Universal Properties of Mythological Networks

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Abstract – As in statistical physics, the concept of universality plays an important, albeit qualitative, role in the field of comparative mythology. Here we apply statistical mechanical tools to analyse the networks underlying three iconic mythological narratives with a view to identifying common and distinguishing quantitative features. Of the three narratives, an Anglo-Saxon and a Greek text are mostly believed by antiquarians to be partly historically based while the third, an Irish epic, is often considered to be fictional. Here we use network analysis in an attempt to discriminate real from imaginary social networks and place mythological narratives on the spectrum between them. This suggests that the perceived artificiality of the Irish narrative can be traced back to anomalous features associated with six characters. Speculating that these are amalgams of several entities or proxies, renders the plausibility of the Irish text comparable to the others from a network-theoretic point of view.

Introduction. – Over the past decades many statistical physicists have turned their attention to other disciplines in attempts to understand how properties of complex systems emerge from the interactions between component parts in a non-trivial manner. Applications include the analysis of complex networks in the natural, social and technological sciences as well as in the humanities [1–5]. One of the notions intrinsic to statistical physics is universality, and attempts have been made to classify complex networks from a variety of areas to facilitate comparison amongst them [3,7].

Universality is also an important, albeit hitherto qualitative, notion in the field of comparative mythology. Campbell maintained that mythological narratives from a variety of cultures essentially share the same fundamental structure, called the monomyth [5]. Here we statistically compare networks underlying mythological narratives from three different cultures to each other as well as to real, imaginary and random networks. In this way we quantitatively explore universality in mythology and attempt to place mythological narratives on the spectrum from the real to the imaginary.

Network theory has recently been developed and applied to polymers, economics, particle physics, computer science, sociology, biology, epidemiology, linguistics and more [1–5]. A number of statistics have been developed to capture features of such networks. Some structural properties are quantified using the characteristic path length $\ell$, the longest geodesic $\ell_{\text{max}}$ and the clustering coefficient $C$. The first of these is a measure of the average minimum separation between pairs of $N$ nodes and $\ell_{\text{max}}$ is the diameter of the network. Clustering measures to what extent a given neighbourhood of the network is cliqued. If node $i$ has $k_i$ neighbours, then the maximal number of potential edges between them is $k_i(k_i - 1)/2$. If $n_i$ is the actual number of bonds between the $k_i$ neighbours of $i$, the clustering coefficient of the node is

$$C_i = \frac{2n_i}{k_i(k_i - 1)}.$$  

Many complex networks have a modular structure implying that groups of nodes organise in a hierarchical manner into increasingly larger groups. Hierarchical networks are characterised by a power-law dependency of the clustering coefficient on the node degree

$$C(k) \sim \frac{1}{k^\alpha},$$

where $\ell_{\text{rand}}$ is the average path length and $C_{\text{rand}}$ is the clustering coefficient of a random network of the same size and average degree.
Table 1: Size, mean degree, mean path length, diameter, clustering coefficient, absolute (relative) size of giant component and assortativity \( r \) for the epics, together with mean path length \( \ell_{\text{rand}} \) and clustering \( C_{\text{rand}} \) for similarly sized random networks.

