A Weed Colonization Inspired Algorithm for the Weighted Set Cover Problem

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Abstract

The Weighted Set Cover Problem (SCP) is a popular optimization problem that has been applied to different industrial applications, including scheduling, manufacturing, service planning and location problems. It consists in to find low cost solutions covering a set of requirements or needs. In this paper, we solve the SCP using a recent nature inspired algorithm: Invasive Weed Optimization (IWO). IWO imitates the invasive behavior of real weeds: natural reproduction and selection where the best weed has more chance of reproduction. We test our approach using known ORLIB test problems for the SCP. The computational results show that the IWO metaheuristic can find very good results.

Keywords

Invasive Weed Optimization Set covering problem Combinatorial optimization

1 Introduction

Nature inspired algorithms are metaheuristics that mimics the nature for solving optimization problems. In the past years, numerous research efforts has been concentrated in this area. The main motivation to use metaheuristics is because former methods to solve optimization problems require enormous computational efforts, which tend to fail as the problem size increases.

Bio inspired stochastic optimization algorithms are computationally efficient alternatives to the deterministic approaches. Metaheuristics are based on the iterative improvement of either a population of solutions (as in swarm or evolutive algorithms [8, 11, 14]) or a single solution (as in hill-climbing or tabu search [23]) and mostly employ randomization and local search to solve a given optimization problem.

In this paper we use Invasive Weed Optimization, this metaheuristic was proposed in year 2006 by Mehrabian, A., and Lucas, C., and it is based on the behavior of invasive weeds seeking to imitate its robustness and facility with which some herbs have front the hardness environment, the playability of the herbs and natural selection of them [19].

The problem to be solved is the Weighted Set Covering Problem (SCP), it is a classic problem which belongs to the category NP-Complex [17]. In general, in this kind of optimization problems the goal is to find a set of solutions that are able to meet the constraints of the problem minimizing the solution cost.

It should also be noted that at present the vast majority of metaheuristics appearing in literature achieved be close of the optimum for each of the instances of SCP especially, when problems have hundreds of rows and thousands of columns [5]. However, when problems grow up exponentially, and they have thousands rows and millions of columns algorithms are approaching the 1 % of the optimum solutions in a reasonable computational performance [6].

Recent metaheuristics used to solve the SCP are: Teaching-learning-based optimization algorithm [8], Artificial bee colony algorithm [10], Cultural algorithms [11], Binary firefly algorithm [12], Binary fruit fly optimization algorithm [14] and Shuffled Frog Leaping Algorithm [13].

This paper is organized as follows. Section 2 explains the SCP. Sections 3 and 4 explain IWO and binary IWO. Section 4 introduces the operating parameters used to configure IWO and the results obtained solving ORLIB SCP instances [3]. Finally in Sect. 6, we conclude.

2 The Weighted Set Cover Problem

The Weighted Set Cover Problem is one of representative combinatorial optimization problems, which has many practical applications. SCP consists of a set of variables that have a relationship together, and by a objective function are able to minimize cost allocation. It is a classic problem that belongs to the category NP-Complex [17]. In the case of this problem in specific, the goal is to search variables assignment to the lowest possible cost. That is, it seeks to cover all the needs (rows) with the lowest cost (columns).

Such as mentioned in the previous paragraph, we can mention that the representation of the problem is a matrix assignments (*M*x*N*). Where *M* represents the needs that must be cover and *N* columns variables to assign. The assignment matrix is based on a series of restrictions that must be satisfied to be considered a "workable solution" [17].

The SCP has many applications in industry and in real life: facility location [16], ship scheduling [2], production planning [1], crew scheduling [7, 18], vehicle routing [4, 27], musical composition [22], information retrieval [30], erritory design [15], sector location [20, 21, 25] or fire companies [28].

As shown in the application examples mentioned, the problem can be applied in different circumstances of decision making. Where more information have these decisions, it will help to improve the quantitative and qualitative performance of the assets of the company, that could be used in a better way, thus improving their performance and quality of service.

To land the explanation of the problem it is necessary to explain the mathematical formulation. This will be explained in a better way by using formulas and mathematical notation helping to expose a more didactic way the complexity of the problem and its characteristics. Thus achieving a better understanding and comprehension of the problem. The mathematical model of the SCP is:

$$Minimize \qquad Z = \sum_{j=1}^{n} c_j x_j$$

(1)

Subject to:

$$\sum_{j=1}^{n} a_{ij} x_j \geq 1 \qquad \forall\, i \in \{1, 2, 3, \ldots, m\}$$

(2)

$$x_j \in \{0, 1\}$$

(3)

Consequently, the Eq. (1) represents the objective function of the problem. This function allows to know the *fitness* of the solution evaluated. Where c_j represents the cost of the $j-th$ column and x_j is the decision variable, this variable determines whether a column is activate or not. Equation (2) represent the constraints: each one row should be cover by at least one column. Where a_{ij} is an element of the *M*x*N* matrix such elements can only have values 0 and 1. Finally, Eq. (3) represents the values that can take the decision variables: 1 or 0, where 1 represents if the column is active and 0 otherwise [17].

