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Network Science in Biblical Studies

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Contents

Abstract: This article introduces the special issue of ASE on network science and biblical studies. After a short presentation of network science and the concept of networks, the article discusses the application of network science in three domains: the natural and built environment of ancient Judaism and Christianity, the social networks of Jewish and Christian actors, and the analysis of textual corpora. In the next part, some technical terms of network science are clarified. The introductory article concludes with the presentation of the contributions to the special issue.

Keywords: Network Science, Social Network Analysis, Network Analysis of Texts, Historical Network Analysis, Vector Semantics

Abstract: Between the first and fourth centuries C.E. networks of like-minded individuals who shared certain religious beliefs and practices developed in both Jewish and Christian society. These networks emerged in the context of Roman imperialism which connected, integrated, and to some extent homogenized the various sectors of the population through road connections, infrastructure, and Romanization. Both rabbis and Christian leaders tried to distinguish themselves from certain aspects of their Graeco-Roman cultural environment by, at the same time, functioning within it and adopting some of its features. This study compares rabbinic and Christian leaders' networking activities within the shared Roman imperial context of the first centuries C.E.

Keywords: Rabbis, Bishops, Imperialism, Romanization, Communication, Travel

Abstract: Social network analysis is applied heuristically to understand how the Epistles of John attempt not only to promote their vision of the community's identity and theology, but also to strengthen their own position in the Johannine social network and weaken the position of its competitors. Insistence on social distance from competing teachings is central to 1 and 2 John, while 3 John is occasioned by the Johannine School being marginalized by an assembly. The errands of these letters can be described in terms of network analysis as attempts to weaken certain social ties and strengthen others to allow the Johannine School more uncontested dispersion of information in the assemblies of the network.

Keywords: Epistles of John, Social Network, Johannine Community, Network Theory, Information Flow, Conflict

Abstract: How successful was the Christian Church's mission to the Jews? The answer to this is a function of numerous factors, such as underlying demographics, fertility rates, competition, and (most importantly) when Christians and Jews severed their ties with one another. Some believe the split as early as 70 CE, but others present evidence that Jews and Christians regularly interacted until the 4th and possibly 5th centuries. In this paper, using computer network simulations that capture various factors, we run a series of models that estimate the proportion of Jewish converts to Christianity from approximately 40 to 600 CE. Our models suggest that whether one considers the Church's mission to the Jews a success largely depends on what one considers a "success." If one measures it solely in terms of raw numbers, then probably not. However, if one considers that the potential pool of Jewish converts was relatively small compared to Gentiles, it was perhaps more successful than many early Church scholars believe.

Keywords: Social Networks, Network Simulations, Early Church, Mission to the Jews, Jewish Converts

Abstract: The article joins the scholarly discussion about the meaning of righteousness language in biblical literature with consideration of changes in the concept from archaic Greek literature to fourth century Christian texts. The article seeks to showcase and evaluate how methods from the area of computational linguistics and distributional semantics can contribute to the discussion. The article suggests that, together with formal network models, namely word co-occurrence networks and similarity networks, the methods reveal changes in large corpora of textual data which are too subtle to be detected by close reading. On the other hand, some questions require or benefit greatly from combining distant and close reading methods.

Keywords: Righteousness, Paul of Tarsus, Quantitative Textual Analysis, Computational Linguistics, Distributional Semantics, Word Co-Occurrence Networks

Abstract: The verb "to circumcise" in Gen 17:24, and elsewhere in that chapter, appears in the niphal form, entailing a passive meaning, and the agent of the action remaining unknown. At the same time, Abraham's circumcision plays a central role in Judaism. It is not simply the prototype of all subsequent instances of a ritual that is central to Jewish identity; but it is also the starting point of a recursive chain of ceremonies by which any later circumcision acquires its religious significance. Hence, the importance of the agent of the first circumcision. First, I describe how this ritual is embedded in the network of concepts, entities, narratives, precepts and further mental representations in Judaism. Subsequently, I shall present a selection of answers from various traditions to the question posed in the title. Then, I introduce a network of meanings, which shall serve as a linguistic model interpreting the agent-less niphal forms of the verb ‘to circumcise’ in Gen 17. This model yields different interpretations under various conditions, corresponding to various traditions. Consequently, it is argued to describe the computation taking place in the human mind, which is able to produce alternative interpretive traditions.

Keywords: Circumcision, Judaism, Midrashim, Biblical Exegesis, Anaphora Resolution, Simulated Annealing

Abstract: This article puts forward the theory that the Bible is a network of cultural items (memes) that developed through an evolutionary process and has been transmitted for many centuries in a relatively stable form. Biblical cross-references reveal how the verses and passages of the Bible are connected into a network that is analogous to genetic networks in biology. The article presents a network model of cross-references, based on the *Treasury of Scripture Knowledge*. The article discusses the history of the database and the origin of the references; network statistics that yield insights into the history of the cross-references; node centrality statistics and the popularity of the respective verses in the history of Western biblical interpretation; and the modular structure of the network. The results are interpreted as tentative evidence for the collective behavior of populations in Western history being co-determined by a network of biblical memes.