| Network      | \( N \)  | \( \langle k \rangle \) | \( \ell \) | \( \ell_{\text{rand}} \) | \( \ell_{\text{max}} \) | \( C \)  | \( C_{\text{rand}} \) | \( G_c \) | \( G_{c,\text{rand}} \) | \( r \) |
|--------------|---------|-------------------|--------|-------------------|-------------------|------|-------------------|------|-------------------|-----|
| Beowulf      | All     | 74                | 4.45   | 2.37              | 2.88              | 6    | 0.69              | 0.06 | 50 (67.5%)        | -0.10|
|              | Hostile | 31                | 1.67   | 2.08              | 3.25              | 4    | 0                | 0.05 | 10 (32.2%)        | -0.20|
|              | Friendly | 68              | 4.12   | 2.45              | 2.98              | 6    | 0.69              | 0.06 | 45 (66.1%)        | -0.03|
| Táin         | All     | 404               | 6.10   | 2.76              | 3.32              | 7    | 0.82              | 0.02 | 398 (98.5%)       | -0.33|
|              | Hostile | 144               | 2.33   | 2.93              | 5.88              | 7    | 0.17              | 0.02 | 131 (90.9%)       | -0.36|
|              | Friendly | 385             | 5.67   | 2.84              | 3.43              | 7    | 0.84              | 0.01 | 350 (90.9%)       | -0.32|
| Iliad        | All     | 716               | 7.40   | 3.54              | 3.28              | 11   | 0.57              | 0.01 | 707 (98.7%)       | -0.08|
|              | Hostile | 321               | 2.25   | 4.10              | 7.12              | 9    | 0                | 0.01 | 288 (89.4%)       | -0.39|
|              | Friendly | 664             | 6.98   | 3.83              | 3.34              | 12   | 0.62              | 0.01 | 547 (82.3%)       | 0.10 |
| Beowulf*     | Friendly | 67               | 3.49   | 2.83              | 3.36              | 7    | 0.68              | 0.05 | 43 (64.2%)        | 0.01 |
| Táin*        | Friendly | 324             | 3.71   | 3.88              | 4.41              | 8    | 0.69              | 0.01 | 201 (62.0%)       | 0.04 |

If \( p(k) \) is the probability that a given vertex has degree \( k \), then the degree distribution for many networks is

\[
p(k) \sim k^{-\gamma}, \tag{3}
\]

for positive constant \( \gamma \), with perhaps a cut-off for high degree. Such power laws indicate that, while most nodes are sparsely connected, some are linked to many others and play an especially important role in maintaining network integrity. Networks are scale free if the power law holds with \( 2 < \gamma \leq 3 \). Assortative mixing by degree is the notion that vertices of high degree associate with similarly highly connected vertices, while vertices of low degree associate with other less linked nodes.

Another measure of the connectivity of the network is the size of the giant component \( G_c \). In a scale-free network, removal of influential nodes causes the giant component to break down quickly whereas it remains intact upon randomly removing nodes from the network [15]. As well as the degree, the betweenness centrality of a node \( g_i \) indicates how influential that node is, it controls the flow of information between other vertices. It is the total number of geodesics (shortest paths) that pass through a given node [16]. If \( \sigma(i, j) \) is the number of geodesics between nodes \( i \) and \( j \), and if the number of these which pass through node \( l \) is \( \sigma_l(i, j) \), the betweenness centrality of vertex \( l \) is

\[
g_l = \frac{2}{(N-1)(N-2)} \sum_{i \neq j} \frac{\sigma_l(i, j)}{\sigma(i, j)} \tag{4}
\]

The normalization ensures that \( g_l = 1 \) if all geodesics pass through \( l \).

The above statistics capture a variety of characteristics of networks and, by comparing them between different networks, we get an idea how similar or different they are. These quantitative indicators therefore play similar roles to critical exponents in the study of phase transitions.

Social networks are usually small world [6,9], highly clustered, assortatively mixed by degree [17,18] and scale free [9,19]. Some real social networks that have been studied include between company directors [20], jazz musicians [21], movie actors [6,9], scientific co-authors [22,25] as well as online social networks [26,28]. Catalogues of the properties of these and other networks are contained in, e.g., refs. [2,3]. In refs. [14,29] the social network of characters appearing in Marvel comics (the so-called Marvel Universe) was constructed. In that network two characters are connected if they appear in the same comic book. This is clearly an artificial social network as the characters in this universe represent an imaginary society, but it is a social network nonetheless. Analysis showed that, while it mimicked other social networks to an extent, it was unable to hide its artificial nature [14,29]. To facilitate comparison between our mythological networks and other real and imaginary networks, we also look here at four works of fiction. With these at our disposal, we seek to compare mythological narratives to other networks, ranging from the real to the imaginary.

