

Combinatorial Optimization

Jens Vygen

University of Bonn, Research Institute for Discrete Mathematics, Lenndstr. 2, 53113 Bonn, Germany

Combinatorial optimization problems arise in numerous applications. In general, we look for an optimal element of a finite set. However, this set is too large to be enumerated; it is implicitly given by its combinatorial structure. The goal is to develop efficient algorithms by understanding and exploiting this structure.

1 Some Important Problems

We first give some classical examples. We refer to the chapter on \rightarrow *Graph Theory* for basic notation. In a digraph, we denote by $\delta^+(X)$ and $\delta^-(X)$ the set of edges leaving and entering X , respectively; here X can be a vertex or a set of vertices. In an undirected graph, $\delta(X)$ denotes the set of edges with exactly one endpoint in X .

1.1 Spanning trees

Here we are given a finite connected undirected graph (V, E) (so V is the set of vertices and E the set of edges) and weights on the edges, i.e., $c(e) \in \mathbb{R}$ for all $e \in E$. The task is to find a set $T \subseteq E$ such that (V, T) is a (spanning) tree and $\sum_{e \in T} c(e)$ is minimum. (Recall that a tree is a connected graph without cycles.)

The figure below shows on the left a set V of eight points in the Euclidean plane. Assuming that (V, E) is the complete graph on these points and c is the Euclidean distances, the right-hand side shows an optimal solution.

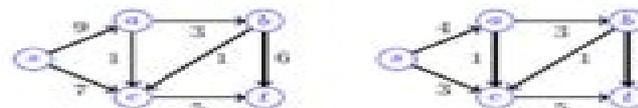


1.2 Maximum flows

Given a finite directed graph (V, E) , two vertices $s, t \in V$ (source and sink), and capacities $u(e) \in \mathbb{R}_{\geq 0}$ for all $e \in E$, we look for an s - t -flow $f : E \rightarrow \mathbb{R}_{\geq 0}$ with $f(e) \leq u(e)$ for all $e \in E$ and

$f(\delta^-(v)) = f(\delta^+(v))$ for all $v \in V \setminus \{s, t\}$ (flow conservation: the total entering flow equals the total leaving flow at any vertex except s and t). The goal is to maximize $f(\delta^-(t)) - f(\delta^+(t))$, i.e., the total amount of flow shipped from s to t . This is called the value of f .

The figure below shows an example. The left-hand side displays an instance, the capacities are shown next to the edges. The right-hand side shows an s - t -flow of value 7. This is not optimal.



1.3 Matching

Given a finite undirected graph (V, E) , find a matching $M \subseteq E$ that is as large as possible. (A matching is a set of edges whose endpoints are all distinct.)

1.4 Knapsack

Given $n \in \mathbb{N}$, positive integers a_i, b_i (profit and weight of item i , for $i = 1, \dots, n$), and B (the knapsack's capacity), find a subset $I \subseteq \{1, \dots, n\}$ with $\sum_{i \in I} b_i \leq B$, such that $\sum_{i \in I} a_i$ is as large as possible.

1.5 Traveling salesman

Given a finite set X with metric d , find a bijection $\pi : \{1, \dots, n\} \rightarrow X$ such that the length of the corresponding tour,

$$\sum_{i=1}^{n-1} d(\pi(i), \pi(i+1)) + d(\pi(n), \pi(1)),$$

is as small as possible.

1.6 Set covering

Given a finite set U and subsets S_1, \dots, S_n of U , find the smallest collection of these subsets whose union is U , i.e., $I \subseteq \{1, \dots, n\}$ with $\bigcup_{i \in I} S_i = U$ and $|I|$ minimum.

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