Keywords: Cultural Evolution, Cross-References, Treasure of Scripture Knowledge, History of Interpretation, Node Centrality, Community Detection

Articles

Abstract: For the gospel passages too, as for any other historical document, it is impossible to interpret their meaning correctly without knowing their context, without therefore assigning them a precise place and time. The scholar of Christian origins is well aware that for the gospels the operation is considered to be mostly impossible, but he cannot resign himself to saying that the original context is irretrievably lost. There are, in fact, a few ways of attempting to recover it. One of these is to try to identify who the recipients of Jesus’ words really were; to try in particular to understand to whom Jesus was addressing himself when he said “you”. Some gospel pericopes allow this operation.

Keywords: Historical Jesus, Sinoptic Gospels, Exegesis

Abstract: New Testament scholars continue to identify the opponents of John of Patmos and his addressees at Smyrna and Philadelphia—despite John’s testimony that “they say they are Judeans and are not, but are lying”—as a Jewish “Synagogue of Satan” (2:9, 3:9), not gentile imposters. Since 2001, David Frankfurter has identified the Smyrnean and Philadelphian opponents as “Pauline or neo-Pauline” gentiles who threatened the Jewish identity of John’s congregations. This proposal anticipated recent Pauline scholarship wary of Christian theological anachronisms, but the resulting "Paul within Judaism" shares more with Frankfurter's "John within Judaism" than with his "Pauline" foil. Refining Frankfurter's hypothesis to distinguish "neo-Pauline" inheritors from Paul promises a clearer view of John, his disciples, and his adversaries in relation to the contested reception of Paul's instructions for his gentile disciples.

Keywords: Synagogue of Satan, Revelation, Paul, Ephesians, Anti-Semitism

Abstract: The dreams of the patriarch Joseph (Gen 37), the dreams of the butler and the baker (Gen 40) and the dreams of Pharaoh (Gen 41) are significant dream examples in the Joseph-narrative. The Jewish exegesis of these dreams by Philo of Alexandria and the Early Christian exegesis of these dreams by Ambrose of Milan (337-397) will be discussed here. Next, we want to investigate whether Philo's exegesis of the dreams influenced Ambrose's exegesis or whether this is unlikely. Although we know that Philo influenced Ambrose far and wide, his influence on the interpretation of the dreams in the Joseph story seems to have been slight. Further investigation reveals that Ambrose relied on Origen for his exegesis of these dreams. As for the scholarly investigation of the latter, a complicating factor is that Origen's exegesis of Genesis is only partially left.

Keywords: Jewish and Christian Exegesis, Joseph's Dreams, Philo of Alexandria, Origen, Ambrose of Milan, Exegetical Influence

Book Discussion

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István Czachesz

Network Science in Biblical Studies: Introduction

I. The science of networks

The notion of a network is ingrained in contemporary culture. In everyday English parlance, we casually talk about television networks, computer networks, professional networks, telephone networks, and so on. Even though the word has a technological flavor, the idea of a network is purely mathematical at its core. A network (or *graph* in mathematical language) is an abstract model that consists of two kinds of elements: nodes connected by links. The nodes of a network can represent social actors, cities, molecules, computers, words, and basically anything we want to think about in terms of network theory. A link represents some connection between two nodes, such as the friendship between two people, a piece of wire connecting two machines, a shared characteristic of two entities, a web link from one page to the other, or a flight route between two cities.[1] Figure 1 shows a widely used example of a small social network, the friendship network of Zachary's Karate club, with nodes standing for members of the club and links representing friendship ties between them. Once we decide what the nodes and the links stand for, an abstract model of the underlying real-world phenomenon can be built that lends itself to further analysis (see below).

Swiss mathematician Leonhard Euler (1707–1783) is often credited with the invention of graph theory. Euler took on the popular challenge to find a route through the Prussian city of Königsberg so that one crosses each of the seven bridges of the city exactly once and arrives back to the starting point. Euler proved this was impossible and meanwhile

[1] Hypergraphs have links that connect more than one nodes, see Berge 1973 and Gazdík 2006.

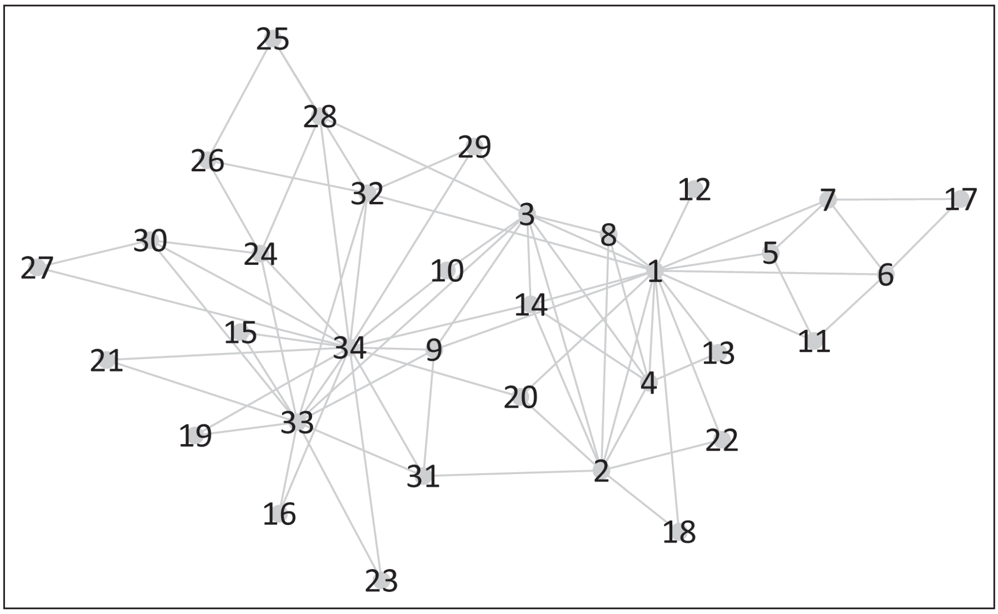

Figure 1. The friendship network of Zachary's Karate club. Nodes represent members of the club, and links represent friendship ties between them.[2]

