Maths Meets Myths:

Quantitative Investigations of Ancient Narratives

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EUROPEAN SCIENCE FOUNDATION

The Leverhulme Trust

Background to Talk

Background:

- In 2012 and 2013, we published papers* in EPL and EPJB which generated enormous interest:
  - Press release by *Institute of Physics* and blogs by the *European Physical Society*
  - Invited articles in magazines of the *Royal Statistical Society, Society for Industrial and Applied Mathematics*, etc.
  - Reports in newspapers worldwide, including *Times*, *New York Times*, etc.
  - Interviews on radio in UK, USA; Coverage in online media.
  - Collaboration with a theatre.
  - Donald Knuth (famous computer scientist and inventor of TeX) sent us a postcard!
- This led to new collaborations with humanities (ongoing).
- I wish to tell you about our experiences visiting a world beyond physics.

* P. Mac Carron and R. Kenna, *Universal properties of mythological networks*, EPL 99 (2012) 28002; *Network analysis of the Íslendinga sögur – the Sagas of Icelanders*, EPJB B 86 (2013) 407.

Outline of Talk

1. The General Relationship between Humanities and Science
2. Maths Meets Myths – Our Emerging Community
3. Network Science applied to Mythology – our work.

Part 1

The General Relationship between Humanities and Science

and a few things to be aware of if you want to apply your skills to the humanities…

Why are statistical physicists interested in humanities?

Personal answer = **curiosity**. We are human too.

Topical Answer = **complexity**, the emergence of *Emergence*.

- The properties of materials are not simple sums of the properties of molecules.
  E.g., a single molecule cannot freeze like ice or flow as water.

- Similarly, the behaviours of a population is not a simple aggregate of individuals.
  E.g., swarms, language, culture, myth...

- In recent years, simple models, inspired by statistical physics, have been developed to account for social phenomena

→ "Sociophysics" or "complexity"
has emerged.

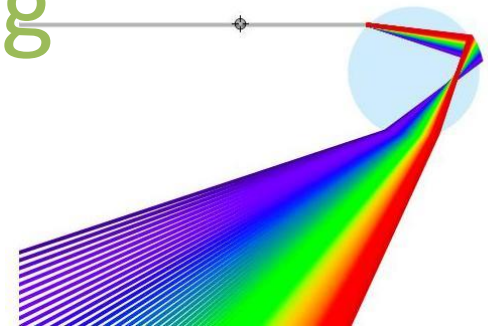
Two Cultures: Relationship between Science and Humanities

The scientifically literate understand the second law of thermodynamics	The humanities literate understand Shakespeare

C.P. Snow (1959): “Society is … split into two polar groups” consisting of scientists on the one hand and literary scholars on the other.

He argued that the breakdown of communication between the "**two cultures**" of modern society was a major hindrance to solving the world's problems

Mistrust/Misunderstanding



19th Century - John Keats poem *Lamia* (1819) argues that the new sciences of physics and chemistry might "unweave the rainbow."

