Network Analysis of *Beowulf*, the *Iliad* and the *Táin Bó Cúailnge*

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Abstract

Mythological epics frequently entail plethoras of characters in timeless narratives beyond documented history. As such, they differ from legends couched in definite historical timeframes and intentionally fictional folktales. The concept of universality is important to comparative mythology and it has been claimed that narratives from a variety of cultures share similar structures. Universality also lies at the heart of network theory, a relatively new branch of theoretical physics with broad applicability. Network theory allows one to classify and compare the interconnectedness underlying a multitude of structures relevant to biology, sociology, economics, chemistry, physics, transport, computer science, and other disciplines. Here we apply this theory to study networks of characters appearing in three different mythological narratives: *Beowulf*, the *Iliad* and the *Táin Bó Cúailnge*. By comparing these amongst each other, and to real, fictitious and random networks, we seek to develop a new, quantitative approach to comparative mythology. In particular, we find that each of the three epics has, to varying degrees, properties akin to those of real social networks. This quantitative approach forms a basis upon which one may speculate as to the extent to which these narratives may be based upon real or imaginary societies.

INTRODUCTION

Statistical physics is concerned with how the macroscopic properties of matter emerge from the interactions of basic components through the fundamental laws of physics. It is a discipline which initially appears remote from the humanities in general and from comparative mythology in particular. However, interdisciplinary approaches, which have been somewhat in ascendancy in recent years, have previously led to valuable syntheses in the pursuit of new insights, perspectives and knowledge in various fields (e.g., Ausburg, 2006). Techniques of statistical physics have been successfully applied to gain quantitative understanding of multitudes of issues, including many of non-physical nature, especially where properties of complex systems emerge from the interactions between component parts in a non-trivial manner. In particular, the application of such techniques to social and economic systems in recent decades led to the emergence of the new sub-disciplines of sociophysics (Galam, 2004) and econophysics (Mantegna & Stanley, 2000).

In physics, one often deals with systems comprising large numbers of mutually interacting components, e.g. atoms or molecules in a material or gas. Since it is impossible to track the location and movement of every individual component, one resorts to a statistical approach, which delivers average, global properties of the macroscopic system. Similarly in quantitative approaches to sociology one seeks to understand the characteristics and behaviours of an entire society on a statistical basis rather than the individuals it comprises. In recent decades, sociophysics has matured into an established academic discipline which offers new perspectives on some aspects of such collective behaviour. Sociophysics is certainly not intended as a replacement for traditional approaches to sociology; although sociophysics may bring a certain degree of mathematical precision in answering specific questions, it cannot capture all of the broader dimensions of more holistic traditional approaches.

In a similar spirit, we seek to develop a quantitative approach to comparative mythology through applications of network theory (Mac Carron & Kenna, 2012). What we attempt to bring to the field is a new way to quantitatively analyse interactions; we seek information on how characters are interconnected in epic narratives. We try to capture these characteristics through sets of numbers which, through quantitative comparisons, may yield meaningful answers to certain questions. This approach cannot, of course, deliver comments on events, emotions, meanings or other qualitative and holistic aspects which form the focus of traditional studies.

There are many obvious caveats and limitations to any pioneering application of network theory or physical techniques to comparative mythology. For example, any attempt to surmise a degree of historical reality behind mythological epics is tempered by distortive political and religious forces which influenced their construction, the obvious enormous lapses in time between the creations of the medieval tracts in which they are recorded and the societies and events they purport to describe, and even the use of modern texts as proxies for, and translations of, the originals. Thus there are layers of obfuscation covering the material to be analysed. The mathematical tools necessarily also suffer from certain limitations. The reliability of any statistical analysis is a function of the sample size, with smaller samples necessarily leading to less reliable results. Ideally the statistical approach is most dependable if applied to extensive narratives with large numbers of characters and plenty of interactions between them. The reader should keep in mind that any such analysis cannot offer proofs – only evidence and comparisons from new perspectives, which need to be combined with other approaches.

With the above caveats in mind, aware that we can only analyse the material which has come down to us in the form it has, and that we can only apply the techniques which we possess, we considered it worthwhile to examine what modern mathematical network techniques have to say on the matter on comparative mythology. All conclusions we draw here are “from a network-theoretic” point of view, and it is up to the experts in mythology and other fields (such as archaeology) to inform further. Ultimately it is up to readers to make informed judgements of their own, while our purpose is to help inform such judgements from a wholly new perspective.