created the first known theorem of graph theory.[3] In this example, the nodes of the network are parts of the city, and the links connecting them are bridges. Two centuries later, Romanian-American psychosociologist Jacob L. Moreno (1889–1974) developed sociometry, the study of small communities in terms of friendship networks, anticipating the field of social network analysis.[4] Contemporary network science emerged in the 1990s from mathematical graph theory, social network analysis, and their applications in diverse fields, such as biology, linguistics, chemistry, and physics.[5] The terminology that scholars in different disciplines use to discuss networks sometimes varies. The object itself can be called a graph (preferred in mathematics) or a network.[6] The things connected can be called points, vertices (sing. vertex, preferred in mathematics), or nodes (preferred in social network analysis).[7] The things connecting

[2] Zachary 1977.

[3] The seven bridges (links) connected four pieces of land (nodes). Euler proved that for a path crossing each link only once and arriving back to the starting point to exist, either all nodes of the network needed to have an even number of adjacent links (in which case one would start and end the walk on the same node), or exactly two of them needed to have an odd number of links (in which case one would start and end the walk on a different node). The bridges of Königsberg were not arranged in either way.

[4] Borgatti, Everett, Johnson 2013; Freeman 2004; Prell 2011.

[5] Barabási, Márton 2016.

[6] Moreno's term "sociogram" also remains in use in the context of studying small groups.

[7] In social network analysis, the nodes are also called "actors".

the points can be called edges, arcs (preferred in mathematics),[8] ties, or links. While the variation in terminology can be confusing in the beginning, the concepts they stand for are consistent across disciplines.

II. Networks in biblical studies

During the last decade or so, an increasing number of publications explored the potential of network science for the humanities. The interdisciplinary program of digital humanities, which emerged in the early 2000s, started to move beyond data digitization toward the use of computer models in the study of texts and other sources. There have been applications of network theory to historiography,[9] including some exploratory work on ancient religions;[10] and in biblical studies.[11] Some applications to historical materials borrowed the terminology and key concepts of network science as heuristic tools or used network theory to provide novel graphical representations of historical data. While such uses of network concepts can result in interesting new insights into historical phenomena, the full potential of network science can be exploited only by the quantitative analysis of networks. The contributions to this thematic session offer case studies that employ network science in different ways to biblical materials, with the ultimate goal of adopting the quantitative methods of network science to the study of biblical literature and the history of early Christianity.

For historians, it is most natural to enter the field of network science through social network analysis. Many of the concepts of network science were developed in the context of social network analysis, and the terminology often preserves the original context (e.g., clique, community, neighborhood) even if the concept is used in other disciplines. As the contributions to this thematic session demonstrate, network science can potentially expand our understanding of biblical literature and earliest Christianity in many ways, including, but not restricted to, social networks. Let us consider three major domains of inquiry that can benefit from the use of network science.[12]

(1) First, network science can be employed to study the natural and built environment of ancient Judaism and Christianity. The study

[8] In mathematical usage, “edge” sometimes means an undirected connection and “arc” a directed one. See below for directed networks.

[9] E.g., Düring *et al*. 2015; Malkin 2013; Malkin, Constantakopoulou, Panagopoulou 2013.

[10] E.g., Álvarez-Folgado 2018; Collar 2013; Elwert, Sellmer 2013; Everton, Schroeder 2019; Fousek *et al*. 2018; Glomb 2021.

[11] E.g., Czachesz 2011; 2016; Duling 1999; 2000; 2013; Kloppenborg 2020; McClure 2016; 2018; 2020; Roitto 2020.

[12] Cf. Kaše, T. Glomb, J. Fousek forthcoming.

of infrastructural networks in the contemporary world is a burgeoning area, and network data about the internet, roads, electric grids, and so on are stock examples in network science literature. When comparing our modern world with that of ancient Mediterranean cultures, it is astonishing how differently people's environment looked without the networked infrastructure that was put in place later by the industrial and communication revolutions. Still, there are opportunities to study networks in this domain in the ancient world, as well. For example, rivers and other bodies of water formed natural networks, on top of which water management created additional built networks. Local and long-distance paths and roads had been forming for times immemorial, providing the networked infrastructure for everyday activities, commerce, military campaigns, administration, and migration. The long-distance road network of the Roman Empire is a prime example of how engineering can shape social reality, including the spread of cultural innovations and religions. A fascinating project focusing on this area is the network model of ancient Roman transportations systems (ORBIS) developed by Walter Scheidel and colleagues.[13] The network includes the major transportation routes across the Roman Empire on land and sea, allowing one to calculate the cost and time of travel and shipping under various conditions. The ORBIS transportation network inspired applications and further research, partly based on better or supplemented data, including the movement of religious innovations across the ancient Mediterranean world.[14]