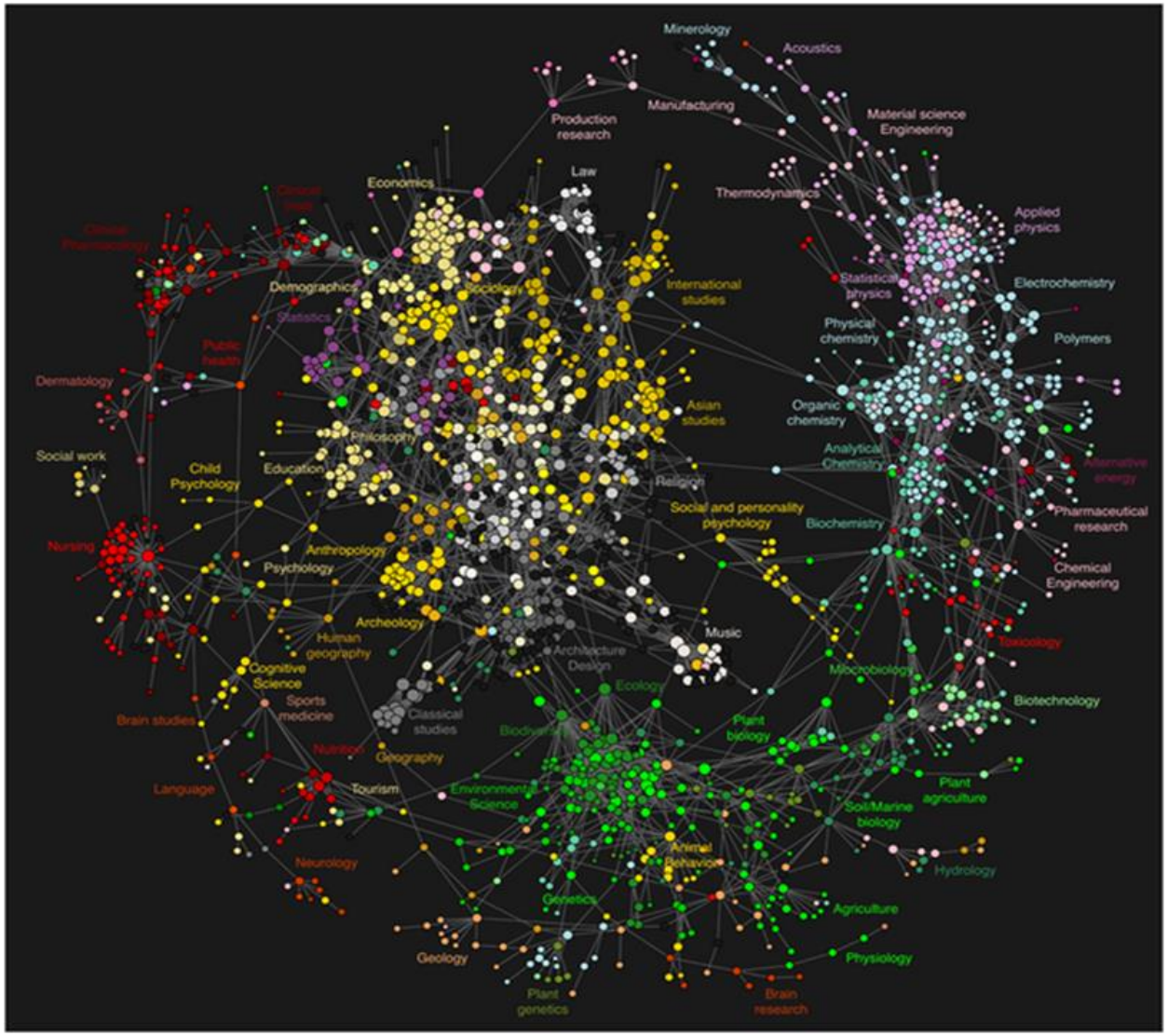
20th Century - "The humanities need to be defended today against the encroachments of physical science."

– Irving Babbitt (Critic and Professor of French Literature, died 1933)

21st Century – "Humanities aren't a science. Stop treating them like one."

By Maria Konnikova (Russian-American writer & journalist) in a New Scientist blog, August 10, 2012

Relationship between Science and Humanities



Source: Bollen et al PLOS ONE 4 (2009) e4803

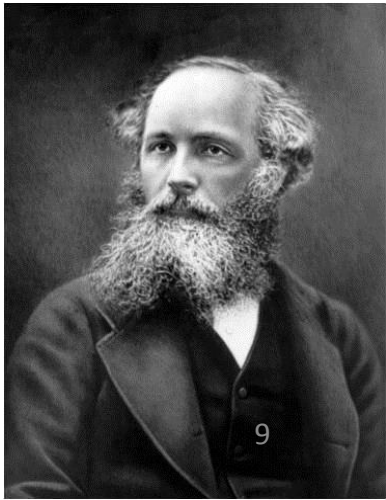
Statistical physics and sociology are closer than one may think:

• In the 18th Century people noticed regularities in numbers of events such births, deaths, etc.

• This was surprising because individuals are unpredictable.

• This partly motivated the development of a statistical approach to the physics of many-body systems.