Before reporting on our network analyses of mythological epics, and for the benefit of these readers unfamiliar with the mathematical technology, we start our exposition with a brief picture of complex network theory. Then, after a reminder of the texts we seek to analyse, we report on the network analyses of *Beowulf*, the *Iliad* and the *Táin Bó Cúailnge* and a quantitative comparison between them.

COMPLEX NETWORKS

Over the past few decades, many statistical physicists and complexity theorists have turned their attention and expertise to non-physical complex systems in attempts to understand how their properties emerge from the relatively simple interactions between component parts. Applications include analyses of complex networks in the natural, technological and social sciences as well as in the humanities. An upsurge of activity came after 1998 when striking similarities were noticed between the structure of an electrical grid, social networks and the neural wiring systems of nematode worms. Network theory allows one to classify and compare these (Watts & Strogatz, 1998). The theory has since been extended to the study of the structure of the internet (Cheswick & Burch, 1999), power grids (Buldyrev et al., 2010), transport networks (von Ferber et al., 2012), food-webs (Dunne, 2004), and many more areas, and network theory is now an extremely useful tool to describe the interconnectivities of a vast variety of real-world systems (da F. Costa et al., 2007; Albert & Barabási, 2001; Newman, 2003).

Universality is an important notion in the field of comparative mythology. Campbell (1949) maintained that mythological narratives from a variety of cultures essentially share the same fundamental structure, which he termed the *monomyth*. The monomyth is clearly a qualitative concept. However, the broad notion of universality is also of great importance in statistical physics, whereby the categorisation of different critical phenomena into so-called universality classes is an important theme. These universality classes have the same or similar essential characteristics. Since these characteristics are quantified through numbers, it is relatively straightforward to gain an understanding of how similar or dissimilar different physical systems are. Our

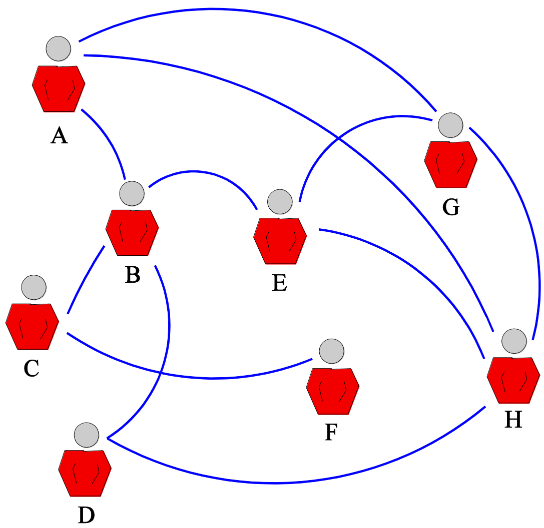

Figure 1: Networks comprise both nodes and links (or edges) which represent relationships between them. In network theory, we are interested in statistics capturing how these relationships are distributed.

objective here is to use network theory to compare the statistics describing the interconnectedness underlying mythological narratives from three different cultures to each other as well as to real and imaginary networks.

A **network** is a set of objects called *nodes* which are connected together by *links* or *edges*. In a **social network** (see figure 1) the nodes represent people and the edges are interactions or acquaintanceships between them (Wasserman & Faust, 1994). A large array of statistical tools has been introduced to describe and quantify various properties of networks and social networks have different characteristics to other types of complex networks (Newman & Park, 2003). Next we briefly outline some of the network tools used in our analysis. The reader interested in the mathematical details is refereed to Mac Carron and Kenna (2012) and references therein.

