One outstanding path from A to B

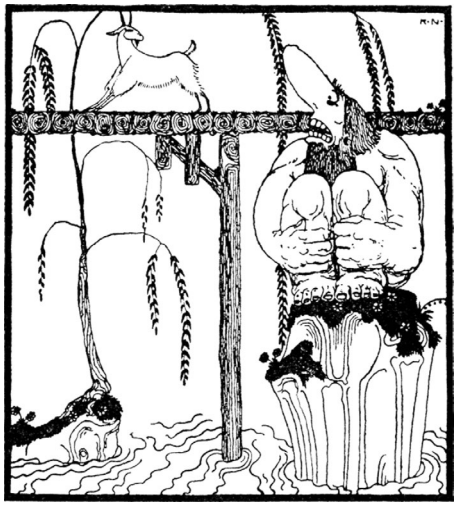
What does it mean for an individual to be 'important' or for a connection to be 'outstanding'? The answer depends on context, as Sarah Shugars and Samuel V. Scarpino explain.

In the Norwegian fairy tale *Three Billy Goats Gruff*, the eponymous billy goats face a serious dilemma: the field they call home is barren and they must cross a bridge to reach greener pastures. The problem is that a terrible troll lives under the bridge and threatens to swallow the goats if they get too close. The troll's authority over the only viable path between the two fields gives it enormous power over who comes and goes. After all, the billy goats, who ultimately outsmart the troll, would surely have taken a different path if one had been available. Seeking to capture the importance of outstanding paths, a network scientist would say that the troll has high betweenness centrality.

Psychologist Kurt Lewin understood the subtlety of the troll's power as early as 1938, when he wrote, "Sometimes the fastest connection is outstanding; at other times it is the cheapest connection, or the most pleasant, or the least dangerous."[1] Modern network scientists now measure importance using a milieu of different strategies designed to capture the 'centrality' of an individual or node. Perhaps the most intuitive of these measures is degree centrality: the more connections you have, the more important you are. But even a small number of 'outstanding' connections can make a node important as well, to which the troll and its betweenness centrality would attest.

More formally, betweenness centrality is a measure of the number of shortest paths that pass through a given node. If you take all the shortest paths between points A and B, which node C will you pass through most often? Each node's betweenness is then the proportion of the shortest paths passing through it. But calculating the betweenness centrality efficiently isn't straightforward, as it requires global knowledge of the network structure. Degree centrality, on the other hand, requires only local knowledge — you don't need to know about every scientist in the world to count one scholar's citations.

Betweenness centrality as we know it was introduced by Linton Freeman in 1977[2]. But Freeman himself noted that Jac Anthonisse had independently developed a similar measure some years earlier. Designed



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to capture "the flow between each pair of vertices,"[3] Anthonisse called his measure 'rush', a name which, unfortunately, seems to have been passed by. Freeman envisioned betweenness centrality as a measure of an individual's control. A node with high betweenness can determine what information gets passed on, spread disease to a previously unaffected community or threaten wayward goats who happen to pass through.

More recently, a different view has emerged, suggesting that individuals who connect across groups are "at higher risk of having good ideas"[4]. Rather than seeing betweenness as a potential for gatekeeping, this perspective casts it as an opportunity for brokering — for disseminating information and connecting those who are otherwise less central.

The value of betweenness centrality implicitly relies on a modular network structure — the ability to bridge across groups is only outstanding if there are, in fact, communities to connect. This raises at least two interesting questions about network formation and dynamics. First, why do we see such modular structure in the first place — if a troll lives under the only available bridge, why not just build a new bridge? Second, if those with high betweenness have such power, wouldn't they ultimately garner more connections, relegating betweenness to a redundant measure of degree centrality?

Despite the forces that should degrade betweenness centrality, community structure and high-betweenness nodes are common across disparate types of network, from social to biological to linguistic. The persistence of such features implies a trade-off between the value of having connections and the cost of maintaining those connections. Certainly most nodes must have limits on the number of connections they can maintain — one cannot know every person in the world, for example. In other words, does the constraint of having only one bridge arise from a dynamic equilibrium between the local challenge of crossing the high-betweenness troll and the global cost of making alternative routes?

That such questions have fascinated and perplexed scholars for nearly 100 years speaks to the depth and complexity of even a seemingly simple measure such as 'importance'. To the network scientist, far from being a parable of greed, the goats and their troll is a story of complex adaptive systems and the power of an outstanding path. ❐

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