The ORBIS model exemplifies some key properties of networks as mathematical objects (and graphical representations of such mathematical objects) as opposed to networks as understood in general usage that are worth pointing out. When creating a graphical representation of a network (such as in Figure 1), the dots standing for the nodes of the network might have identical or different sizes or colors, and the links might have identical or different widths, lengths, colors, etc. The sizes and shapes of these graphical objects, however, do not necessarily represent the physical length of a route or the actual size of a city. Generally speaking, the physical arrangement of the elements on a graphical representation of a network usually follows requirements of readability; alternatively, it can show some abstract relationship between the nodes, such as members of the same sports team grouped together or the width of links showing the amount of time two individuals spend together. In the case of the ORBIS model, the user can generate various types of maps such that physical distances on the map will represent travel costs or travel times between two locations. Apart from the particular case

13 Scheidel 2014; 2015. The model is available at https://orbis.stanford.edu/.

14 E.g., Fousek *et al*. 2018; Glomb 2021; Glomb *et al*. 2018.

of representing the network visually, the *weight* of a link is a numerical value and can stand for some chosen property of the connection, such as physical distance, the cost of traveling the route, or the strength of the emotional bond between individuals.

(2) Second, the social networks of ancient Jewish and Christian actors can be modeled and analyzed. There are several fundamental questions associated with the use of network science in this domain, which we need to address briefly at this point.

(a) Although the concept of a social network is intuitive, finding a social network in the real world with any precision is not a trivial task. In order to build a model of social relationships, one needs to obtain quantifiable data about interactions between social actors. A traditional way to collect such data is the use of questionnaires. This kind of data collection immediately brings social psychology into the equation since we are asking people to make judgements about themselves and other social actors. Taking advantage of the technological networks that people use to maintain social relationships in the modern world, easily quantifiable data can be derived from a variety of sources, such as email and cell-phone meta-data (that is, data of connections but not of actual content), Facebook friendships, Twitter followership, and other social media. Co-authorship (of academic publications) is yet another established area of study. The problem with the latter type of data collection can be, however, that it shifts the focus to aspects of human interaction that involve the use of telecommunications technology, while ignoring essential human interactions that cannot be accessed or measured in this way.

(b) It is obvious that most of the above-mentioned means of collecting data about social networks cannot be applied to the study of the ancient Mediterranean world. As is the case with studying any aspect of human history, we can rely on two types of sources to obtain information about human interactions in the ancient world: archeological evidence and textual sources. Thus, we can infer how cities or groups of people interacted from all sorts of objects that show up at different settlements and in different regions, such as commercial goods, coins, and objects of art. Textual sources include, among others, letters that inform us about contacts between individuals or groups, inscriptions that document the presence of an individual, ethnic group, or religion at a certain place and time, and literary texts belonging to various genres.

(c) Although archeological evidence is often open to alternative interpretations, we can be certain that an archeological object (unless we deal with a forgery) in fact existed in the historical past. Textual evidence is often open to interpretation in more radical ways. In modern Biblical studies, scholars have treated every detail of the textual sources with utter suspicion, questioning its authorship, date, and the historical existence of the people and events mentioned in the text. As a result, almost nothing in biblical literature is thought to be any longer what it appears on the surface. Thus, a conversation between Moses and Pharaoh in the book of Exodus (5:1–21; etc.) cannot be read (according to modern biblical scholars) as evidence of a social tie between two individuals in the historical past. At the other end of the spectrum, we can infer such social ties from the letters of the apostle Paul that are widely accepted as authentic. For example, chapters 1 and 2 of the Epistle to the Galatians inform us about meetings between Paul and Peter that scholars usually accept as having taken place in the historical past (even if perhaps not exactly as Paul reports them). Between these two extremes, most narratives in biblical literature are thought to be at least partly fictional or following agendas (authorial concepts, group interests, and theological programs) to such a degree that we can infer very little from them with certainty about the interaction of social actors in the historical past. It is therefore important to make a clear distinction between two ways of applying network science to textual sources: reading texts as sources of data about real-world social networks, on the one hand, and studying the narrative (or fictional) world with which that the text presents us, on the other. The latter type of network analysis will take us to the third kind of use of network science (see below).

Due to the nature of the data about social networks in antiquity, the resulting networks that we ultimately analyze are often either (very) partial or hypothetical (and idealized). An important question that arises is whether we can use the models to "complement" the data. The problem is not limited to the use of network science but presents itself whenever scholars apply social-scientific models to historical data in general. Building a model from a limited set of data is usually understood to reveal larger patterns. We are then justified to ask if the model offers reasonable approximations of the missing data, as well. This is related to the question of how much predictive power a network model (or social scientific model in general) has. Under the influence of the post-modern, there has been a widespread push-back against generalization in biblical studies. However, one needs to ask, first, what kinds of regularities social scientific studies could be after if their models had no implications beyond the particular datasets on which the models are based and second, in what ways we expect yet-to-be-discovered reality to deviate from the models. Unless we believe that human behavior (on the level of groups and individuals) is completely unpredictable or models are only valid for the particular data at our disposal, we are forced to reason about the extent to which social scientific models predict data that is yet unknown to us. Finally, if the model had no predictive power at all, it would also be impossible to find data that contradicted it; that is, it would be impossible to falsify the model.