Connectivity: Social networks tend to be highly connected and are often called "*small world*" (Watts & Strogatz, 1998). The connectivity is measured in at least two ways. The first is the *mean path length*. This is the average shortest number of steps between pairs of individuals in a social network. In figure 1 for example, there are various routes by which individuals G and D may be connected (e.g., G→E→H→D), but the shortest of these have only two steps (i.e., route G→H→D). Thus the path length between G and D is 2. We next measure the (shortest) path lengths between all other pairs of nodes (e.g. A to B; A to C; ...; G to H). The average of all of the resulting numbers is the mean path length of the network. The idea of mean path length connects to the famous notion in sociology of *six degrees of separation*. This is the idea that, despite the world's population of about seven billion, everyone is, on average, only about six steps away from any other person, in the sense that a chain comprising of "a friend of a friend of a friend of..." connects most pairs of people, worldwide, in only six or fewer steps (hence the term "small world").

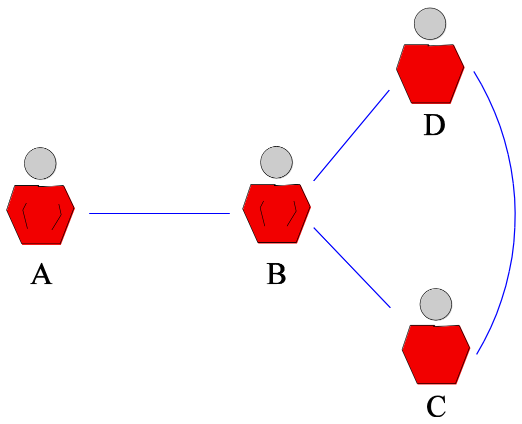

Figure 2: To calculate the clustering coefficient for node B, one observes that of the three potential relationship-triads involving it (ABC, ABD, and BCD), only one is realised, namely BCD. The clustering coefficient of node B is therefore deemed to be 1/3.

The second measure of connectivity which we consider here is the *clustering coefficient*. This is designed to give an indication as to how cliqued a network is; if an individual knows two people then there is a high probability that those two people also know each other. In social networks the average clustering coefficient tends to be very high compared to other networks; for example in a client server network where each computer is connected to a central sever, there is no clustering as the computers are not directly connected to each other − there are no closed triadic loops. An example of how to calculate the clustering coefficient of an individual node is given in figure 2. The clustering coefficient for the entire network is determined by simple averaging over all nodes.

To summarise then, the connectivity of real social networks tends to be characterised by small path length and high clustering.

Degree: The *degree* of a node is the number of links emanating from it (or entering into it). In a social network it is the number of people an individual is acquainted with. Since different individuals have differing numbers of acquaintances the degree varies from node to node. The spread of degrees across nodes throughout a network is called the *degree distribution*. The shape of the degree distribution depends upon the type of network under scrutiny. In figure 3, three such networks are schematically illustrated. The leftmost network in the figure is random in the sense that the probability that any two nodes are joined by a link is a random number. This is very different to the regular, ordered network structure one has in a lattice (the middle network of the figure). Complex networks are different again, and an illustration is given in the rightmost panel of figure 3. In social networks of this type, the degree distribution tends to follow a mathematical relationship called a *power law* and is often found to be *scale free* (Amaral et al., 2000). This means that only a few people tend to interact with a very large number of others.

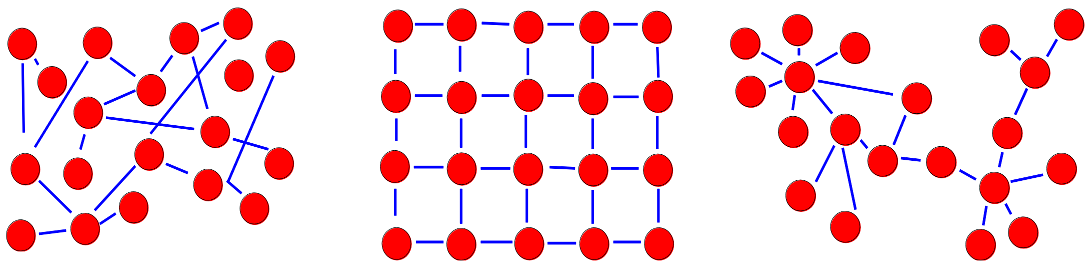

Figure 3: Schematic diagrams representing three different types of networks: random graph (left), regular lattice (middle) and a complex network (right).

One way to appreciate the difference between the networks in figure 3 is to consider removing the most connected nodes. In the random network and lattice, this has little effect, but in the complex network with scale-free degree distributions, such targeted elimination of important nodes causes the network to break down very quickly and become disconnected. However, even for the complex network, removing nodes at random tends not to have a strong affect.

