Optimization of Capacitated Vehicle Routing Problem using Artificial Bee Colony Algorithm

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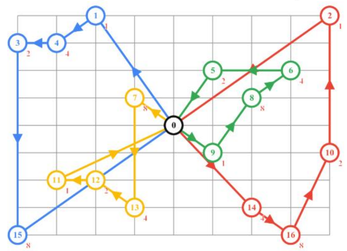
Introduction

Capacitated vehicle routing problem(CVRP) is a combinatorial optimization problem which states as follows:

" Find the optimal delivery routes for a set of vehicles to supply a set of customers with given demands minimizing the total cost of all the routes."



Number of vehicles: 4
Vehicle Capacity: 45

Exact Algorithm

1. Subset finder:

- Given a set of customers find all the ways in which the customers can be served given a set of vehicles.
- Pruning of the sets is done by maintaining the capacity constraint of the truck.

$$U(n,k) = k \times U(n-1,k) + U(n-1,k-1)$$

2. Traveling salesman:

- Out of all the ways found find the best route amongst them.

$$C(S,i) = \forall i \in S \ \min\{C(S-\{i\},j) + c_{ij}\}$$

The traveling salesman algorithm will be applied on each path *J* of a candidate subset *C* of all possible subsets of *U(n, k)*. For all *J* in *C* we apply the TSP.

Approximate Algorithm (Bee Colony Algorithm)

"Artificial bee colony algorithm is based on the foraging behavior of honey bees"

1. Scout bee phase:

- Go out and find FEASIBLE food sources (Initial solution) for next phase.

2. Employed bee phase:

- Go out and explore the food source's (found by scout bee's) neighborhood and try and find better solutions.

	Truck1				Truck2				Truck3			
Solution	0	1	2	3	0	4	5	6	0	7	8	9	0
shuffled	0	5	2	3	0	1	4	9	0	6	8	7	0
BMX	0	2	3	1	0	4	5	6	0	9	8	7	0

	Truck1				Truck2				Truck3			
Before Swap	0	1	2	3	0	4	5	6	0	7	8	9	0
After Swap	0	1	7	3	0	4	5	6	0	2	8	9	0

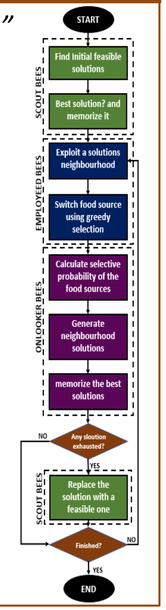
3. Onlooker bee phase:

- Selects an employed bee using roulette wheel selection. Explores the neighborhood of that employed bee for better solution.

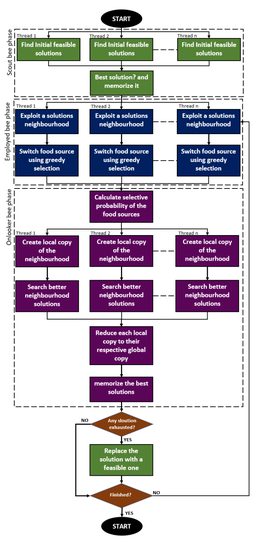
$$f(x) = o(x) + \beta * p(x)$$

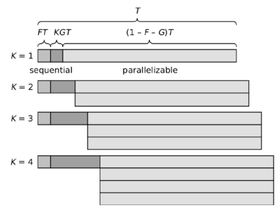
where,
$p(x) = \sum_{i=1}^{N} d_i y_{ik} - q_k$
$o(x) = \sum_{i=1} c_{i,i+1}$
$\beta = iteration\_index \times no\_of\_iterations$

- Allows infeasible solutions in the beginning
- Penalizes infeasible solutions in the end to prevent it from getting stuck at local minima

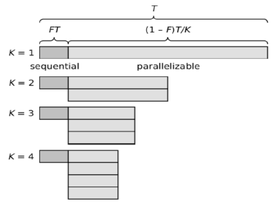


Parallel Algorithm





Strong scaling:
problem size: (same) ; cores: ↑



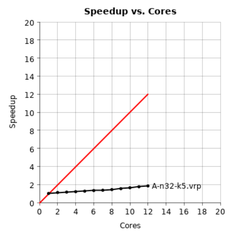
Weak scaling:
problem size: ↑ ; cores: ↑

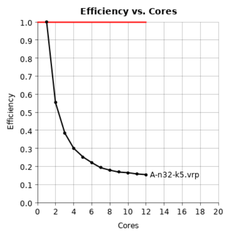
Results

Solution and performance comparison

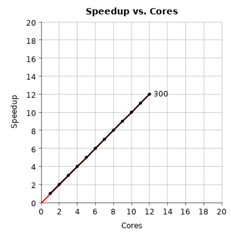
Nodes		Exact algorithm (Time Taken)		Approximate Algorithm (Swarm Size = 70) Iterations = 1500		
Number of Nodes	Optimal Answer	Brute Force	Optimized	Approximate Answer	Avg. ans	Time Taken
P-n16-k8.vrp	450	3 ms	5s	455	463	1000ms
P-n22-k2.vrp	216	~77 Years	~4 Days	224	231	1062 ms
E-n23-k3.vrp	569	~490 Million Years	~122 Days	654	671	1048 ms
E-n30-k3.vrp	534	~8.4xE15 Years	~2 Years	575	603	1125 ms
B-n50-k7.vrp	741	~9.7xE47 Years	~136 Years	884	925	1551 ms

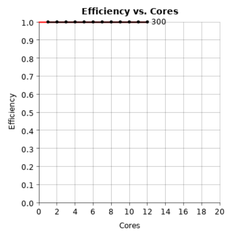
Strong Scaling





Weak Scaling





Future Work

There are multiple ways in which the project can be improved, some are stated as follows:

- Certain parts of the Bee colony algorithm have the potential to be further parallelized.
- In this project CPU cores are used for the parallel algorithm which can be replaced by GPU cores.

References

[1] S. Z. . C. Lee, "An improved artificial bee colony algorithm for the capacitated vehicle routing problem,"2015 IEEE International Conference on Systems, Man, and Cybernetics, vol. 53, pp. 512–522, 2015

[2] geeksforgeeks, "Count number of ways to partition a set into k subsets." [Online]. Available: https://www.geeksforgeeks.org/count-number-of-ways-to-partition-a-set-into-k-subsets/

[3] A. Kaminsky, BIG CPU, BIG DATA Solving the World's Toughest Computational Problems with Parallel Computing Second Edition, 2006.