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The 3rd International Seminar on Operational Research

(InteriOR 2015)

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Combination Methods for Solving Quadratic Assignment Problem

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Abstract. The quadratic assignment problem is a combinatorial problem of deciding the placement of facilities in specified locations in such a way as to minimize a nonconfex objective function expressed in terms of flow between facilities, and distance between location. Due to the non-convexity nature of the problem, therefore to get a 'good' starting point is necessary in order to obtain a better optimal solution. In this paper we propose a Combination Methods (random point strategy to get initial starting point and then use forward exchange strategy and backward exchange strategy) to get 'optimal' solution. As a computational experience we solve the problem of Had12, Esc 16b, Esc 16c and Esc 16h from QAPLIB. Finally, we present a comparative study between Combination Methods and Data –Guided Lexisearch Algorithm. The computational study shows the effectiveness of our proposed combination methods.

Keywords: Quadratic Assigment Problem, Random Point Strategy, Combination Methods

1. Introduction

The Quadratic assignment problem (QAP) is in simplest form concerned with locating facilities on locations, such that total transportation costs are minimized. The transportation cost incurred by locating two facilities is proportional both to the flow of transportation between the facilities and the distance between their locations. In 1957 QAP was introduced by Koopmann and Beckmann as a mathematical model for the location of a set of indivisible economic activities. The QAP however is not only nonlinear but it is not unimodal. As a consequence this problem class has attracted active investigation by numerous researches. An heuristic yielding a good solution seems a more appropriate course of action than attempting an optimal solution, and many of the papers aim at achieving improvements to an initial assignment. The paper by Ahmed ZH. (2011a and 2011b) provides a good review for recent advances in QAP.

One of the oldest applications of the QAP is the assignment of specialized rooms in a building (Elshafei, 1977). In this case, a_{ij} is the flow of people that must go from service i to service j and b_{ij} is the time for going from room i to room j. A more recent application is the assignment of gates to airplanes in an airport; in this case, a_{ij} is the number of passengers going from airplane i to airplane j (a special "airplane" is the main entrance of the airport) and b_{kl} is the walking distance between gates k and l.

Finally, let us mention other applications in imagery (Taillard, 1995), turbine runner balancing (Laporte and Mercure, 1988) and the fact that problems such as the travelling salesman or the linear ordering can be formulated as special QAPs.

2. Literature Review

The quadratic assignment problem was one of the first problems solved by metaheuristics methods first conceived in the 1980's. Burkard and Rendl (1984) proposed a simulated annealing procedure that was able to find much better solutions than all the previously designed heuristic methods. Six years later, Connolly (1990) proposed an improved annealing scheme. His method is easy to set up, since the user has to select the number of iterations; and all other parameters are automatically computed. At around the same time, Skorin-Kapov (1990) proposed a tabu search. Then, Taillard (1991) proposed a more robust tabu search, with fewer parameters and running n times faster than the previous implementation. Even though Taillard's method was proposed over 24 years ago, it remains one of the most efficient for some problem instances. It is available on the web (see address above). Other tabu searches have been proposed, such as the reactive tabu search of Battiti and Tecchiolli (1994a), the comparison of tabu search techniques and simulated annealing. Battiti and Tecchiolli (1994b), and the star-shape diversification approach of Sondergeld and Voss (1996). Recent T. James *et al* (2007), addressed a multi-start tabu search and diversification strategies for the quadratic assignment problem.

Genetic algorithms have also been proposed, for instance by Tate and Smith (1995), but hybrid approaches, such as those of Fleurent and Ferland (1994), Ahuja et al. (2000), Drezner (2002a, 2002b), are more efficient. Another

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heuristic, GRASP (greedy randomized adaptive search procedure) was proposed by Li, Pardalos and Resend (1994). An ant colony system approaches by Taillard (1998) , Gambardella et al., (1999), Stutzle and Hoos 1999,) have been proposed, as well as a scatter search (Cung et al., 1997). Some of these methods have been compared in Taillard (1995) who showed that the efficiency of these methods strongly depends on the problem instance type to which they are applied. Most recently, Ahmed ZH., (2010) addressed a genetic algorithm for the traveling Salesman Problem using sequential constructive crossover operator.