3 Invasive Weed Optimization

Invasive Weed Optimization is based on how the invasive weeds behave in when colonize. An invasive weed is a type of plant that grows without being desired by people. In general, the term invasive or undesirable, is used in agriculture, and it is used for herbs that are a threat to the crop plants.

In IWO a weed represents a point in the search space of solutions and seeds represent other points explored [26].

Considerations for a more detailed explanation: D as the problem dimension, P_{int} as the initial size of the colony of herbs, P_{max} as the maximum size of the colony where $1 \leq P_{int} \leq P_{max}$ and W^P as a set of herbs, where each weed represents a point in the search space. Importantly, for calculating the *fitness* of each weed it is used the objective function defined in the problem. Which is as follows $F : R^D \rightarrow R$ [26].

There are some distinctive properties of IWO in comparison with other metaheuristics: *Way of reproduction*, *Spatial dispersal* and *Competitive exclusion* are its main stages. In the following subsections we show their main characteristics.

3.1 Initialization

The IWO process begins with initializing a population. Given the generation *G*, we proceed to create a weed population size P_{int}, which is randomly generated and the weeds W_i^P are uniformly distributed (W_i^P $(U(X_{min}, X_{max})^D)$). Where X_{min} and X_{max}, are defined according to the type of problem to be implemented [26]. For the SCP, these values are determined by 0 and 1 [26].

3.2 Reproduction

In each iteration, each weed W_i^P of the current population, are reproduced from seed. The amount of seeds for each weed W_i^P, is given by S_{num}, this number depends on the *fitness* [26]. Where best *fitness* has the evaluated weed, the greater the amount of seeds for may have to breed [26].

$$S_{sum} = S_{min} + (\frac{F(W_i^P) - F_{worse} F_{best} - F_{worse}}{)} (S_{max} - S_{min})$$

(4)

where S_{max} and S_{min} represent the maximum and minimum allowed by weed W_i^P [26]. All seeds S_{sum} are distributed in space and close to the father weed, that is, starting these solutions is created a neighborhood of solutions [26].

3.3 Spatial Distribution

As explained in the previous section, the seeds are distributed in the search space and in this way in, generating new solutions looking to the best for the problem [26]. To achieve this, we should be consider a way to achieve the correct distribution of seeds for this, the use of the normal distribution [26].

$$S_j = W_i^P + N(0, \sigma_G)^D \qquad (1 \leq j \leq S_{num})$$

(5)

where σ_G represents the standard deviation, which will be calculated as follows:

$$\sigma_G = \sigma_{final} + \frac{(N_{iter} - G)^{\sigma^{mod}}}{(N_{iter})^{\sigma^{mod}}}(\sigma_{init} - \sigma_{final})$$

(6)

where N_{iter} represents the maximum number of iterations, σ_{mod} represented nonlinear index modulation, σ_{init} and σ_{final} is parameters input.

3.4 Competitive Exclusion

At this stage, we proceed to verify the amount of herbs and seeds created by the algorithm not exceeding the maximum permitted W_{max}, it proceeds to make a pruning the worst weed. This, in order to let the herbs with better results to own the best opportunities to breed and find the best solution to the problem [26].

4 Binary Invasive Weed Optimization

Most of the IWO applications have been solving continuous problems. Our implementation of IWO is aimed to solve combinatorial problems in a binary search space such as SCP. The Binary Invasive Weed Optimization (BIWO) is a variation of the main algorithm, it has some modifications to the main algorithm [26]:

Instead of working with real domains R^D for solutions, BIWO works in a binary search space $B^D \in \{0, 1\}$. Therefore, the objective function also undergoes changes in its definition. Consequently, the objective function is:

$$F : B^D \rightarrow R$$

In the phase *Distribution Spatial*, the formula for the distribution of seed undergoes the following:

$$S_j = N(W_i^P, \sigma_G)^D \qquad (1 \leq j \leq S_{num})$$

(7)

Algorithm 1. Binary Invasive Weed Optimization

Generate initial random population of W^P weeds (Stage-I)
for $iter \ni 1..MaxIter$ **do**
  Calculate maximum and minimum fitness in the population
  for $w_i^P \ni W^P$ **do**
    Determine number of seeds w_i^P, corresponding to its fitness (Stage-II)
    $NewWeed$ = Use Neighborhood generation algorithm (Stage-III)
    Add $NewWeed$ to the W^P
  end for
end for
if $W^P.Size > W^P.SizeMax$ **then**
  Remove Weeds with worst Fitness (Stage-IV)
  Sort the population of weed with smaller fitness
end if

Algorithm 2. Neighborhood generation algorithm

Require: Weed W_i^P and σ_G
$Nchange_{bits} = N^+(0, \sigma_G)$
$Change_{probality} = \dfrac{Nchange_{bits}}{ProblemDimension}$
$Seed =$ Weed W_i^P
for $d \ni 1..D$ **do**
  $Random_{number} = U(0,1)$
  if $Random_{number} \leq Change_{probality}$ **then**
    $Seed_d = \neg Seed_d$
  end if
end for
return $Seed$

In the new formulation we propose that a seed is the assignment of a father weed to the seed; but a bit change which is determined by the calculate of normal distribution and it will determine that so close is the seed of the father weed W_i^P [26]. In turn, the positive part of the normal distribution is used, which will imply that the number of bits that will change will diminish with each iteration on seeds and weed, belonging the population. It is explained because the algorithm is sensitive to changes, across of calculating the standard deviation, which directly impacts on the calculation of the normal distribution and therefore in the mutation of solutions. Importantly, that the mutation of solutions is similar as it is used in genetic algorithms.

