

# Path statistics for letter correspondence networks of the European Reformation

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## 1 Background

This contribution discusses the challenges of accounting for temporal information in the transmission of ideas in historical communication networks. Traditional approaches have mainly analyzed temporal snapshots of aggregated networks to account for changes in the network (Lemerrier 2015; Petz, Ghawi and Pfeffer 2020; Düring et al. 2011). In this approach, the observation period is divided into subperiods (snapshots), interactions within one subperiod form a network snapshot, and topological differences between consecutive network snapshots are analyzed.



Figure 1: Betweenness scores differ when computed on the aggregated network (a, c) and when accounting for time-stamped edges (b, d). In the aggregated network, time is ignored which allows information to spread backwards in time (e.g., Zwingli passes information to Luther in 1527 which Luther passes on to Bucer in 1520).

Since aggregated networks ignore the temporal ordering of edges, information being passed on in the network can flow backwards in time. This model choice biases topological network measures (Scholtes, Wider and Garas 2016), by for example overestimating the role of individuals in the spread of ideas (Fig. 1).

To address this issue, I analyze time-respecting paths in a historical communication network. A time-respecting path is a sequence of nodes that are connected by time-consecutive edges (e.g.,  $A \xrightarrow{1527} B \xrightarrow{1541} C$ ) with the inter-edge time being bounded to account for a minimal reaction time and the maximum time through which ideas are remembered (memory). Using the example of a letter correspondence network of protestant reformers from the 16th century, I use time-respecting paths to identify influential reformers for the spread of ideas and dominant communication patterns.

## 2 Methods

I use the python package `pathpy` to extract time-respecting paths from a letter correspondence network of protestant reformers. To identify influential reformers for the spread of ideas, I compute the betweenness centrality of nodes in the time-respecting paths. To identify dominant communication patterns, I use statistical significance tests to identify path lengths in the data that are different from random. I explain the resulting significant path lengths with exemplary paths from the data, using biographical information of the involved reformers.

Since time-respecting paths are bounded parameter values for the minimum and maximum time between consecutive edges have to be set. I discuss several methods for these parameter choices and present robustness checks on how these choices affect the results.

## 3 Results

Results reveal that reformer Philipp Melanchthon has the largest betweenness scores for both the time-respecting paths and the aggregated network (Fig. 2). He seems to be the most influential reformer for the spread of ideas in the network. Moreover, paths of length two, i.e., three nodes connected by two time-consecutive edges, represent the dominant communication pattern among reformers. The center reformer mediates between the two peripheral ones. By inspecting paths where the reformers Melanchthon and Zwingli act as mediators, respectively, I show that they may have shaped theological disputes (Melanchthon) and provided less glamorous reformers, such as Johannes Oekolampad, with information (Zwingli).

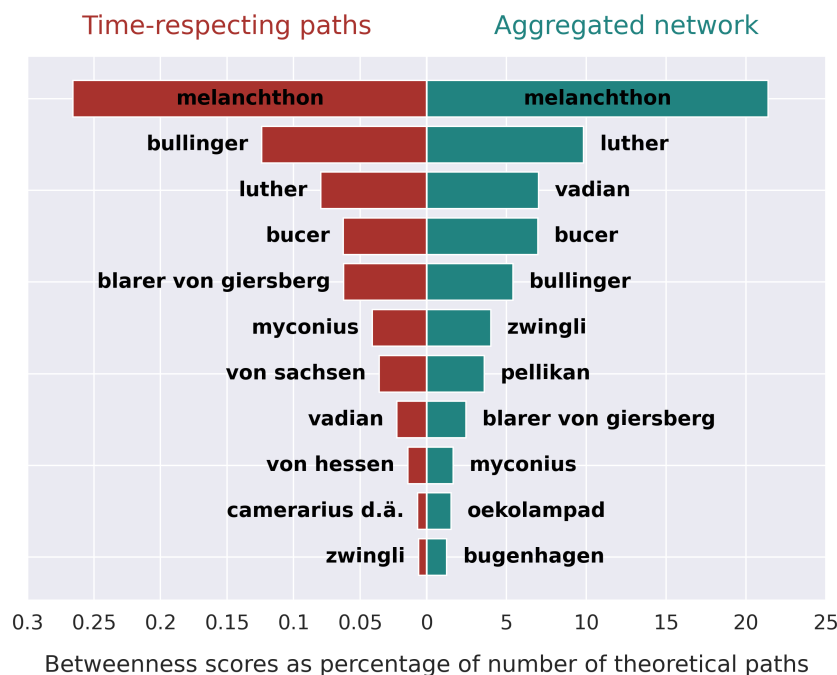


Figure 2: Betweenness centrality scores as percentage of theoretically possible paths. The ten nodes with the largest betweenness scores are shown. Scores for the time-respecting paths are smaller than for the aggregated network since the latter also considers shortest paths where time can run backwards.

## 4 Discussion

This contribution applies a path-based temporal network approach to explore the transmission of ideas during the Protestant Reformation. In contrast to aggregated networks, time-respecting paths force information to spread forward in time, which reduces the biases of topological network measures. In the current analysis, these paths helped reveal influential reformers for the spread of ideas (Philipp Melanchthon) and dominant communication patterns (mediating).

Time-respecting paths are an important precondition for analyzing causal relations in networks. By discarding achronological connections in networks, we restrict the pool of true causal connections making its analysis more tangible. Future research should use letter texts to construct paths based on topic similarity between letters. These ‘topic paths’ could be used to validate time-respecting paths and provide a better understanding of how ideas influenced reformers during the Reformation.

Despite this promising potential, several limitations in the current analysis also require attention. Despite reducing bias in topological network measures, time-respecting paths are also affected by selection bias in the data. To improve current results, representative historical samples should be striven for. Moreover, path analyses require parameter choices which are a) not straightforward and b) can substan-

tially change results. Precise justifications of these choices and robustness check as performed in this analysis are necessary to understand the impact of parameters and calibrate them correctly.

## References

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