3. The Quadratic Assignment Problem

This is combinatorial problem of deciding the placement of facilities in specified locations in such a way as to minimise a quadratic objective function. Consider the problem of locating n facilities in n given locations. If the flow f_{ik} between each pair of facility i and facility k and the unit transportation cost (or distance) d_{jl} between locations j and l are known, then the problem is defined to be

minimize $$\Phi = \tfrac{1}{2}\sum_{i=1}^{n}\sum_{k=1}^{n}\sum_{j=1}^{n}\sum_{l=1}^{n} f_{ik} d_{jl} x_{ij} x_{kl}$$

$$\sum_{j=1}^{n} x_{ij} = 1 \quad i = 1,\ldots,n$$

subject to $$\sum_{i=1}^{n} x_{ij} = 1 \quad j = 1,\ldots,n$$

$$0 \le x_{ij} \le 1$$

$$x_{ij} \quad \text{integer}$$

Matrices $[f_{ik}]$ and $[d_{jl}]$ are assumed to be symmetric. The assignment variable x_{ij} has a value 1 if facility i is at location j, and is zero otherwise. The constraints reflect the fact that each location can be assigned to only one facility, and each facility can be assigned to only one location.

Generally the QAP is a non-convex problem so any solution obtained will necessarily be a local optimum and not a global optimum.

4. Combination Methods

4.1. Strategy to get Initial Starting Point

Since the quadratic form may be non-convex, the chances of obtaining a good integer feasible solution are considerably enhanced by paying some attention to the starting point for the search procedure.

In this case we create a computer program that would generate a random assignment. Then we calculate the value of objective function using this random assignment. In order to get a good initial starting point it is neccessary to input an arbitrary value of objective function θ enough big say θ=10000000, so its value always greater than $\bar{\theta}$, at last from the numbers of iteration θmin will be reached, match to the assigment x_i.

The steps used to get a random initial starting point are written as follows :

1. Read θ= 10000000, matrix $[f_{ik}]$ dan $[d_{jl}]$, n = problem dimension and *ITEM* as the number of iteration, a = 1
2. Generate random permutation, x_i= randperm (n); for every facility i, i = 1, 2, …, n.
3. $x_{ij}=1$ for gen $x_i=j$; $x_{ij}=0$ for generate $x_i \neq j$; i,j = 1,2,..,n
4. Calculate the objective function value

$$\bar{\theta} = \sum_{i=1}^{n}\sum_{k=1}^{n}\sum_{j=1}^{n}\sum_{l=1}^{n} f_{ik} d_{jl} x_{ij} x_{kl}$$

5. if $\bar{\theta} < \theta$, then $\theta = \bar{\theta}$; $a = a+1$
6. if $a < ITEM$, back to (2)
7. STOP

4.2. Forward Exchange Strategy

We could adopt a branch and bound approach, solving a sequence of quadratic programming in the same manner as integer program are solved with a sequence of (continuous) linear program. However, for large problem the computation would be prohibitive with a lot less effort we may obtain an integer feasible solution of the QAP using an initial starting point which has been generated randomly.

We use random point strategy to get an initial assignment, then combine by heuristic method, namely forward exchange strategy and backward exchange strategy to get the integer feasible solution of QAP. We call this method as combination methods.