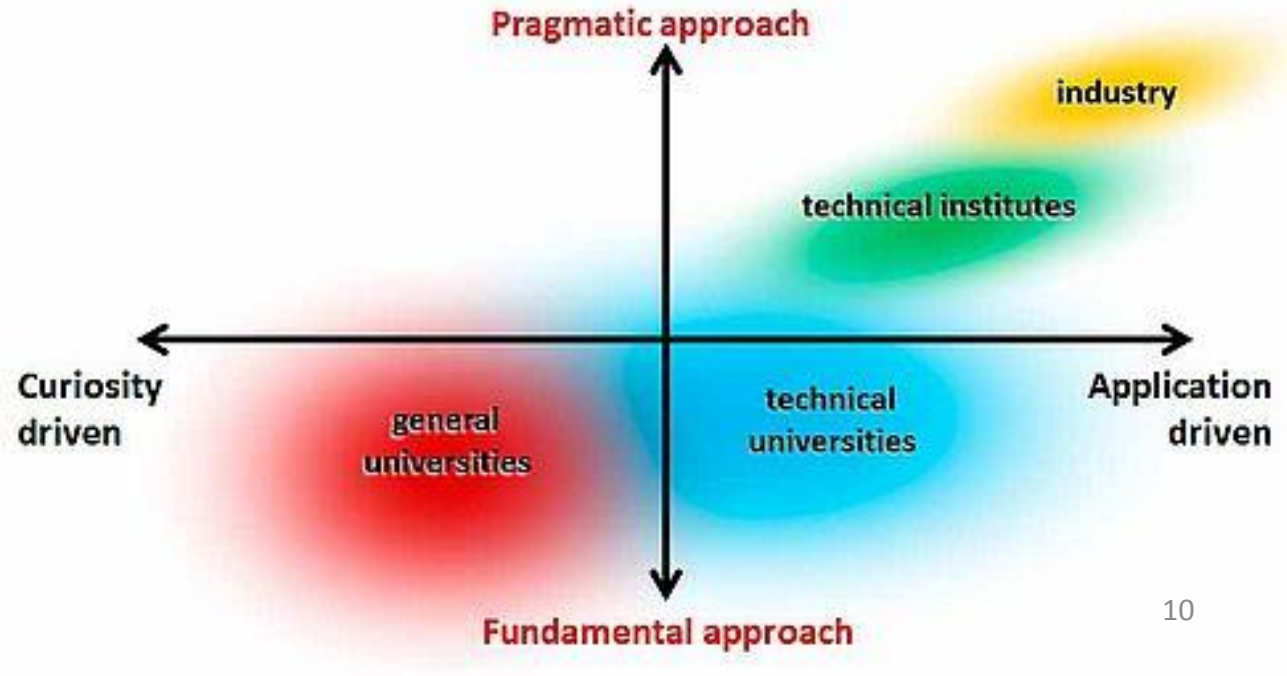
• So statistical physics and sociology are siblings.



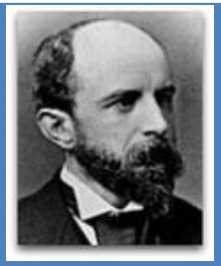
Statistical physics and humanities are closer than one may think:

We do fundamental science - curiosity driven not €-driven!

E.g., our closest allies in Coventry Uni are the humanities!



SOCIOPHYSICS IS OLDER THAN ONE MAY THINK

First generation – social physics **(polymaths – persons who "knew everything")**	 **Henri Saint-Simon (1760-1825)**	 **Auguste Comte (1798-1857)**	 **Adolphe Quetelet (1796-1874)**	 **Henry Adams (1838-1918)**
Second Generation – social physics (thermodynamics, pde's etc)	 Percy Bridgman (1882-1961)	 John Q. Stewart (1894-1972)	 Ettore Majorana (1906-1938)	 Arthur Iberall (1918-2002)
Third generation - sociophysics (statistical mechanics)	 Paris Arnopoulos (c.1935-)	 Serge Galam (c.1945-)	 Jürgen Mimkes (1939-)	 Dietrich Stauffer (1943-)

The (re-)emergence of emergence

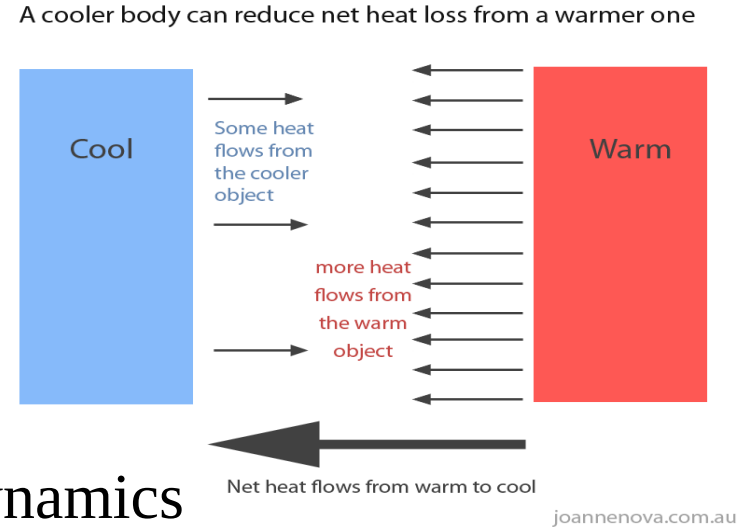
"Now that the human mind has grasped celestial and terrestrial physics, …there remains one science … social physics. This is what men have now most need of."