To summarise, social networks have power-law degree distributions and are scale free. They tend to be robust to random attacks but vulnerable to targeted attacks, unlike random and regular networks (Albert et al., 2000).

Assortativity: In real social networks, people tend to be friends with other people who are similar to themselves; popular people tend to be acquainted with other popular people, for example. Networks in which most nodes have this property are called *assortative* (Newman, 2002) and those without it are *disassortative* (see figure 4). Assortativity is a very important property which distinguishes social networks from other networks. In fact, most non-social networks are disassortative (Newman & Park, 2003). For our analysis too, assortativity will play a key role. To investigate the assortativity properties of a network, one simply compares the degree of a node (acquaintances of a character in the case of mythological narratives) to the degrees of its neighbours to see if popular individuals are more likely to be mutually acquainted, as is normally observed in real social networks.

To summarise, assortativity is the tendency for similar nodes to be connected (as in the maxim “birds of a feather flock together”). Social networks tend to be assortative and most other networks tend not to have this property.

Characteristics of real and fictitious social networks: In the past decade, many social networks have been studied and their properties catalogued. Examples include the networks formed by actors who have appeared in different movies (Amaral, 2000), musicians in Jazz bands (Gleiser and Danon, 2003), users of online forums (Kujawski & Abell, 2011), scientific co-authors collaborating on research papers (Newman, 2001) and directors of various companies (Davis et al., 2003). What constitutes a relationship link in these various networks may have different meanings – e.g., the social link between two scientists who write a paper together may be far stronger than that between two actors who appear together on a large film set (Newman, 2001). The general properties of a wide variety of real social networks are therefore well established and well documented.

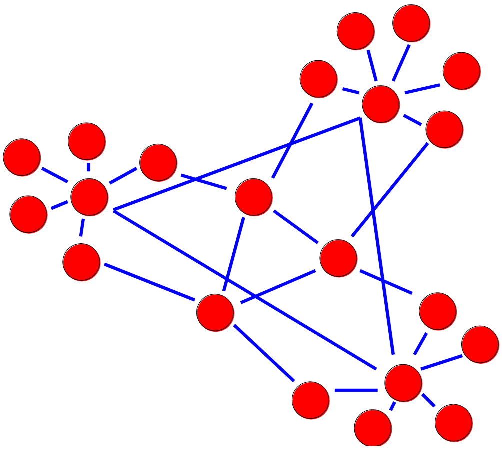

Figure 4: The network on the left represents assortativity because nodes of similar degree tend to be linked to each other. E.g., the three nodes of highest degree are linked to each other. The network on the right, which has the same distribution of nodes, represents disassortivity – e.g., the three most linked nodes are not mutually connected.

The collection of the various characters which have appeared in Marvel comics and the relationships between them form an example of a social network which is clearly fictional. It is called the *Marvel Universe* and has been studied by Alberich et al. (2002) and by Gleiser (2007). In this universe, two characters are considered linked if they appear in the same comic book. The mathematical analyses showed that the Marvel Universe does not look like a real social network. In particular, although it is highly connected like a real social network, it is also highly disassortative – a tell-tale sign of artificiality. All of the major characters are too highly connected making the network appear unrealistic.

Because there are few if any other analyses of artificial or fictional networks, we also examined four works of fiction, namely Rowling's *Harry Potter*, Tolkien's *Lord of the Rings*, Shakespeare's *Richard III* and Hugo's *Les Misérables.* Clearly these four, along with the Marvel Universe, are not meant to embody all of the network features of the entire corpus of world fiction. Some are chosen because they are examples of clear works of fiction – works involving fabulous characters, which do not attempt to emulate reality. For others, the data were readily available, facilitating a speedy study. It is hoped that, in the future, other scientists will analyse other works of fiction, so that a more extensive list of typical features will ultimately be built.

We found that each of the fictional networks we analysed are small world, just like real social networks but none of their degree distributions are well fitted to power laws. Crucially, they are all disassortative. Moreover, unlike real social networks, the fictional ones are very robust upon targeted removal of the most connected nodes.