(3) A third way of using network science is to zoom in on a text or textual corpus. In this domain, two main avenues can be identified.

(a) Network science can be applied to the study of the narrative world of the text, that is, the world that we as modern readers infer from the written source, without attempting the make assumptions about the existence in the historical past of things, people, and events mentioned in the narrative. Thus, we can study the social network of characters in Exodus or even in the entire Protestant Bible without worrying whether the characters correspond to historical figures or if such figures existed they interacted in ways that the text suggests.[15] By extension, we can study, theoretically speaking, other details of the narrative world in a similar fashion as we would study various aspects of the ancient world itself, provided that we are careful not to confuse the narrative world with a historically reconstructed reality. The boundary between these two approaches is sometimes blurred or at least depends on the critical stance of the scholars working with the method. For example, the social interactions of Jesus in the gospels can be seen either as taking place in a narrative world (to which most scholars would agree without any problem) or as an approximation of the social networks of the historical Jesus (which would be highly problematic to many modern scholars).

(b) The text as a linguistic artifact lends itself to network modeling of various kinds.[16] An established field of computational linguistics is the construction and study of semantic networks.[17] The nodes of a semantic network represent objects or concepts, whereas semantic relations between the objects and concepts appear as labels on the links (see Figure 2). The creation of a semantic network traditionally involved human input, but the process has been largely automated recently. For example, a semantic network can be built from all named entities (people, places, etc.) in the New Testament.[18]

A different approach to building network models of texts concerns itself with the co-occurrence of entities in the same part of a text or textual corpus. For example, a simple model could connect entities appearing in the same gospel story with each other (see Figure 3 for a sketchy implementation).[19] Looking at a graphical representation of the network, we can observe, among others, that "Jesus" has the greatest number of links to other entities in the network and stands as a bridge between elements of various episodes. This is not surprising given that

[15] E.g., Choi, Kim 2007 generated a social network of Greek and Roman mythological characters.

[16] Mihalcea, Radev 2012.

[17] Dengel 2012; Sowa 1992.

[18] Cf. Boisen 2011.

[19] For a similar study of Jesus' sayings in the gospels, see Everton, Cunningham 2020.

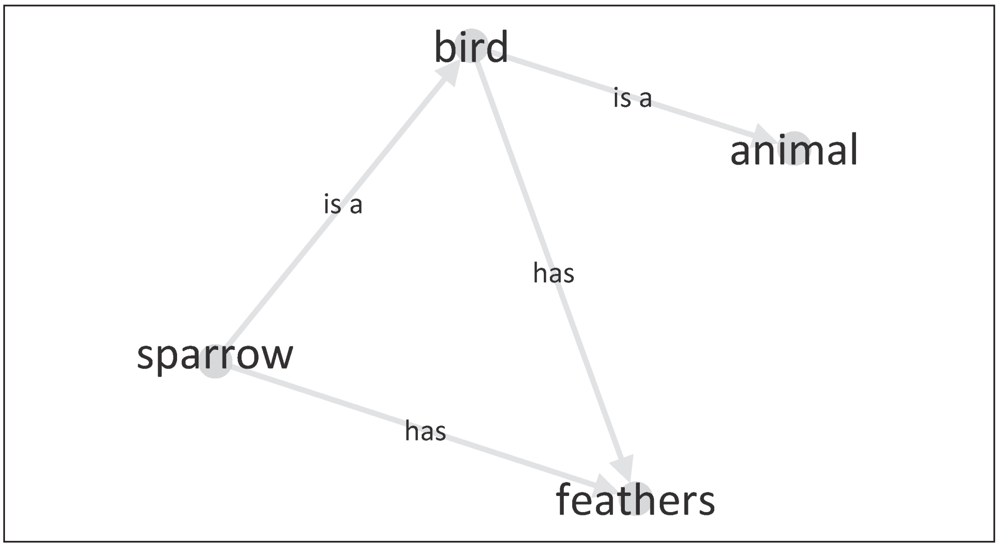

Figure 2. A simple semantic network. Directed and labeled links represent relations between concepts represented by the nodes.

Jesus is the protagonist of the gospel and appears in almost every episode of Mark 1. Somewhat more surprising is the central position of "voice" in the chapter, which exemplifies how a simple model can produce new insights.

The model also demonstrates some of the difficulties involved in the network analysis of the text of the Bible (and of texts in general). (a) First, identifying elements of the text that become nodes of the network is not straightforward. For example, we included "Peter's mother-in-law" as a character without a name; however, from a semantic perspective, "mother-in-law" (a noun) could be taken as a node, alongside other nouns for family members in the gospels (mother, father, etc.).