Auguste Compte, 1856

"I think the next century will be the century of complexity."

Steven Hawking, 2000

The thermodynamicist's approach



E.g.: The Second Law of thermodynamics – entropy increases.

The **Bridgman paradox** (1946) :

"How can we compute or even evaluate the entropy of a living being? … There is absolutely no way to define the change of entropy that takes place in an organism at the moment of death."

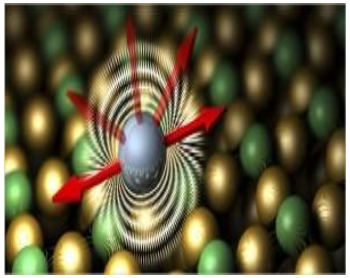
Leon Brillouin, 1949

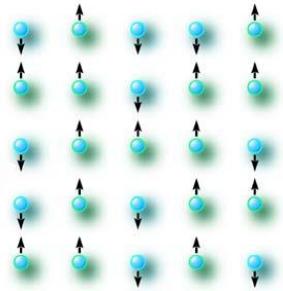
Theory of History (Henry Adams):

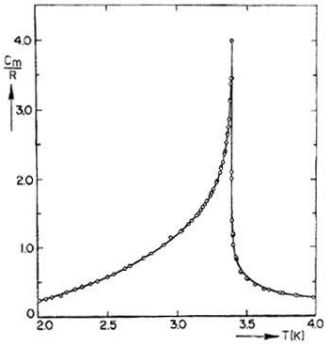
"All energy dissipates, order becomes disorder, and the earth will eventually become uninhabitable. "

The statistical physicist's approach

is simple and microscopic or agent based and relies on **universality**







- Vastly simplified in the detail, Correct in the aggregate

Objections Typical criticisms are along lines of

- Humans are not numbers
- Humanities are more complicated than physics
- Physicists neglect details

"True; but the Earth is more complicated than a point mass; nevertheless Kepler's laws are quite accurate and were very useful. Physicists should try to find the simplest model giving the desired result, and not to make the model more realistic only for the sake of realism. Of course, Kepler knew that the Earth was not a point."

"Of course, if you want to be a geographer, the assumption of a point-like Earth is dangerous for your employment: The same model may be good for some and bad for other purposes."

[Stauffer, 2004]

Objections by physicists

- Serge Galam's first paper (1980) was initially confiscated by his Head of Dept!
- It is too easy – or - "it makes statistical physics look easy".

No new physics in my talk – the novelty lies in the applications.

(Although interesting mathematical problems in network theory can arise.)

Acceptance? "Do other fields welcome physicists?"

Stauffer (2004): "From my own experience -

Economics: yes;
Sociology: yes, if computational sociologists;
Biology: no, but changing" [that was 2004]

Acceptance time?

Years, not months. Perhaps a decade.

Humanities:

I would say > 85% acceptance (if presented gently).

"*Recognising the Value of the Arts and Humanities in a Time of Austerity*" (HERA, 2013):

> "The work … provides an example of how digital techniques and technologies, applied to literary works, can open up a new field of inquiry. … By investigating these poetic works, they have maintained the importance of continued support for research in the humanities, but also expanded the notion of what humanities research is or can be."