To summarise, our initial research indicates that degree distributions, disassortativity and robustness are indicators which may distinguish some fictional social networks from real ones.

COMPARATIVE MYTHOLOGY

Beowulf is an Old English heroic epic, set in Scandinavia. A single codex survives which has been estimated to date from between the 8th and 11th centuries. The story tells of the coming of Beowulf, a Gaetish hero, to assist Hrothgar, king of the Danes. After slaying two monsters, Beowulf returns to Sweden to become king of the Geats and, following another fabulous encounter many years later, is fatally wounded. Although the poem is embellished with obvious fictional elements and creatures, archaeological excavations in Denmark and Sweden offer support for the historicity associated with some of the human characters (Anderson, 1999). Nonetheless, the character Beowulf himself is mostly believed not to have existed in reality (Klaeber, 1950; Chambers, 1959). We base our network analysis on Heaney's translation (1999).

The *Iliad* is an epic poem attributed to Homer and is dated to the 8th century BC. It is set during the final year of the war between the Trojans and a coalition of besieging Greek forces. It relates a quarrel between Agamemnon, king of Mycenae and leader of the Greeks, and Achilles, their greatest hero. Also much debated throughout the years (Wood, 1998), some historians and archaeologists maintain that the *Iliad* is entirely fictional (Finley, 1954), while recent evidence suggests that the story may be based on a historical conflict around the 12th century BC interwoven with elements of fiction (Kraft et al, 2003; Korfmann, 2004; Papamarinopoulos et al., 2012). Our network analysis of the *Iliad* is based upon the translation by Rieu (2003).

The *Táin Bó Cúailnge* *(Cattle Raid of Cooley)* is the most well known epic of Irish mythology. The tale describes the invasion of Ulster by the armies of queen Medb of Connacht and the defence by Cúchulainn, Ireland's most famous hero. Related to *The Táin* itself are a number of pre-tales and tangential tales (*remscéla*) which give the backgrounds and exploits of the main characters. *The Táin* has come down to us in three recensions. The first has been reconstructed from partial texts contained in *Lebor na hUidre* (the Book of the Dun Cow, dating from the 11th or 12th century) and *Lebor Buide Lecáin* (the Yellow Book of Lecan, a 14th century manuscript) and other sources. The second, later recension is found in *Lebor Laignech* (the Book of Leinster, a 12th century manuscript formerly known as the *Lebor na Nuachongbála* or Book of Nuachongbáil). A third recension comes from fragments of later manuscripts and is incomplete. Two popular English translations of *The Táin* (Kinsella, 1969; Carson, 2007) are mainly based on the first recension, although they each include some passages from the second.

The Táin was dated by medieval scholars to the first centuries BC, but this may have been an attempt by Christian monks to artificially synchronise oral traditions with biblical and classical history. Its historicity is often questioned. O'Rahilly (1946) that such tales have no historical basis whatsoever. Jackson (1964) argues that, while such narratives corroborate Greek and Roman accounts of the Celts and offer us a "window on the iron age", "the characters Conchobar and Cúchulainn, Ailill and Medb and the rest, and the events of the Cattle Raid of Cooley, are themselves entirely legendary and purely un-historical". On the other hand, Lynn (2003) has claimed some evidence that the landscape reflected in the story may be based on reality. While the analysis which we present here is based on Kinsella's version, we also examined Carson's version to check that the two translations give very similar networks. Therefore, for the purposes of this analysis, Kinsella's translation serves as a proxy for what is commonly understood as the *Táin Bó Cúailnge.*

NETWORK ANALYSES OF *BEOWULF*, THE *ILIAD* AND THE *TÁIN BÓ CÚAILNGE*

The networks were formed by carefully reading each of the three narratives and entering each character's name into databases, meticulously listing interactions between them. Kinsella's *Táin* has 404 characters and 1,233 links. Heaney's translation of *Beowulf* was found to have 74 unique characters linked by 165 edges. Rieu's version of the *Iliad* has 716 characters and 2,650 links between them. Two distinct types of interactions were defined. Links between characters were designated as "friendly" if they know each other, are related to each other, speak to one another, or appear in a small congregation together. Links were deemed to be "hostile" if two characters meet in combat. A "weight" was assigned to the links based on how often they encountered each other. For example, in *The Táin*, the characters Ailill and Medb (respectively king and queen of Connacht) are more strongly linked than Ailill, for example, is linked to the Ulster hero Cúchulainn.