Comparative mythology. – The mythological narratives studied here are Beowulf [32], the Iliad [31] and the Táin Bó Cúailnge [32]. In comparative mythology, these have statuses similar to that of the Ising model in statistical physics. They are widely studied, frequently compared to each other and still present puzzles which continue to be investigated. Beowulf is an Old English heroic epic, set in Scandinavia. A single codex survives which is dated from between the 8th and early 11th centuries [33,34]. Although the poem is embellished by obvious fiction, archaeological excavations in Denmark and Sweden support historicity associated with some of the human characters although the main character Beowulf is mostly not believed to have existed [35,36]. The Iliad is an epic poem attributed to Homer and is dated to the 8th century BC [31]. Recent evidence suggests that the story may be based on a historical conflict during the 12th century BC [37,38]. The Táin Bó Cúailnge ("Táin" from here on) is an Irish epic, surviving in three 12th and 14th century manuscripts. It describes a conflict between Connaught and Ulster, Ireland’s western and northern provinces. Before it was committed to writing, the Táin had an ex-
tensive oral history. It was dated by medieval scholars
to the first centuries BC, but this may have been an at-
tempt by Christian monks to artificially synchronise oral
traditions with biblical and classical history [22]. Its his-
toricity is often questioned. Jackson (1964) argues that
such narratives corroborate Greek and Roman accounts
of the Celts and offer us a ‘window on the iron age’ [20]
but O’Rahilly (1964) objects that such tales have no his-
torical basis whatsoever [10].

From the databases created for each mythological epic,
74 unique characters were identified in Beowulf, 404 for
the Táin and 716 for the Iliad. (The reader should keep in
mind that these networks, like many others [2], are
necessarily of limited extent and incomplete - potentially
representing spotlights on the societies from which they
are drawn.) We define two distinct relationship types:
friendly and hostile edges. Friendly links are made if
two characters are related; speak directly to one another;
speak about one another or are present together and it
is clear they know each other. Hostile links are made
when two characters meet in a conflict and a friendly link
is not made if they speak here and only here; or when
a character explicitly declares animosity against another
and it is clear they know each other. To ensure consis-
tency throughout, we first separately constructed the net-
work for one of the narratives. Comparing our individual
interpretations allowed us to tune the rules to a consistent
and implementable set and to satisfy ourselves that the
networks could be constructed in a reasonably objective
manner. We also inspected different translations of the
original texts to verify that these did not result in signifi-
cant differences to our quantitative results.

In table 1 a list of statistics for the networks underly-
ing each epic is compiled. These include the mean degree
<k>, the average path length ℓ, diameter ℓ_max, clustering
coefficient C, the size of the giant component G, in ab-
solute terms and as a percentage of the size N, and the
assortativity r. In addition the average path length ℓ_rand
and the clustering coefficient C_rand for a random network
of the same size and average degree are listed. The statis-
tics indicate that the complete networks are similar to the
friendly ones reflecting that, even though conflict is an ele-
ment of each narrative, they are still stories about human
relations, and the discussions rather than disputes drive
the stories. Like real social networks the mythological net-
works have average path lengths similar to those of ran-
dom networks of the same size and average degree. They
also have high clustering coefficients compared to random
networks indicating they are small world. The hostile net-
works are quite different; the facts that their average path
lengths are smaller than those of random networks and
that they have virtually no clustering tell us they are not
small world. The reason for such low clustering in hostile
networks relates to the idea of ‘the enemy of my enemy
is my friend’ – in general a common foe tends to suppress
hostilities between two nodes.