- Algorithm for Forward Exchange strategy
  1. Input n as problem dimension.
  2. Read flow matrix $[f_{ik}]$, distance matrix $[d_{jl}]$, initial asssignment $[x_{ij}]$
  3. Calculate $\theta = \sum_{i=1}^{n}\sum_{k=1}^{n}\sum_{j=1}^{n}\sum_{l=1}^{n} f_{ik} d_{jl} x_{ij} x_{kl}$
  4. Generate $x_i=j$ for $x_{ij}=1$; $i,j=1, \ldots, n$
  5. $a=1$
  6. $b=1$
  7. c=Gen $x_{i=a}$; Gen $x_{i=a}$=Gen $x_{i=a+b}$; Gen $x_{i=a+b}=c$
  8. $x_{ij}=1$ for Gen $x_i=j$, $x_{ij}=0$ for Gen $x_i \neq j$, $i,j=1,\ldots, n$
  9. Calculate objective function
  $$\bar{\theta} = \sum_{i=1}^{n}\sum_{k=1}^{n}\sum_{j=1}^{n}\sum_{l=1}^{n} f_{ik} d_{jl} x_{ij} x_{kl}$$
  10. if $\bar{\theta} < \theta$ then $\theta = \bar{\theta}$ go to (14)
  11. Gen $x_{i=a+b}$ = Gen$x_{i=a}$; Gen $x_{i=a}=c$
  12. $b = b+1$
  13. if $b \leq n-a$ go to (7)
  14. $a = a+1$
  15. if $a \leq n$ go to (6)
  16. STOP

4.3. Backward Exchange Strategy

- Algorithm for Backward Exchange Strategy
  1. Input n as problem dimension
  2. Read flow matrix $[f_{ik}]$, distance matrix $[d_{jl}]$, initial assignment X = $[x_{ij}]$
  3. Calculate $\theta = \sum_{i=1}^{n}\sum_{k=1}^{n}\sum_{j=1}^{n}\sum_{l=1}^{n} f_{ik} d_{jl} x_{ij} x_{kl}$
  4. Gen $x_i=j$, for $x_{ij}=1$; $i,j = 1, \ldots, n$
  5. $a = n$
  6. $b = n$
  7. c=Gen $x_{i=a}$; Gen $x_{i=a}$= Gen $x_{i=b}$; Gen $x_{i=b}=c$
  8. $x_{ij}=1$ for Gen $x_i=j$, $x_{ij}=0$ for Gen $x_i \neq j$, $i,j=1,\ldots, n$
  9. Calculate objective function
  $$\bar{\theta} = \sum_{i=1}^{n}\sum_{k=1}^{n}\sum_{j=1}^{n}\sum_{l=1}^{n} f_{ik} d_{jl} x_{ij} x_{kl}$$
  10. if $\bar{\theta} < \theta$ then $\theta = \bar{\theta}$ go to (14)
  11. Gen $x_{i=b}$ = Gen $x_{i=a}$; Gen $x_{i=a}=c$
  12. $b = b-1$
  13. if $b \geq a+1$ go to (7)
  14. $a = a-1$
  15. if $a > 1$ go to (6)
  16. STOP

5. Computational Experience

To run the program we use laptop with processor intel (R) core (TM) i3-3217U, CPU 1.80 GHz RAM 4.00 GB.

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5.1. 12 × 12 Problem

The 12 × 12 QAP is adopted from Hadley (1992). This is a large scale problem with 144 binary variables. To solve the problem, we input n as dimention of problems, number of iteration, matrix flow [f_{ik}] and matrix distance [d_{jo}]. In each iteration we use random point strategy to get the initial assignment of the QAP and then we use forward exchange strategy and backward exchange strategy to get the integer feasible solution.
We try many kind of iterations. The result can be seen in table 1 below.