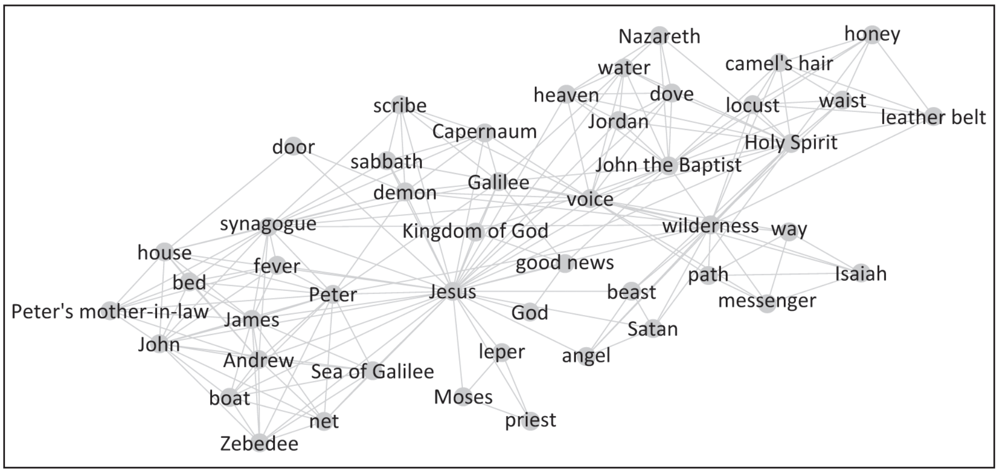

Figure 3. An incomplete network of the entities mentioned in the first chapter of the Gospel of Mark. Links connect entities that appear in the same episode.

The former approach is closer to social network analysis, while the latter to semantic analysis.[20] (b) Second, it is not straightforward either to identify the units of the text that determine the links between entities. Where a story or episode begins and ends is not clearly defined. The same goes for the demarcation of sentences and biblical verses (the system of verses being added in the 16th century). (c) Third, decisions about both questions should be based on the texts in the original languages. However, this makes it difficult to create models that involve texts from both the Hebrew Bible and the Greek New Testament. Furthermore, the original text is often uncertain, and sometimes there are multiple versions that are accepted with more or less the same authority.

Finally, vector semantics is an area of linguistics that studies the meaning of words by looking at their co-occurrences in texts.[21] For example, two words that occur in similar contexts (that is, both words tend to occur in the company of the same set of words) are likely to have similar meanings.[22] Although vector semantics does not study networks explicitly, it lends itself to an interpretation in terms of network science: nodes can represent words, and words that co-occur in a piece of text (or in a document of a textual corpus) can be connected by a link. A slightly different approach to word co-occurrence looks at words that appear within a given distance from each other (also called a "sliding window") in the text. Empirical studies suggested that such an approach can approximate the connections that people make between words when they freely associate words with each other.[23] Thus, it can be argued that by creating a word co-occurrence network from biblical texts, we arrive at a novel understanding of the minds of ancient readers.

III. Some technicalities

The articles in this thematic session use several methods to create, represent and analyze networks, including statistical methods to describe the position of nodes within the network and the overall structure of the network. A handful of basic concepts in network science will be briefly introduced in this section in order to provide a general idea of what they are and how they work, while the individual articles will delve deeper into those concepts and provide definitions and examples as necessary.

[20] Another problem is worth pointing out: we treated "Peter" and "Simon" as the same entity, since Mark 1 (as the rest of the gospel) uses the names interchangeably to refer to the same character.

[21] See recently chapter 6 in Jurafsky, Martin 2021.

[22] For an application to Biblical Studies, see Vojtěch Kaše, Nina Nikki, and Tomáš Glomb's article in this thematic session.

[23] Lemaire *et al.* 2006. See Czachesz (2016) for an application to Biblical Studies.

Above we defined networks in terms of nodes and links and used graphical representations to study them, which consisted of dots (for nodes) connected by lines or arrows (for links). If the links of a network have a direction, which is indicated by arrowheads on the links (as in Figure 2), we speak of a *directed network*; otherwise we speak of an *undirected network*. However, the graphical representation of a network is not the only one possible, even though it is probably the most intuitive one to the human eye. When working with networks in computer programs, they are usually represented either as edge lists or adjacency matrices.

An *edge list* contains the starting and ending points of all links (edges) of a network, resulting in a list of items containing two nodes each. If the network is directed, the edge points from the first node to the second.[24] The partial edge list of the friendship network of Zachary's Karate club is shown in Figure 4. Note that the network (as constructed by Zachary in the original publications) is undirected; thus, the order of the elements in each pair is not important.

{(1, 2), (1, 3), (1, 4), (1, 5), (1, 6) … (1, 22), (1, 32), (2, 3) (2, 4). (2, 8), (2, 14), (2, 18) … (2, 22), (2, 31), (3, 4), (3, 8) … (3, 28), (3, 29), (3, 33) … (4, 8), (4, 13), (4, 14) … (32, 33), (32, 34), (33, 34)}

Figure 4. The partial edge-list of the friendship network of Zachary's Karate club (see Figure 1). Each pair of numbers identifies two nodes between which there is an edge (link).[25]

Yet another way to represent networks is the adjacency matrix. An adjacency matrix is essentially a table including a row and a column for each node, with the cells of the table indicating whether there is a link from the node of the row to the node of the column. Figure 5 shows part of the adjacency matrix of Zachary's friendship network. If no links are allowed from the nodes to themselves (called *loops*), which is the case in our example, the diagonal of the table from the upper left corner to the lower right corner is filled with zeroes. If the network is undirected (and no parallel links are allowed, see below), the table is

[24] That is, an edge list consists of ordered pairs or 2-tuples. A directed edge is sometimes called an "arc," see note 8 above.