The friendly network for *The Táin* is depicted in figure 5. The top right and bottom left communities reflect the fact that characters from Ulster more commonly associate in a friendly manner with other characters from Ulster, and characters from Connaught with characters from Connaught. The opposite occurs for the hostile network, suggesting that only in the friendly networks may disassortativity be confidently interpreted as signalling artificiality.

All three epics were found to be small world; that is, they had a low average path lengths and high clustering coefficients. All the networks become disconnected upon targeting the most connected 5% of characters for removal but they are all robust to removing 5% of characters at random. However, of the three narratives, only the *Iliad* turns out to be assortative. *Beowulf* is mildly disassortative and *The Táin* is very disassortative. These results indicate that the social-network properties of the *Iliad* are similar to those of real social networks and dissimilar to random networks and the fictitious social networks listed above. This is what one might expect if the narrative is a reasonable portrayal of a real society. As cautioned in the introduction, it does not categorically *prove* that the *Iliad* is based on real events, but it may be interpreted as evidence to *support* the case for historicity (Kraft et al, 2003; Korfmann, 2004; Papamarinopoulos et al., 2012).

By the same token, *Beowulf* has some of the properties of real social networks, but its disassortativity may be a signal of artificiality. However, recall that archaeological evidence suggests that while the society in *Beowulf* may be based on reality, the eponymous character is believed fictitious. To utilise this information we remove the character Beowulf from the network and redo the analysis. It turns out that the remaining network is assortative – a potential real-life indicator! So *Beowulf* (without the character Beowulf) has all of the features of realistic social networks, corroborating archaeological evidence.

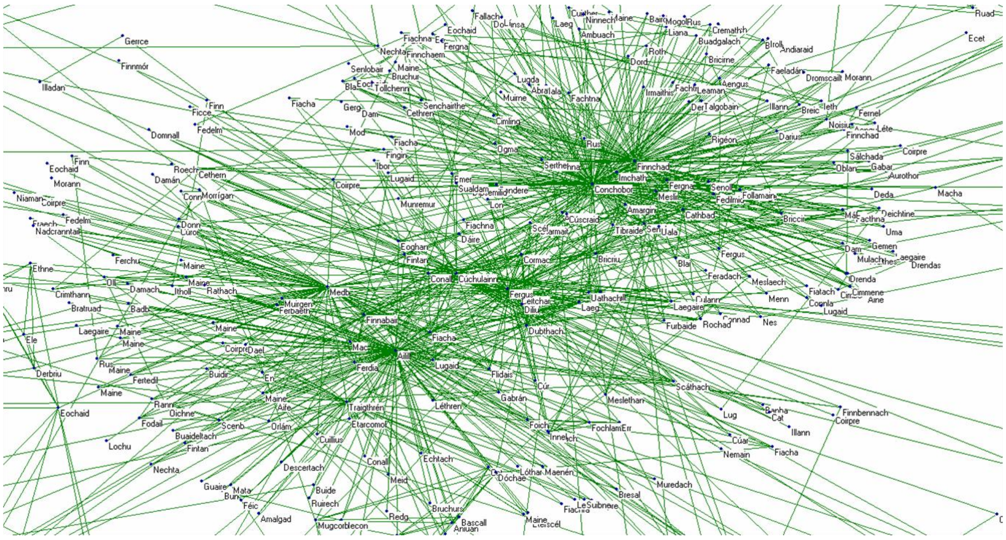

Figure 5: The *Táin* friendly network. Three main clusters are identifiable by eye. The right upper cluster is that of Ulster, with Conchobor at its centre. The lower left cluster is that of Connacht, centred on Medb and Ailill. The middle cluster centres on Cúchulainn, Fergus mac Roich and other warriors (mostly the Ulster exiles).

Next we turn to *The Táin.* Its strong disassortativity signals artificiality on the bases established above. We wish to investigate wherein this artificiality lies. Does the society depicted in *The Táin* appear fictional in its entirety or is its artificiality localised in a few characters, as *Beowulf's* artificiality is localised in Beowulf himself?

