVNS algorithm isolated.
- Threads are autonomous and utilize identical search procedures.
- When a stopping criteria is met the best solution is picked.

Parallel strategies, Managed Cooperative Model (MCM)



- Initial solution is given using Clarke and Wright.
- One of the threads is used as a solution warehouse (Server Manager).
- Threads communicate with the Server Manager.
- No broadcasting takes place.

Parallel strategies - MCM communication strategy



MCM communication strategy

- Upon solution improvement then and only then a threads communicates with the Server Manager.
- Communication between the threads and the server manager is very dense at the start (intensification).

GVNS algorithm - MCM

Algorithm 1 GVNS, Managed Cooperative Model (MCM)

function GVNS(fr, $kmax$, $timelimit$, $manager$)
  while true **do**
    $t \leftarrow CpuTime()$
    $fr' \leftarrow Shake(fr, kmax)$
    $fr'' \leftarrow VND(fr', t, timelimit)$
    if $thread\_solution < thread\_current\_best$ **then**
      $thread\_current\_best \leftarrow thread\_solution$
      if $thread\_current\_best < manager\_global$ ▷ Communicate with warehouse
      then $manager\_global \leftarrow thread\_current\_best$
      else $thread\_current\_best, thread\_solution \leftarrow manager\_global$
    if $t > timelimit$ **then** break
    if $manager\_global == optimum$ **then** break ▷ if optimum value exists
  end while
end function

Parallel strategies - Parameterized Cooperation Model (PCM)

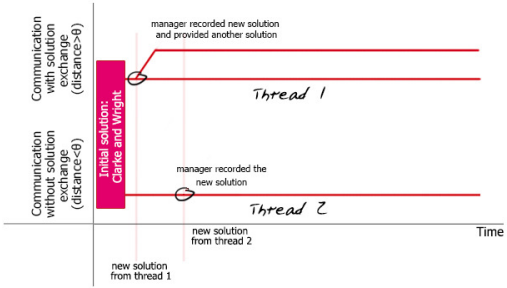


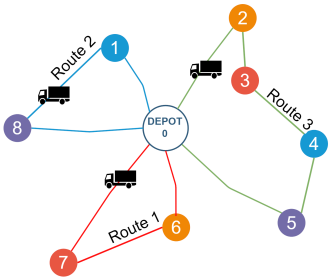
Figure: Thread-1 changes its solution.
Thread-2 continues to work with the same solution.

Bridging the gap

- Same communication strategy as MCM.
- A self-adaptive parameter (θ) is used.
- Solutions are compared using Levenshtein.
- Solution exchange is filtered using distance and θ.

PCM - Levenshtein distance

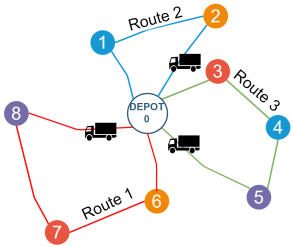
The distance between two solution is calculated using the Damerau - Levenshtein distance:



4 edit operations

+8 -8 +2 -2

06780 — 08120 — 02 3450



Solution 1
string representation: 06700810023450
Length:14

Solution 2
string representation: 06780012003450
Length=14

Normalized distance = 0.2857

PCM - Criterion calculation

θ criterion

θ is based on the remaining time and GVNS iterations as depicted in Algorithm 2:

Algorithm 2 Parameter self-adaptation

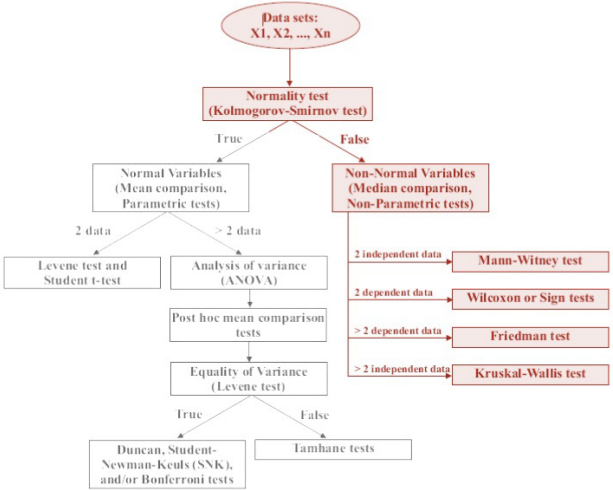
$\theta \leftarrow 1$
if $(niter_i > 0.2 \times niter_{\max}) \vee (currenttime > 0.2 \times time_{\max})$
then $\theta = \min\left((1 - \frac{niter}{niter_{max}}), (1 - \frac{time}{time_{max}})\right)$

GVNS algorithm

Algorithm 3 GVNS, Parameterized Cooperative Model (PCM)

function GVNS(*fr*, *kmax*, *timelimit*, *manager*)
  while true **do**
    $t \leftarrow CpuTime()$;
    $fr' \leftarrow Shake(fr, kmax)$;
    $fr'' \leftarrow VND(fr', t, timelimit)$;
    $\theta \leftarrow dynamic\_decrease(time, iter\_count)$;
    if $thread\_solution < thread\_current\_best$ **then**
      $thread\_current\_best \leftarrow thread\_solution$
      if $thread\_current\_best \leq manager\_global$ **then** ▷ Communicate with manager
        $manager\_global \leftarrow thread\_current\_best$
      else
        if $\theta < distance(manager\_global, thread\_current\_best)$ **then**
          $thread\_current\_best, thread\_solution \leftarrow manager\_global$ ▷ solution exchange
    if $(t > timelimit)$ or $(manager\_global = optimum)$ **then** break
  end while
end function

Statistical analysis



- Kolmogorov-Smirnov test was used.
- The distribution deviates significantly from the normal distribution.
- non-parametric tests were used (Wilcoxon, Friedman, Kruskal).

Experimental results

In the results shown in the table 1 we can observe essential differences among the compared methods.

Table: Comparison of the three GVNS parallel variants at 300 GVNS iterations

	NCM	MCM	PCM
average error	0.837%	1.260%	0.729%
average CPU time (secs)	76.880	92.100	88.640
Optimal number of solutions	21	16	21

Findings

Our results show that:

- The full cooperative model (MCM) produced almost the same quality of solutions as the non-cooperative model when solving easier instances.
- Filtered cooperation (PCM) and the MCM produced superior quality solutions regarding the more computationally difficult test instances.
- Filtered cooperation (PCM) produced superior quality solutions in all instances.
- Although, the non-cooperative model (NCM) has a more intense diversification phase, the sparse communication between processes achieved by the communication coordination in the Parameterized Cooperative Model is producing better solution quality by maintaining a balanced level of interaction between the threads.

Conclusions

- We used several known instances in order to compare and analyze the co-operation strategies.
- We have proposed three parallel GVNS versions based on python multiprocessing library for solving the CVRP.
- The communication strategy used by the PCM is a novel approach that, reduces the communication overhead and producing better solution quality.
- There seems to be a strong indication that, the cooperation strategy can have a decisive influence on the quality of the solutions.

End of presentation

Thank you for your attention!