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Günther R. Raidl (Eds.)

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Preface

Metaheuristics have often been shown to be effective for difficult combinatorial optimization problems appearing in various industrial, economical, and scientific domains. Prominent examples of metaheuristics are evolutionary algorithms, simulated annealing, tabu search, scatter search, memetic algorithms, variable neighborhood search, iterated local search, greedy randomized adaptive search procedures, estimation of distribution algorithms, and ant colony optimization. Successfully solved problems include scheduling, timetabling, network design, transportation and distribution problems, vehicle routing, the traveling salesperson problem, satisfiability, packing and cutting problems, planning problems, and general mixed integer programming.

The EvoCOP event series started in 2001 and has been held annually since then. It was the first specifically dedicated to the application of evolutionary computation and related methods to combinatorial optimization problems. Evolutionary computation involves the study of problem-solving and optimization techniques inspired by principles of natural evolution and genetics. Following the general trend of hybrid metaheuristics and diminishing boundaries between the different classes of metaheuristics, EvoCOP has broadened its scope over the last years and invited submissions on any kind of metaheuristic for combinatorial optimization problems.

This volume contains the proceedings of EvoCOP 2006, the 6th European Conference on Evolutionary Computation in Combinatorial Optimization. It was held in Budapest, Hungary, on April 10–12 2006, jointly with EuroGP 2006, the 9th European Conference on Genetic Programming, and EvoWorkshops 2006, which consisted of the following seven individual workshops: EvoBIO, the 4th European Workshop on Evolutionary Bioinformatics; EvoCOMNET, the Third European Workshop on Evolutionary Computation in Communications, Networks, and Connected Systems; EvoHOT, the Third European Workshop on Hardware Optimization; EvoIASP, the 8th European Workshop on Evolutionary Computation in Image Analysis and Signal Processing; EvoInteraction, the First European Workshop on Interactive Evolution and Humanized Computational Intelligence; EvoMUSART, the 4th European Workshop on Evolutionary Music and Art; and EvoSTOC, the Third European Workshop on Evolutionary Algorithms in Stochastic and Dynamic Environments.

EvoCOP, originally held as an annual workshop, became a conference in 2004. The events gave researchers an excellent opportunity to present their latest research and to discuss current developments and applications, besides stimulating closer future interaction between members of this scientific community. Accepted papers of previous events were published by Springer in the series *Lecture Notes in Computer Science* (LNCS – Volumes 2037, 2279, 2611, 3004, and 3448).

EvoCOP	submitted	accepted	acceptance ratio
2001	31	23	74.2%
2002	32	18	56.3%
2003	39	19	48.7%
2004	86	23	26.7%
2005	66	24	36.4%
2006	77	24	31.2%

The rigorous, double-blind reviewing process of EvoCOP 2006 resulted in a strong selection among the submitted papers; the acceptance rate was 31.2%. Each paper was reviewed by at least three members of the international Program Committee. All accepted papers were presented orally at the conference and are included in this proceedings volume. We would like to give credit to the members of our Program Committee, to whom we are very grateful for their quick and thorough work and the valuable advice on how to improve papers for the final publication.

EvoCOP 2006 covers evolutionary algorithms as well as various other meta-heuristics, like scatter search, tabu search, memetic algorithms, variable neighborhood search, greedy randomized adaptive search procedures, ant colony optimization, and particle swarm optimization algorithms. The contributions are dealing with representations, heuristics, analysis of problem structures, and comparisons of algorithms. The list of studied combinatorial optimization problems includes prominent examples like graph coloring, knapsack problems, the traveling salesperson problem, scheduling, graph matching, as well as specific real-world problems.

We would like to express our sincere gratitude to the two internationally renowned invited speakers, who gave the keynote talks at the conference: Richard J. Terrile, astronomer, Director, of the Center for Evolutionary Computation and Automated Design at NASA's Jet Propulsion Laboratory, and Stefan Voß, Chair and Director of the Institute of Information Systems at the University of Hamburg.

The success of the conference resulted from the input of many people to whom we would like to express our appreciation. We would like to thank Philipp Neuner for administrating the Web-based conference management system. The local organizers and Judit Megyery did an extraordinary job for which we are very grateful. Last but not least, the tremendous effort of Jennifer Willies and the School of Computing, Napier University, in the administration and coordination of EuroGP 2006, EvoCOP 2006, and EvoWorkshops 2006 was of paramount importance.

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EvoCOP 2006 was organized jointly with EuroGP 2006 and EvoWorkshops 2006.