To investigate this, we analyse the degree distributions of all three networks. They are reasonably described by power laws (which translate into straight lines on a double-logarithmic scale, as used in figure 6). In this regard, they are just like real social networks. The degree distributions for *Beowulf* and *The Táin* are given in figure 6. Most notable is a remarkable similarity between the degree distribution of *Beowulf* and that of *The Táin* for all but the six rightmost data points corresponding to the Irish narrative. These data correspond to the six most connected characters in *The Táin*.

The two lines in figure 6 represent power laws "best fitted" to the data points which correspond to *Beowulf* (solid line) and *The Táin* (dashed line). The six rightmost data points, which represent the most connected characters in *The Táin*, are offset relative to the rest. This means that the degrees of these *Táin* characters are out of sync with the remaining characters of *The Táin,* and indeed *Beowulf.* The dashed line is a "best fit" to the *Táin* data and it is clear that the anomalous six points on the right drag that line upwards relative to the solid *Beowulf* line. The overall impression is that the network structure of *The Táin* may be rather similar to that of *Beowulf,* but for the six anomalous characters in the Irish narrative. We interpret this as a potential indicator of where the artificiality of *The Táin* is located.

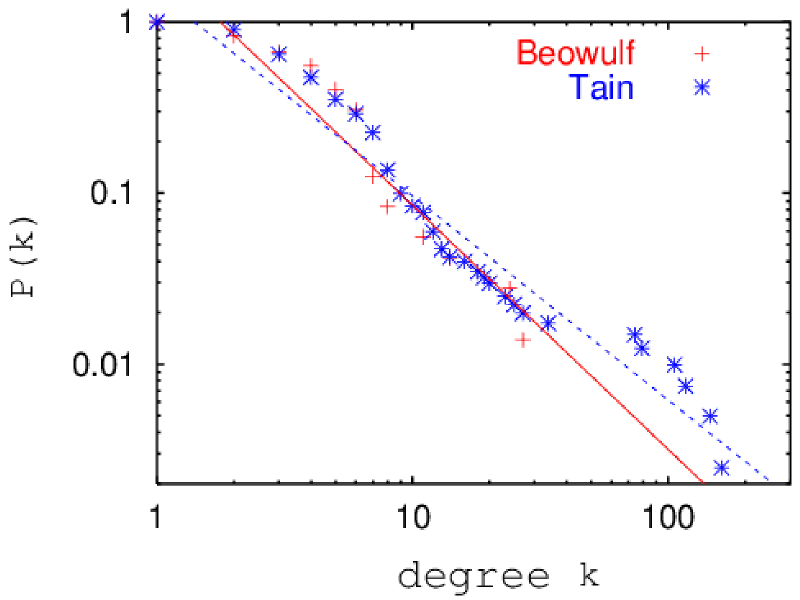

Figure 6: The degree distributions of *Beowulf* and *The Táin* on a double logarithmic scale. Notice the strong overlap except for the six characters with the highest degree for the *Táin* offsetting the best-fit line (dashed line). Here, *P(k)* represents the cumulative probability of a character having a specific degree *k* (number of people a character knows).

The six anomalous *Táin* characters in figure 6 are Conchobor Mac Nessa, Cúchulainn, Ailill Mac Mágach, Medb, Finnchad Fer Benn and Fergus Mac Roich. It is interesting to note that the first four of these were identified by as unhistorical by Jackson (1964). However, we do not go so far as to remove them from the *Táin* network. Instead, and inspired by comparison between the two lines in figure 6, we observe that reduction in their degrees would be sufficient to synchronise them with the remaining *Táin* society. To this end, we define a *weak link* as one that occurs when two characters meet only once in the entire narrative. We then remove the weak links associated with the six most connected characters. This has the effect of reducing their degrees but *not* of removing the characters themselves. In figure 7 the degree distribution for the adjusted *Táin* network is depicted. In it, the top six data points are no longer offset and virtually all the data points fall close to the best-fit line, even for the high degree characters.

