A topology visualisation tool for large-scale communications networks

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A visualisation tool is presented to facilitate the study on large-scale communications networks. This tool provides a simple and effective way to summarise the topology of a complex network at a coarse level.

Introduction

It is relevant to study the topology of information and communications networks, such as the Internet, the World Wide Web and peer-to-peer (P2P) overlay networks, because structure fundamentally affects functions. These networks contain thousands or even millions of connections and their topologies are usually characterised by statistics [1, 2]. Here we introduce a simple tool to visualise a network’s connectivity.

Methodology

In graph theory degree is defined as the number of links a node has. We sort network nodes in a list of decreasing degrees, i.e. at the top position is the best-connected node and next is the second best-connected node. For each group of nodes that have the same degree, we rearrange the nodes in the decreasing order of their neighbours largest degree; for those
having the same neighbours largest degree as well, we sort their neighbours second-largest degree; and this process continues until all neighbours degrees have been considered. We then assign each node an index according to its position in the sorted list.

If a network contains \( N \) nodes, the network’s connectivity information can be represented as an \( N \times N \) adjacency matrix, in which entry \( a_{ij} \) is the number of links connecting between nodes with the sorted indexes of \( i \) and \( j \), where \( i, j = 1, 2, 3...N \). For a simple undirected graph (i.e. no self-loop and no multiple links between a pair of nodes), the adjacency matrix is a symmetric \((0, 1)\)-matrix with zeros on its diagonal. Then the network’s topology information can be visualised as a bitmap of sorted adjacency matrix (BOSAM). One may consider the neighbours largest degree as a measure of the ‘cohesion’ force a node receives from the network core of high-degree nodes. Then an alternative BOSAM can be obtained by sorting the neighbours smallest degree, i.e. a measure of the ‘radiation’ force the node receives from the peripheral low-degree nodes.

**Results** Figure 1(a) shows BOSAM of the Internet topology at the autonomous systems (AS) level collected by CAIDA [3], on which black pixels
are densely concentrated along the top and the left borders where $i < 0.5k$ or $j < 0.5k$. This indicates that the Internet AS graph exhibits the following properties: (1) power-law degree distribution [4], which means a small number of nodes have very large numbers of links whereas the majority of nodes have only a few links; (2) negative degree-degree correlation [5], which means low-degree nodes tend to connect to high-degree nodes and vice versa; and (3) rich-club phenomenon [6], which describes the fact that high-degree nodes, or rich nodes, are tightly interconnected with themselves. These properties explain why the Internet is so ‘small’ that the average shortest path between a pair of nodes is only 3.12 hops: while the rich nodes know each other very well and collectively function as a super traffic hub for the network, the majority of the nodes, peripheral low-degree nodes, are always near the rich-club core. Figure 1(b), (c) and (d) show that by comparison, the positive-feedback preference (PFP) Internet model [7] better resembles the Internet AS graph than the Erdös-Rényi (ER) random model [8] and the Barabási-Albert (BA) scale-free model [9].

The Gnutella peer-to-peer (P2P) file-sharing network [10] contains 317,592 nodes and 7,396,948 links. Figure 2 shows Gnutella is profoundly different from the Internet AS graph. Instead it shows similarity to the ER random
model. Figure 2 also reveals that Gnutella exhibits a fractal-like structure which has not been captured by the usual statistic studies.

**Conclusion** Although BOSAM is a coarse representation of a network’s structural properties, we show that this simple tool is effective in distinguishing network topologies.

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Figure 1  BOSAM of (a) the Internet AS graph collected by CAIDA; (b) the PFP Internet model; (c) the ER random model; and (d) the BA scale-free model. All networks have 9,204 nodes and 27,612 links.

Figure 2  BOSAM of (a) Gnutella P2P network and enlargements of the top-left corner of (a) at scales of (b) 1:4, (c) 1:16, and (d) 1:64.
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