Pitfalls

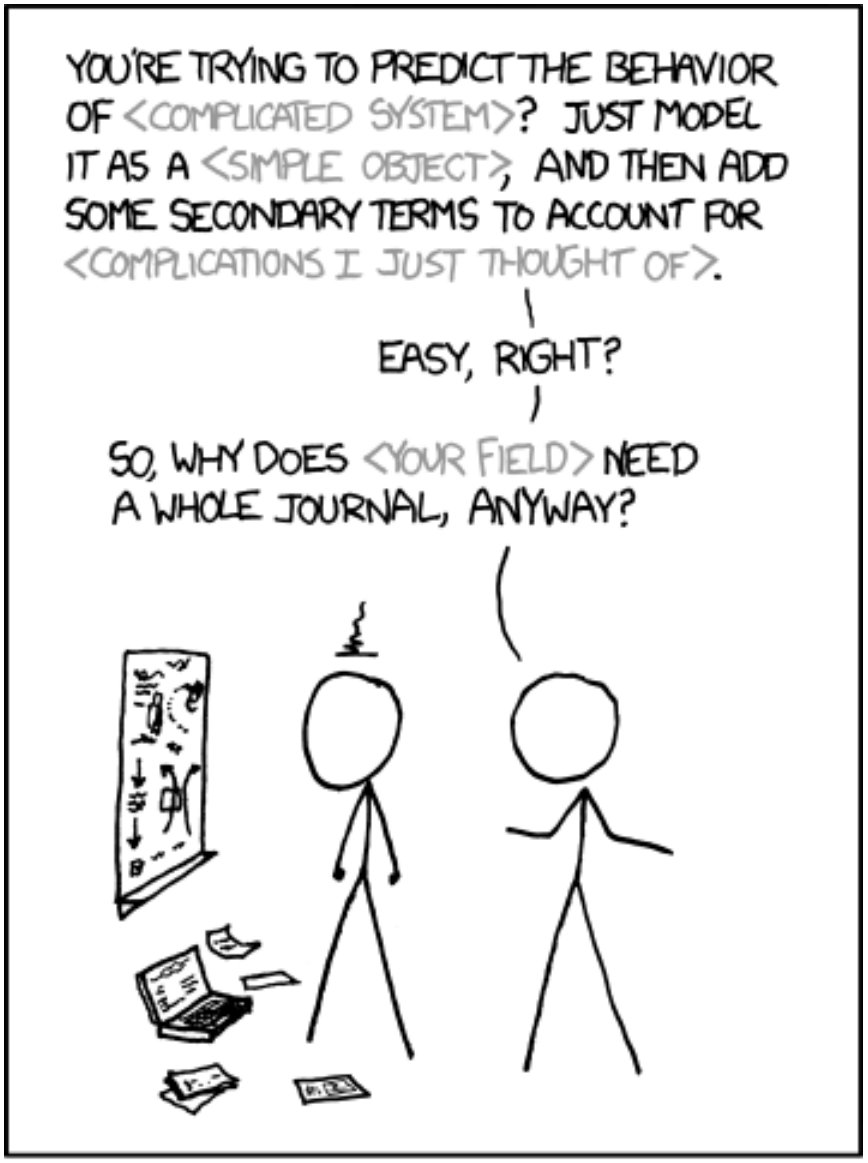
Ravens and Writing-Desks: Sokal and the Two Cultures by R. Schusterman (1998)

In a paper about a lecture by a neurologist about how the brain perceives art:

"the motivation behind this reductionism in the context of the two cultures controversy ... becomes … clear. By … reducing art to a matter of pure perception, the lecturer was trying to eliminate those bodies of knowledge which his tools cannot master -- history and criticism. **And in the context of the two cultures controversy, this elimination is a way of saying to humanists that they are not needed**.

Lesson: Don't appear to be arrogant!

Say what you're not doing as well as what you are doing.



LIBERAL-ARTS MAJORS MAY BE ANNOYING SOMETIMES, BUT THERE'S *NOTHING* MORE OBNOXIOUS THAN A PHYSICIST FIRST ENCOUNTERING A NEW SUBJECT.

Part 2

Maths meets Myths

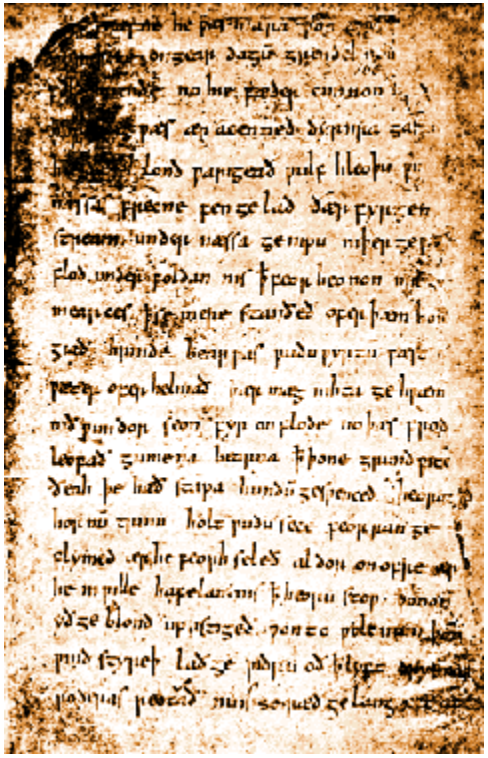
An Emerging Community

Maths meets Myths

We started by applying network theory to Mythology.