Most remarkably, the resulting, adjusted *Táin* society is assortative! In other words, it has all of the characteristics of a real social network. This suggests that all the artificiality in the network is indeed associated with just these top six characters, as we suspected on the basis of figure 6. To justify the removal of the weak links we hypothesise that these six characters are perhaps amalgams of numbers of entities and proxies whose collective degrees are large but whose individual degrees are reduced. For example, the single encounters described in the text between Medb and her many warriors may rather represent encounters between Medb and a small number of proxies, and subsequent interactions between the proxies and those warriors. This interpretation would keep the societal network properties similar to that of real networks, making the properties of *The Táin*'s social network more like those of a real social network.

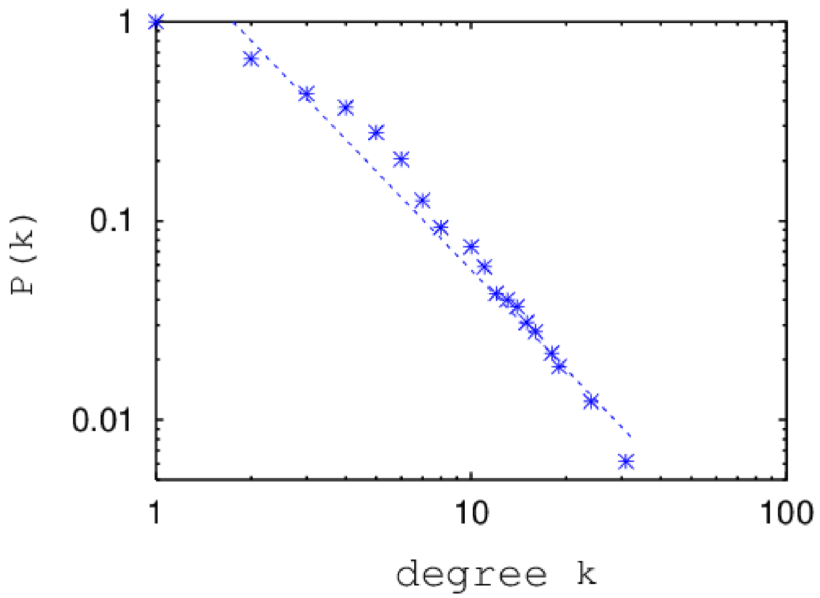

Figure 7: The degree distribution of adjusted *Táin* network, the dashed blue line is the best-fit line. Note the top six characters no longer offset the fit.

CONCLUSIONS

We have used modern mathematical tools from theoretical physics to analyse the *relationships* that underpin the societies depicted in three iconic mythological epics. The use of statistics – quantities which capture certain aspects of the structures of these societies – allows a new type of comparison to be made and introduces a new quantitative aspect to the field of comparative mythology.

Of the three epics analysed, the societal structure in the *Iliad* has properties most similar to those of real social networks. This similarity may be interpreted as corroborating archaeological evidence supporting a degree of historicity underlying the narrative. There is also archaeological evidence suggesting some of the characters in *Beowulf* may be based on real people, although the events in the story often contain elements of obvious fantasy associated with the eponymous protagonist. The network for this society, while small, has some of the properties of real social networks, although, like fictional narratives studied, it is disassortative. The remarkable observation is that removal of the main character from the network renders the remaining society assortative. Thus, while the entire network is not realistic, the assortative subset has properties akin to real social networks. This may be interpreted as corroborative evidence of traces of historicity.

By quantitative comparison of *The Táin* to the *Iliad* and *Beowulf*, we can seek to ask pertinent questions there too. The question we ask is: what would it take to render the society in *The Táin* realistic? Would one have to dramatically alter the full set of relationships underlying the entire society depicted in the tale, or would local adjustment to a small number of characters suffice? We find the latter is the case.

Indeed, our analysis indicates that the apparent artificiality in the *Táin* network is contained within its six most connected characters. Similar to the heroes of Marvel comics, they are too super-human to be realistic, or in terms of the network, they are too well connected. A minimal speculation, that these characters may be based on amalgams of a number of entities and proxies, is supported by removing their direct weak social ties. The resulting society is assortative, similar to *Beowulf*, the *Iliad* and to real social networks and very different to random networks and those of certain works of fiction.

We therefore conclude with the suggestion that, if the society in *The Táin* is to be believed, each of the top six characters is likely to be an amalgam that became fused as the narrative was passed down orally through the generations.

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