# Edmonds' algorithm

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In graph theory, **Edmonds' algorithm** or **Chu–Liu/Edmonds' algorithm** is an algorithm for finding a spanning arborescence of minimum weight (sometimes called an *optimum branching*). It is the directed analog of the minimum spanning tree problem. The algorithm was proposed independently first by Yoeng-Jin Chu and Tseng-Hong Liu (1965) and then by Jack Edmonds (1967).

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# Algorithm

## Description

The algorithm takes as input a directed graph $D = \langle V, E \rangle$ where $V$ is the set of nodes and $E$ is the set of directed edges, a distinguished vertex $r \in V$ called the *root*, and a real-valued weight $w(e)$ for each edge $e \in E$. It returns a spanning arborescence $A$ rooted at $r$ of minimum weight, where the weight of an arborescence is defined to be the sum of its edge weights, $w(A) = \sum_{e \in A} w(e)$.

The algorithm has a recursive description. Let $f(D, r, w)$ denote the function which returns a spanning arborescence rooted at $r$ of minimum weight. We first remove any edge from $E$ whose destination is $r$. We may also replace any set of parallel edges (edges between the same pair of vertices in the same direction) by a single edge with weight equal to the minimum of the weights of these parallel edges.

Now, for each node $v$ other than the root, find the edge incoming to $v$ of lowest weight (with ties broken arbitrarily). Denote the source of this edge by $\pi(v)$. If the set of edges $P = \{(\pi(v), v) \mid v \in V \setminus \{r\}\}$ does not contain any cycles, then $f(D, r, w) = P$.

Otherwise, $P$ contains at least one cycle. Arbitrarily choose one of these cycles and call it $C$. We now define a new weighted directed graph $D' = \langle V', E' \rangle$ in which the cycle $C$ is "contracted" into one node as follows:

The nodes of $V'$ are the nodes of $V$ not in $C$ plus a *new* node denoted $v_C$.

- If $(u, v)$ is an edge in $E$ with $u \notin C$ and $v \in C$ (an edge coming into the cycle), then include in $E'$ a new edge $e = (u, v_C)$, and define $w'(e) = w(u, v) - w(\pi(v), v)$.
- If $(u, v)$ is an edge in $E$ with $u \in C$ and $v \notin C$ (an edge going away from the cycle), then include in $E'$ a new edge $e = (v_C, v)$, and define $w'(e) = w(u, v)$.
- If $(u, v)$ is an edge in $E$ with $u \notin C$ and $v \notin C$ (an edge unrelated to the cycle), then include in $E'$ a new edge $e = (u, v)$, and define $w'(e) = w(u, v)$.

For each edge in $E'$, we remember which edge in $E$ it corresponds to.

Now find a minimum spanning arborescence $A'$ of $D'$ using a call to $f(D', r, w')$. Since $A'$ is a spanning arborescence, each vertex has exactly one incoming edge. Let $(u, v_C)$ be the unique incoming edge to $v_C$ in $A'$. This edge corresponds to an edge $(u, v) \in E$ with $v \in C$. Remove the edge $(\pi(v), v)$ from $C$, breaking the cycle. Mark each remaining edge in $C$. For each edge in $A'$, mark its corresponding edge in $E$. Now we define $f(D, r, w)$ to be the set of marked edges, which form a minimum spanning arborescence.

Observe that $f(D, r, w)$ is defined in terms of $f(D', r, w')$, with $D'$ having strictly fewer vertices than $D$. Finding $f(D, r, w)$ for a single-vertex graph is trivial (it is just $D$ itself), so the recursive algorithm is guaranteed to terminate.

# Running time

The running time of this algorithm is $O(EV)$. A faster implementation of the algorithm due to Robert Tarjan runs in time $O(E \log V)$ for sparse graphs and $O(V^2)$ for dense graphs. This is as fast as Prim's algorithm for an undirected minimum spanning tree. In 1986, Gabow, Galil, Spencer, and Tarjan produced a faster implementation, with running time $O(E + V \log V)$.

# References


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# External links

- Edmonds's algorithm ( edmonds-alg ) (http://edmonds-alg.sourceforge.net/) – An open source implementation of Edmonds's algorithm written in C++ and licensed under the MIT License. This source is using Tarjan's implementation for the dense graph.