[25] Alternatively, an edge list can be given as a table with two columns (columns for starting and ending nodes).

symmetrical along the above-mentioned diagonal, and it is sufficient to use only one-half of the table.[26] Finally, if the links have a *weight* attribute, the numerical value of the weight appears in the respective cell of the table instead of a "1." In a *weighted network*, the weights can represent, for example, the strength of friendship ties as measured by the time people spend together; in a word co-occurrence network, the weight can indicate the number of times two words of a text occur next to each other.

	1	*2*	*3*	*4*	*5*	…	*33*	*34*
1	0	1	1	1	1		0	0
2	1	0	1	1	0		0	0
3	1	1	0	1	0		1	0
4	1	1	1	0	0		0	0
5	1	0	0	0	0		0	0
…								
33	0	0	1	0	0		0	1
34	0	0	0	0	0		1	0

Figure 5. The partial adjacency matrix of the friendship network of Zachary's Karate club (Figure 1). A "1" in a given cell indicates that there is a link from the node in the respective row to the node in the respective column, and a "0" indicates the absence of such a link.

The adjacency matrix allows for the calculation of various statistical characteristics of the network. For example, by calculating the sum of the values of all cells on a row, we receive the *degree* of the node represented by the row (or the *in-degree* of the node if the adjacency matrix defines a directed network). The degree of a node is one of the *node centrality metrics* and shows how many connections each node has.

A *path* between two nodes is a sequence of links that one needs to pass through in order to reach one node from the other. If the network has no parallel links (multiple links between any two nodes),

[26] That is, under this condition, the link from node k_1 to node k_2 is identical with the node from k_2 to k_1.

we can simply enumerate the nodes on the path to identify the path. For example, in Zachary's friendship network, (27, 30, 24, 28) is a path between nodes 27 and 28, and (27, 30, 26, 25, 28) is another path between the same two nodes. By comparing the lengths of all paths between two nodes, we can find the *shortest path* (also known as a *geodesic*) between them, and the number of links on the shortest path will give us the *distance* between the two nodes. For example, the distance between nodes 27 and 28 in the Karate club is 3. The *diameter* of the network is given by the longest of all shortest paths (i.e., the longest geodesic) between all possible pairs of nodes in the network. For example, the friendship network of the Karate club has a diameter of 5.[27]

In a *fully connected network*, each node has a link to every other node. For example, each of the 34 members of Zachary's Karate club could potentially have 33 friendship ties, which would give 1,122 links. Note, however, that in this case, there would be two links between each pair of nodes (e.g., one link from member 1 to member 2 and an additional link from 2 to 1). Consequently, in an undirected network with N nodes, without parallel links, the fully connected network contains N×(N-1)/2 links, yielding 561 links in a fully connected version of Zachary's network. The *density* of a network indicates the proportion of all possible links that actually exist in the network. In the actual network of Zachary's Karate club, there are only 78 links out of the possible 561, yielding a network density of 0.139.

Network topology concerns itself with the overall arrangement of the nodes and links and answers questions such as the relationship between the density and diameter of the network, or the resilience of the network if links are being removed. For example, one can ask how many friendships can break up in the Karate club randomly before the friendship network falls apart into unconnected pieces.

A *community* within a network consists of a group of nodes that are especially well-connected with each other, and a *clique* consists of a fully connected set of nodes (that is, a group of nodes in which all possible links are present). For example, members 1, 2, 4, and 14 of Zachary's Karate club form a clique. There are several methods of *community detection*. Network communities are also called *modules*, and the *modularity* of networks (including the presence of modules, the size of the modules, the connections between modules, and so on) is an important topic in the study of biological networks, among others. Many networks change through time, in which case we call them *dynamical networks*. Recent work has increasingly turned to the study of *network dynamics*.

[27] E.g., the shortest path between nodes 17 and 19 has a length of 5: (17, 6, 1, 9, 22, 19).

IV. The plan of this special issue

This thematic session includes six articles that apply network science to the study of early Christianity and biblical literature. Three of the six articles investigate the social networks of early Christians and the ancient society surrounding them. The remaining three contributions, in turn, deal with linguistic and conceptual networks in the textual sources.

Catherine Hezser in her article (*Between Scholasticism and Populism: Rabbinic and Christian Networks in the Roman Empire*) compares rabbinic and Christian leaders' networking activities within the shared Roman imperial context of the first to fourth centuries CE. The author argues that networks of like-minded individuals emerged in the period under consideration in the context of Roman imperialism, which connected, integrated, and to some extent homogenized the various sectors of the population through road connections, infrastructure, and Romanization. Both rabbis and Christian leaders tried to distinguish themselves from certain aspects of their Graeco-Roman cultural environment, while functioning within it and adopting some of its features. Hezser examines the nature of ties between network participants, the type of communication conducted in them, and the scope and function of the networks in question. She suggests that rabbinic scholarly networks differed considerably from Christian leaders' more populist and wide-ranging outreach activities that eventually led to the so-called triumph of the Church in the fourth century CE.