In the overall network, closed triads with just one hostile
edge are also disfavoured as a single hostile link prompts
the opposite node in a triangle to take sides. The propen-
sity to disfavour odd numbers of hostile links in a closed
triad is known as structural balance [41, 42]. Structural
balance has been observed in real-world situations, such
as the shifting alliances in the lead-up to war [43]. We find
similar results in our three networks with only 3.8% of Be-
owulf’s closed triads containing an odd number of hostile
links, 8.0% of the Táin’s and just 1.7% of the Iliad’s.

In fig. 1 we test for hierarchical structure by plotting
the mean clustering coefficient per degree Ĉ(k) versus k
and comparing with eq. (2). The nodes with a smaller
degree present higher clustering than those with larger
degree and the decay approximately follows eq. (2). The
nodes with low degree are part of densely interlinked clus-
ters, while the vertices with high degree bring together
the many small communities of clusters into a single, in-
tegrated network.

In most collaboration networks, a very large subset of
nodes are connected to each other (the giant component).
The full Táin and Iliad networks contain about 98% of
the nodes. Beowulf has a smaller giant component (68% of
all nodes) because the narrative contains two stories
dealing with events from the past, disconnected from the
main plot. Usually for collaboration networks, the giant
components contain less than 90% of all nodes [23] and the
friendly networks of each epic falls into this category. Re-
moving the top 5% of nodes with the highest betweenness
centrality causes all three networks to break down quickly,
reducing the giant component of Beowulf and the Táin by
over 30%. This lack of robustness shows how reliant they
are on the most connected characters. If, however, 5% of
the nodes are removed at random the giant component in
each case is largely unaffected. Vulnerability to targeted
attack but robustness to random attack, and the hierar-
chical structure of the networks, hint that these networks
may be scale free.

Newman showed that real social networks tend to be as-
sortatively mixed by degree [17] and Gleiser demonstrated
that disassortativity of social networks may signal artifi-
ciality [14]. However disassortativity may also reflect the
conflictual nature of the stories. In the *Táin* and the *Iliad*, in particular, characters are frequently introduced to fight one of the heroes and are killed virtually immediately. These encounters link the high-degree heroes to low-degree victims and may explain why the hostile networks are highly disassortative. This suggests that only in the friendly networks may disassortativity be confidently interpreted as signaling artificiality.

The assortativity coefficient $r$ is given by the Pearson correlation coefficient of the degrees between all pairs of linked nodes and is listed for each network in table 1. Positive correlation indicates assortative mixing and a negative value indicates disassortativity. As expected, all hostile networks are strongly disassortative. However, the *Iliad* friendly network is assortative and the *Beowulf* friendly network is only mildly disassortative. *Beowulf* takes place in two different settings, years apart, with the eponymous protagonist being the only character to appear in both places. As it is a small network, the main character has high degree but most of his neighbours have lower degree rendering the network disassortative. Indeed, removing the protagonist (labeling the resulting network *Beowulf* *) delivers a positive assortativity coefficient ($r = 0.012$) for the interactions between the remaining characters.

Thus the *Iliad* and *Beowulf* * friendly networks have properties associated with real social networks. While the *Táin* has many such features, it is not assortative. This corroborates antiquarians’ interpretations of the historicity of these myths (obviously fabulous entities and interactions notwithstanding) – the societies in the *Iliad* and *Beowulf* * (without the eponymous protagonist) may be based on reality while that of the *Táin* appears fictional [10]. We next turn our attention to networks which are definitely fictional, before an analysis of degree distributions which will illuminate the reasons behind the apparent artificiality exhibited by the *Táin*.

**Fictional Narratives.** – The above characteristics of the three mythological networks distinguish them from the intentionally fictitious Marvel universe studied in refs. [14,29]. The question arises whether these characteristics are properties of non-comic fictional literature in general or whether this may truly signal a degree of historicity underlying the three mythological narratives. To investigate this, we applied our network tools to four narratives from fictional literature. These are Hugo’s *Les Misérables* ($N = 77$), Shakespeare’s *Richard III* ($N = 70$), Tolkien’s *Fellowship of the Ring* (the first part of the *Lord of the Rings* trilogy, with $N = 118$) and Rowling’s *Harry Potter* ($N = 72$). We found that each of these, together with the *Marvel* universe ($N = 6846$), has a very high clustering coefficient, is disassortative and has a giant component containing almost every character.