Table 1. The Search Table

Number of Iteration	Objective Value	Permutation	Running Time (Second)
500	1660	3 10 11 2 12 7 5 1 8 6 4 9	57.997902
600	1664	3 10 2 12 11 5 6 7 8 1 4 9	70.160402
700	1660	3 10 12 2 11 5 6 7 8 1 4 9	81.361419
750	1654	3 10 11 2 12 5 7 6 8 1 9 4	86.357992
800	1654	8 10 2 11 12 5 6 7 3 1 4 9	92.285597
850	1654	8 10 2 11 12 5 7 6 3 1 4 9	99.568710
900	1656	3 10 5 2 12 11 7 1 8 6 4 9	104.039284
950	1656	3 10 5 2 12 11 7 1 8 6 4 9	110.342666
1000	1660	3 10 11 2 12 6 5 1 8 7 4 9	117.018335
1050	1652(OPT)	3 10 11 2 12 5 6 7 8 1 4 9	122.512347

From table above we can conclude :

1. By the increasing of number iteration, the objective value approach to the optimum value.
2. On iteration 1050 the optimum value was reached, as reported on QAPLIB.
3. There is a number of iteration have same objective value but different permutation (just in case, based on the matrix flow [f_{ik}] and matrix distance [d_{jo}]

5.2. 16 x 16 Problem

The 16 × 16 QAP is adopted from B. Escermann (1990). This is a large scale problem with 256 binary variables. We try the number of iteration is 500, no other number of iteration, because by using this number of iteration we found the optimal solution according to the QAPLIB.

The result can be seen in table 2 below.

Table 2. The Search Table

Instance	Number of Iteration	Objective Value	Permutation	Running Time (Second)
Esc 16b	500	292 (OPT)	2 3 16 9 7 13 1 5 15 11 14 4 12 8 10 6	371.654879
Esc 16c	500	160 (OPT)	5 16 15 8 7 6 11 3 4 9 2 10 12 14 1 13	270.088915
Esc 16h	500	996 (OPT)	16 15 8 5 14 9 10 6 1 2 13 4 3 11 12 7	326.956387

If we compare Combination Methods (CM) and Data–Guided Lexisearch Algorithm (DGLSA) by Ahmed (2014), the result as follow :

Table 3. The Comparison of DGLSA and CM

Instance	BKV	DGLSA			CM		
		BSV	Error (%)	Running Time (Second)	BSV	Error (%)	Running Time (Second)
Esc 16b	292	292	0.00	14400.00	292	0.00	371.654879
Esc 16c	160	160	0.00	2984.60	160	0.00	270.088915
Esc 16h	996	996	0.00	1298.50	996	0.00	326.956387

BKV = Best known value (from QAPLIB)
BSV = Best solution value
Error = { (BSV-BKV)/BKV } x 100%

From table 3 above we show that Combination Methods (CM) much more better than Data–Guided Lexisearch Algorithm (DGLSA).

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5. Conclusion

The procedure described here has proved successful in obtaining integer feasible solution to the Quadratic Assignment Problem in relatively short computing times (as can be seen from the running time).

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Hasil Penilaian Peer Review :

KOMPONEN YANG DINILAI		NILAI MAKSIMAL PROSIDING INTERNASIONAL			NILAI AKHIR YANG DIPEROLEH
		Prosiding Internasional	Prosiding Nasional	LaporanAkhir	
		9			
a.	Kelengkapan dan Kesesuaian Unsur Isi Karya Ilmiah (10%)	0,9			0,9
b.	Ruang Lingkup dan Kedalaman Pembahasan (30%)	2,7			2,7
c.	Kecukupan dan Kemuthahiran Data dan Metodologi (30%)	2,7			2,7
d.	Kelengkapan Unsur dan Kualitas Penerbit (30%)	2,7			2,7
	TOTAL = (100%)	9			9

KOMENTAR PEER REVIEW		
1.	Kelengkapan dan Kesesuaian Unsur	: unsur-unsur karya ilmiah ini sangat lengkap dan sesuai dengan kriteria prosiding internasional
2.	Ruang Lingkup dan Kedalaman Pembahasan	: Pembahasan cukup mendalam, dalam ruang lingkup optimisasi
3.	Kecukupan dan Kemuthakiran Data dan Metodologi	: Data yang digunakan cukup dan mutakhir Metodologi sangat tepat
4.	Kelengkapan Unsur dan Kualitas Penerbit	: Unsur-unsur dari penerbit cukup lengkap dan berkualitas

Penilai,

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