The above process can be understood better through the Algorithms 1 and 2:

5 Experiments and Results

BIWO has a number of parameters that are required to tune.

5.1 Configuring the Algorithm

BIWO was configured before performing the experiments. To this end and starting from default values, a parameter of the algorithm is selected to be tuned. Then, independent runs are performed for each configuration of the parameter, considering a reduced stop condition. Next, the configuration which provides the best performance on average is selected, assuming the hypervolume metric as quality indicator. Next, another parameter is selected so long as all of them are fixed. At following we show the values considered for the best configuration obtained:

- Number of generations 30.
- Number of iterations (N_{iter}) 400.
- Initial amount of weed (P_{init}) 100.
- Maximum number of weed (P_{max}) 20.
- Minimum number of seed (S_{min}) 20.
- Maximum number of seed (S_{max}) 80.
- σ_{init} = Problem Dimension.
- σ_{final} = 1.
- σ_{mod} = 3.

It is necessary to mention that the BIWO was executed on a computer with the following characteristics:

- Operative System. Microsoft Windows 8.1.
- Memory Ram: 6 Gb.
- CPU: Intel Core i5 2.60.

Table 1.

Results of experiments

Results

Instances	Optimum	Best results	Worse results	Average	RPD (Best results)
scp41	429	429	443	432,2	0 %
scp42	512	512	535	519,57	0 %
scp43	516	516	550	526,4	0 %
scp44	494	494	530	503,07	0 %
scp45	512	512	528	518,3	0 %
scp46	560	560	574	563,5	0 %
scp47	430	430	444	434,37	0 %
scp48	492	492	505	496,57	0 %
scp49	641	649	675	661,83	1,25 %
scp51	253	253	275	259,1	0 %
scp52	302	302	324	310,63	0 %
scp53	226	226	231	228,93	0 %
scp54	242	242	247	244,13	0 %
scp55	211	211	219	215,63	0 %
scp56	213	213	222	215,83	0 %
scp57	293	293	303	295,56	0 %

Results

Instances	Optimum	Best results	Worse results	Average	RPD (Best results)
scp58	288	288	300	292,47	0 %
scp59	279	279	289	281,13	0 %
scp61	138	142	151	144,2	2,90 %
scp62	146	146	159	150,56	0 %
scp63	145	145	157	151,1	0 %
scp64	131	131	135	132,96	0 %
scp65	161	161	169	165,37	0 %
scpa1	253	254	266	257,93	0,40 %
scpa2	252	256	266	260,9	1,59 %
scpa3	232	233	244	237,4	0,43 %
scpa4	234	236	245	241,07	0,85 %
scpa5	236	236	240	237,9	0 %
scpb1	69	69	77	72,4	0 %
scpb2	76	77	85	80,63	1,32 %
scpb3	80	80	86	82	0 %
scpb4	79	80	87	86,23	1,27 %

Results

Instances	Optimum	Best results	Worse results	Average	RPD (Best results)
scpb5	72	72	77	72,7	0 %
scpc1	227	229	237	232,33	0,88 %
scpc2	219	221	231	224,83	0,91 %
scpc3	243	250	262	255,23	2,88 %
scpc4	219	219	237	227,83	0 %
scpc5	215	215	229	220,77	0 %

5.2 Computational Results

The following table presents the results obtained for the ORLIB instances of SCP. We should mention that instances used in our experiments were preprocessed deleting redundant columns. This delete redundant column process is explain in [24, 29].

The table is structured as: First column is the instance name, Second shows best value known, Third column is best result obtained; Fourth is worse result obtained; Fifth is average of the results obtain by each instance and the Sixth column is Relative Percentage Deviation (RPD) [9], it is calculate as:

$$RPD = \frac{(Z - Z_{opt})}{Z_{opt}} * 100$$

(8)

Where Z is our best result and Z_{opt} is the optimum known by instance Table 1.

6 Conclusion

In this paper, we solve the Weighted Set Cover Problem using a Binary Invasive Weed Optimization algorithm. After performing the experiments solving ORLIB instances of SCP, our main conclusions is in relation with the parameter tuning, we recommend a tuning of parameters by group of instances because, this will allow generate custom tests and results better for each group of instances.

In order to improve the performance we are working in the incorporation of an elitist method for mutation. It is expected that the incorporation of elitism can improve performance in the search for good solutions in terms of quality and further making improvements in execution times.

The results obtained with BIWO show very good results in almost all ORLIB instances tested.

Notes

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