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Hybrid Genetic Algorithm Within Branch-and-Cut for the Minimum Graph Bisection Problem

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Nikolay Jetchev², and Alexander Martin²

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Abstract. We develop a primal heuristic based on a genetic algorithm for the minimum graph bisection problem and incorporate it in a branch-and-cut framework. The problem concerns partitioning the nodes of a weighted graph into two subsets such that the total weight of each set is within some lower and upper bounds. The objective is to minimize the total cost of the edges between both subsets of the partition. We formulate the problem as an integer program. In the genetic algorithm the LP-relaxation of the IP-formulation is exploited. We present several ways of using LP information and demonstrate the computational success.

1 The Minimum Graph Bisection Problem

We consider a weighted graph $G = (V, E)$ with edge costs $w_e \in \mathbb{R}_+$, $e \in E$, and node weights $f_i \in \mathbb{Z}_+$, $i \in V$. A pair (V_1, V_2) satisfying $V_1 \cup V_2 = V$ and $V_1 \cap V_2 = \emptyset$ is called *bipartition*, if $V_1 \neq \emptyset$ and $V_2 \neq \emptyset$. V_1 and V_2 are called *clusters*. Given a real number $\tau \in [0, 1]$ we define bounds l_τ and u_τ such that

$$l_\tau = \frac{1-\tau}{2} \sum_{i \in V} f_i \quad \text{and} \quad u_\tau = \frac{1+\tau}{2} \sum_{i \in V} f_i.$$

A bipartition (V_1, V_2) such that the total node weight of each cluster stays within the bounds l_τ, u_τ , i.e., $l_\tau \leq \sum_{i \in V_k} f_i \leq u_\tau$, $k = 1, 2$, holds, is called *bisection*. A *bisection cut* $\Delta(V_1, V_2)$ is the set of edges joining nodes in different clusters of the bisection (V_1, V_2) . The minimum graph bisection problem is to find a bisection (V_1, V_2) with the minimum cost of $\Delta(V_1, V_2)$:

$$\sum_{e \in \Delta(V_1, V_2)} w_e.$$

This problem is known to be NP-hard [8].

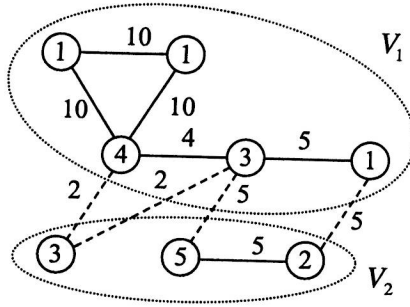


Fig. 1. An example of a graph bisection (V_1, V_2) with $\tau = 0.1$, $l_\tau = 9$ and $u_\tau = 11$. The dashed edges build a bisection cut $\Delta(V_1, V_2)$. The numbers within the nodes and the numbers nearby the edges correspond to node and edge weights respectively.

Graph bisection and its generalizations, e.g. when V is partitioned into more than two subsets [6], have considerable practical significance, especially in the areas of VLSI design and parallel computing. With state-of-the-art solution methods it is still unrealistic to obtain exact solutions for large instances. Usually such problems are tackled heuristically. Genetic algorithms are known to find good solutions to graph partitioning problems, see e.g. [5, 11, 12, 14]. Successful approaches combining methods from different classical metaheuristics, among others including evolutionary algorithms, are presented in [4, 14]. This motivated us to incorporate a primal heuristic based on a genetic algorithm in a branch-and-cut framework. In [13] a classification of methods that combine exact and heuristic procedures is given. Within this scheme our work can be categorized as a heuristic that *exactly solves relaxed problems*: We exploit the solution of the LP-relaxation for generating a start population as well as in the mutation procedures of our genetic algorithm.

Our paper is structured as follows. In Section 2 we present integer programming formulations for the minimum graph bisection problem. In Section 3 we outline the structure of the genetic algorithm based on the fractional solution of the LP-relaxation hybridized with the edge costs. In Section 4 we provide computational results.

2 Integer Programming Models

For an integer programming formulation of the minimum graph bisection problem we introduce binary variables y_{ij} for all $ij \in E$. Each $y \in \{0, 1\}^{|E|}$ satisfying $y_{ij} = 1$ if nodes i and j are in different clusters, and $y_{ij} = 0$ otherwise, corresponds to an incidence vector of a bisection cut in G . Let

$$Y = \{y \in \{0, 1\}^{|E|} \mid y \text{ is an incidence vector of a bisection cut in } G\}.$$

