

Combinatorial Optimization

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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.

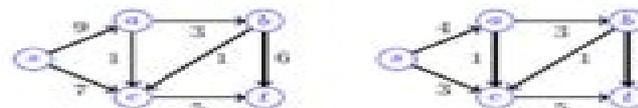


1.2 Maximum flows

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.

Combinatorial Optimization Mathematical Programming Study 1

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