Attacking the smaller fictional networks by removing the top five characters with the highest betweenness centralities, we find that the networks are quite robust. The giant component goes from 100% to 73.6% for *Les Misérables*, 94.3% to 84.6% for *Richard III*, 94.1% to 85.8% for *Fellowship of the Ring* and 97.2% to 77.4% for *Harry Potter*. Removing the top 10% of nodes with highest betweenness shows *Les Misérables* and *Harry Potter* are less robust than the others, however the Marvel Universe is barely affected by losing the top 684 vertices. This robustness is also indicative of an exponential degree distribution (see below and ref. [15]). The robustness and the high clustering coefficient shows how well connected the networks are. All five fictional networks have a hierarchical structure. While these networks display the high clustering coefficient that is common to all social networks, the fact that they are all disassortative and are almost entirely connected is perhaps an indication of their societies’ artificiality. In a sense they are too small world to be real.

**Degree distributions.** – We finally turn to the degree distributions associated with the various networks. This will allow us to identify the source of the disassortativity of the *Táin* in particular and to speculate as to what it would take to render that network more realistic.

The cumulative distribution functions for the three narratives are plotted in fig. 2. Estimates from eq. 3 for *Beowulf*, the *Táin* and the *Iliad* yield $\gamma = 2.4 \pm 0.2, 2.2 \pm 0.1$ and $2.4 \pm 0.1$ (with $\chi^2$/df 0.3, 0.2 and 0.4), respectively. The degree exponents for the friendly networks are very similar to these values. These results signal that the degree distributions of these networks are indeed scale free.

For comparison, the degree distribution for the fictional
narratives only follows a power law in the tail in one instance (Harry Potter) and only this appears to be scale free. The other three, as the Marvel Universe, are better described by exponential distributions.

In fig. 2(a) we observe a striking similarity between the degree distributions of Beowulf and the Tain for all but the six most connected characters in the latter. In fact, omitting the corresponding 6 points delivers the estimate \( \gamma = 2.4 \pm 0.1 \), the same value as for Beowulf and the Iliad. However, we have no legitimate basis to omit the six most important characters of the narrative, especially if the degree distribution is scale free, because our previous results indicate this would destroy the giant component. Instead we speculate that these six characters are in fact amalgams of several entities or proxies, whose collective degrees are large, but whose individual degrees are reduced. To test this hypothesis, we removed the weak links (where they interact with characters only once in the entire narrative) from the characters and denote the result by Tain*. In fig. 2(b), this is compared to Beowulf* as a power law. Because six characters now have lower degree, the estimate for \( \gamma \) increases. The modified exponent is \( \gamma = 2.65 \pm 0.10 (\chi^2/df = 0.15) \), close to for Beowulf*, which has \( \gamma = 2.58 \pm 0.19 (\chi^2/df = 0.27) \). The steeper slope, particularly for large \( k \), is indicative of the presence of a fast decay and is common in many networks. To understand this a comparison of the Tain with the larger network of the Iliad is appropriate.

The Iliad is, in fact, better fitted by a truncated power law \( P(k) \sim k^{1-\tau} \exp(-k/k^*) \) with \( \tau = 1.51 \pm 0.03 (\chi^2/df = 0.07) \). The Tain* is compared to Iliad in fig. 2(c). It is also well fitted by a truncated power law and delivers \( \tau = 1.74 \pm 0.06 (\chi^2/df = 0.03) \).

The modified friendly Tain* network has assortativity coefficient \( r = 0.042 \). This positive value, together with the fact that the fitted degree distribution captures the top six data, ensures that the networks share all the properties of real social networks. (In comparison, simply removing the top six characters results in \( r = -0.122 \) and destroys the giant component.)