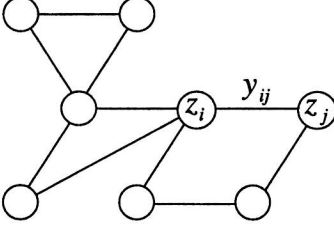


Fig. 2. Variables y_{ij} , $ij \in E$ and z_i , $i \in V$

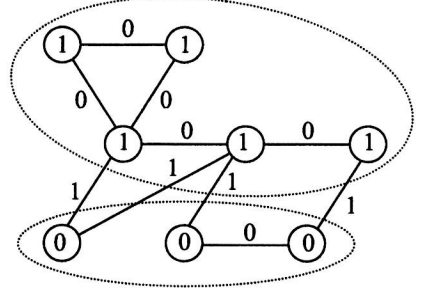


Fig. 3. Values of variables y_{ij} , $ij \in E$ and z_i , $i \in V$ corresponding to the bisection cut presented in Fig. 1

We search for such an element of the set Y that minimizes $\sum_{e \in E} w_e y_e$. It remains to describe Y by linear constraints. One formulation can be derived directly from the model presented in [6] concerning a generalization of the graph bisection problem. There are introduced additional binary variables z_i for each node $i \in V$. It is required that all z -variables corresponding to nodes assigned to one cluster have the same value, see Fig. 2 and Fig. 3.

The following constraints guarantee that $y_{ij} = 1$ if and only if $z_i \neq z_j$, i.e., nodes i and j are in different clusters, and $y_{ij} = 0$ otherwise.

$$\forall ij \in E \quad z_i - z_j - y_{ij} \leq 0 \quad (1)$$

$$\forall ij \in E \quad z_j - z_i - y_{ij} \leq 0 \quad (2)$$

$$\forall ij \in E \quad -z_j - z_i + y_{ij} \leq 0 \quad (3)$$

$$\forall ij \in E \quad z_i + z_j + y_{ij} \leq 2 \quad (4)$$

The constraint

$$l_\tau \leq \sum_{i \in V} f_i z_i \leq u_\tau \quad (5)$$

assures that the total weight of nodes in each cluster stays within the given lower and upper bound. The projection of the feasible set defined by constraints (1) - (5) onto the y -space equals the set Y . Note that, since our objective is to minimize a positive weighted sum of y -components, constraint (4) is redundant in the problem formulation.

Since the node variables z_i , $i \in V$ do not appear in the objective function we get rid of them in the following way. We replace the constraints (1) - (4) with a known class of valid inequalities for $P = \text{conv}(Y)$ called *odd-cycle* inequalities (see also [3]):

$$\sum_{e \in F} y_e - \sum_{e \in E_C \setminus F} y_e \leq |F| - 1, \quad \forall C \subset G, F \subset E_C, |F| \text{ is odd},$$

where $C = (V_C, E_C)$ is a cycle in G . These constraints require that each cycle C in G must contain an even number of edges from the cut. Next, we reformulate constraint (5) by selecting a node $s \in V$ and extending E so that s is adjacent to all other nodes in V . The weights w_{is} of new edges are set to zero, see Fig. 4.

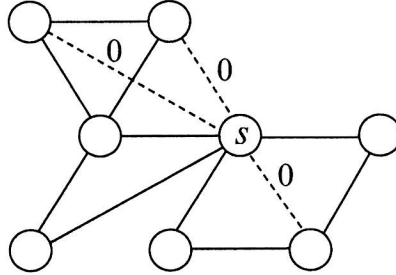


Fig. 4. New edges (dashed) incident to node s and their costs

For all nodes $i \in V$, which are in the same cluster as s , holds

$$l_\tau \leq f_s + \sum_{i \in V \setminus \{s\}} f_i(1 - y_{is}) \leq u_\tau,$$

which is equivalent to

$$l_\tau \leq \sum_{i \in V \setminus \{s\}} f_i y_{is} \leq u_\tau$$

using $l_\tau + u_\tau = \sum_{i \in V} f_i$.

Thus we obtain a new integer programming model for the minimum graph bisection problem:

$$\begin{aligned}
 (B) \quad & \min \sum_{e \in E} w_e y_e \\
 & \text{s.t.} \\
 & \sum_{e \in F} y_e - \sum_{e \in E_C \setminus F} y_e \leq |F| - 1, \quad \forall C \subset G, F \subset E_C, |F| \text{ is odd} \\
 & l_\tau \leq \sum_{i \in V \setminus \{s\}} f_i y_{is} \leq u_\tau, \text{ for some } s \in V \\
 & y_e \in \{0, 1\}, \forall e \in E.
 \end{aligned}$$

The feasible solutions of (B) are in one-to-one correspondence to the elements of Y . In the sequel we consider the latter model. Since the number of all possible odd-cycles is exponential in $|E|$ we do not include them all in the initial formulation. Using the polynomial time separation algorithm given in [3] we add violated odd-cycle-inequalities sequentially during separation within the branch-and-cut algorithm.