Rikard Roitto in his contribution (*The Johannine Information War: A Social Network Analysis of the Information Flow Between Johannine Assemblies as Witnessed by 1-3 John*) applies social network analysis heuristically to the Epistles of John. In particular, the author uses network science to understand how the Epistles of John attempt not only to promote their vision of the community's identity and theology, but also to strengthen their own position in the Johannine social network and weaken the position of its competitors. Insistence on social distance from competing teachings is central to 1 and 2 John, while 3 John is occasioned by the Johannine School's being marginalized by an assembly. Roitto argues that the errands of these letters can be described in terms of network analysis as attempts to weaken certain social ties and strengthen others to allow the Johannine School's more uncontested dispersion of information in the assemblies of the network.

Sean F. Everton and Robert Schroeder in their article (*The Church Among Jews and Gentiles: A Network Simulation of the Christian Mission to the Jews*) use computer simulation that is based on network science. The authors take on the problem known in early Christian studies as "the parting of the ways." Most scholars of the early Church agree that although Christianity was initially one of many Jewish sectarian movements (including Rabbinic Judaism), it eventually shed its Jewish ties, leading it to attract more Gentile converts than Jewish ones. When the split occurred is a matter of debate. Some date it as early as 70 CE when Rome destroyed the Jerusalem Temple. Many date it to 135 CE and the Bar-Kochba revolt. There are other scholars who argue that Jews and Christians regularly interacted into the 4th and possibly 5th centuries. When the split occurred has direct bearing on how successful the early Church's mission to the Jews was, as do other factors such as underlying demographics, fertility rates, competition from other religious groups, and so on. Everton and Schroeder do not take sides in the debate concerning the success of the Christian mission to the Jews. Instead, using computer network simulations that capture a wide variety of assumptions, they present a series of models that produce a range of estimates of the number of Jewish converts to Christianity. The authors discuss some of the potential implications of their results and how the results can possibly inform future studies of the early Christian Church and the spread of Rabbinic Judaism in the first few centuries of the common era.

Vojtěch Kaše, Nina Nikki, and Tomaš Glomb in their contribution (*Righteousness in Early Christian Literature: Distant Reading and Textual Networks*) investigate changes over time in the concept of righteousness from the Apostle Paul to early Christian texts until the fourth century. The authors study the problem from a quantitative perspective, employing the methods of distributional semantics, especially word embedding models and word co-occurrence networks. These methods reveal trends and changes in large corpora of textual data which are often too subtle to be detected by close reading. Thus, by employing a comprehensive corpus of publicly available ancient Greek texts from the Homeric period to late antiquity, the computational analysis enables the authors to inspect the Pauline and Christian usage of the relevant terminology in a wider literary and temporal context. In Protestantism there is a widely shared belief that the forensic understanding of justification traditionally held by Protestant Christians follows Paul's original interpretation of the concept. Scholarly opinions, in turn, have tied Paul's use of the concept of justification to his debates around the Gentile observance of the Mosaic Law. Scholars also believe that later Christian writers turned to an ethical use of the term because of the changed historical context, especially the gradual separation of Christianity and Judaism. The article sheds new light on these arguments and aims especially to clarify the extent to which righteousness is a morally loaded term in post-Pauline Christian literature, if and how Christian usage differed from that of non-Christian authors, and how the varying uses of the term are affected by the wider social and economic contexts.

Tamás Biró in his article (*Who Circumcised Abraham? A Cognitive Network Model to the Interpretations of Gen 17*) investigates a network of the meanings of the Hebrew verb "to circumcise." The verb "to circumcise" in Gen 17:24, and elsewhere in that chapter, appears in the *niphal* form, entailing a passive meaning. Thus, the agent of the action remains unknown. Yet, Abraham's circumcision plays a central role in Judaism. Biró argues that Abraham's circumcision is not simply the prototype of all subsequent instances of a ritual that is central to Jewish identity, but it is also the starting point of a recursive chain of ceremonies by which any later circumcision acquires its religious significance. Hence, the importance of the agent of the first circumcision. The author presents a selection of answers from various traditions to the question of who circumcised Abraham. Then he introduces a network of meanings, which serves as a linguistic model interpreting the agent-less *niphal* forms of the verb "to circumcise" in Gen 17. The model yields different interpretations under various conditions, corresponding to various traditions. Consequently, Biró suggests, the model describes the computation taking place in the human mind, which is able to produce alternative interpretive traditions.

István Czachesz in his contribution (*The Bible as a Network of Memes: Analyzing a Database of Cross-References*) uses network science to analyze cross-references between verses and passages of the Protestant Bible. The author argues that the text of the Bible can be understood as a network of cultural items (memes) that developed through an evolutionary process and has subsequently been transmitted for many centuries in a relatively stable form. He suggests that biblical cross-references reveal how the verses and passages of the Bible are connected into a network that is analogous to genetic networks in biology. He then presents a network model of cross-references, based on the online edition of the *Treasury of Scripture Knowledge*. After discussing the history of the database and the origin of the references, Czachesz presents various network statistics that yield insights into the history of the cross-references; he also highlights central verses in the network, comparing the results with the popularity of the respective verses in the history of Western biblical interpretation. Finally, the author discusses the modular structure of the network. Czachesz considers the results as tentative evidence for the collective behavior of populations in Western history being co-determined by a network of biblical memes.

The contributions to this thematic session present a range of applications of network science to the study of ancient Christianity and its social and cultural environment. The articles jointly make a case for the viability of network models as tools for the analysis of early Christian materials. The authors argue that the use of network science increases our knowledge of the biblical text and early Christian history and claim a place for network science and computational models in the field of biblical studies.

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