Another way to test for assortativity is to plot the degree of the neighbours of a vertex as a function of its degree. Positive slope indicates assortativity and negative slope signals disassortativity. Plots for the averages of the neighbouring degrees are contained in fig. 3. Beowulf and the Iliad are assortative, while the Tain is clearly disassortative. However, removing weak links associated with the six strongest characters (resulting in the Tain* network) again renders that Irish narrative assortative, suggesting possibly historicity on a level comparable to Beowulf.

**Conclusions.** We have analysed the networks of relationships between characters of three mythological epics and four fictional narratives and compared them to each other and to other social networks, both real and imaginary. We found that all seven networks are small world, highly clustered, hierarchical and resilient to random attack – properties generally associated with real social networks. The fictional networks are, however, discernable from real social networks in that they mostly have exponential degree distributions, have relatively larger giant components, are robust under targeted attack and are disassortative. Moreover, they share this latter set of properties with the network underlying the Marvel universe previously studied in refs. [11-29].

In an attempt to place the three mythological networks on the spectrum from the real to the fictitious, we compared their properties to actual and imaginary social networks. Table 2 summarises the broad properties of the different types of networks. Of the three myths, the network of characters in the Iliad has properties most similar to those of real social networks. It has a power-law degree distribution (with an exponential cut-off), is small world, assortative, vulnerable to targeted attack and is structurally balanced. This similarity perhaps reflects the archaeological evidence supporting the historicity of some of the events of the Iliad.

There is also archaeological evidence suggesting some of the characters in Beowulf are based on real people, although the events in the story often contain elements of fantasy associated with the eponymous protagonist. The network for this society, while small, has some properties similar to real social networks, though like all the fictional narratives it is disassortative. However, removing the main character from the network renders it assortative. Thus, while the entire network is not credible as reflecting a real society, we suggest that an assortative subset has properties akin to real social networks, and this subset has corroborative evidence of historicity.

Currently there is very little evidence for the events and the society in the Tain. While there is some circumstantial evidence in terms of the landscape [41], its historicity is often questioned [39, 40]. Indeed, the social network of the full narrative initially seems similar to that of the Marvel Universe perhaps indicating it is the Iron Age equivalent of a comic book. However, comparing the Tain’s degree distribution to that of Beowulf reveals a remarkable similarity, except for the top six vertices of the Irish narra-
Table 2: Summary of properties of mythological networks (Beowulf*, Táin* and Iliad) compared to social and fictional networks. Here, small world implies $\ell \approx \ell_{\text{rand}}$, $C \gg C_{\text{rand}}$, hierarchical means that $C(k) \sim 1/k$ and scale free refers to a power-law degree distribution with $\gamma \leq 3$. “TA” and “RA” refer respectively to resilience to targeted and random attacks.

| Small world | Social | Myth (friendly) | Fiction |
|-------------|-------|-----------------|---------|
| Hierarchy   | Yes   | Yes             | Yes     |
| $p(k)$      | Power law | Power law | Exp. |
| Scale free  | Yes   | Yes             | No      |
| $G_c$       | $< 90\%$ | $< 90\%$ | $> 90\%$ |
| TA          | Vulnerable | Vulnerable | Robust |
| RA          | Robust | Robust          | Robust |
| Assortative | Yes   | Yes             | No      |

This suggests the artificiality of the network may be mainly associated with the corresponding characters. They are similar to the superheroes of the Marvel Universe – too super-human to be realistic, or in terms of the network, they are too well connected. We speculate that these characters may in fact be based on amalgams of a number of entities and proxies. To test the plausibility of this hypothesis, we removed the weak social links associated with these six characters. The resulting network is assortative, similar to the Iliad and to other real social networks and very different to that of the Marvel Universe and works of fiction. We therefore suggest that if the society in the Táin is to be believed, each of the top six characters is likely an amalgam that became fused as the narrative was passed down orally through the generations.

* * *

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