Our aim was/is:

- to compare the social networks in big narratives to each other across cultures
- and to other social networks, real and fictitious.



Actually it is evolving to be broader than maths & myths...

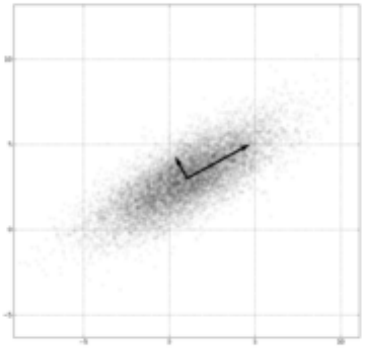
Others have been applying their tools to old sources →

- **digital humanities,**
- **computational folkloristics,**
- **computistics,**
- **mythematics.**

Maths meets Myths

Our goals:

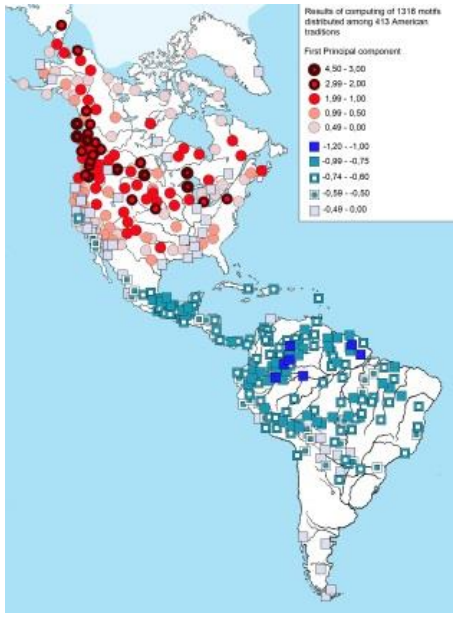
- Make each side aware of the other – who's who
- Raise awareness of perspectives, sensitivities
- Can we help/inspire each other?
  - What questions to ask?
  - What tools to apply?
  - How to obtain funding?
  - How to manage impact, outreach, etc?
  - Mainly we want to collaborate to generate new knowledge (papers in journals, books, ...)
- (Book due out in 2016)



Distribution of Folklore Motifs

Yuri Berezkin, St Petersburg

Over the past two decades, Yuri has constructed a catalogue of folklore and mythology which contains 50,000 abstracts with 2000 motifs from almost 1000 traditions.



Ex of a motif: **K56C. "Golden axe", ATU 729.**

The presence or absence of motifs indicates similarities or differences between cultures.

He uses Principal Component Analysis to quantify this.

His suggestion (based on myths) 20 years ago that two different populations that took part in the peopling of America has just been been verified using genetics

(Skoglund et al., Nature, 2015).

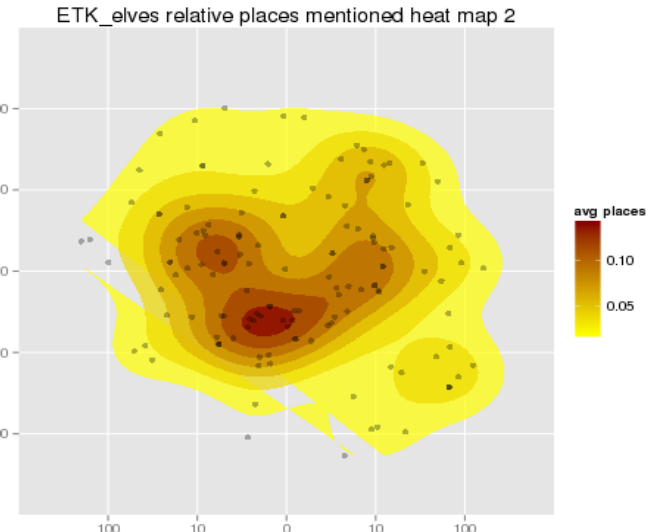
Computational Folkloristics:

Peter Broadwell & Tim Tangherlini 's (UCLA)

They map the supernatural in Danish folklore.

They look at 35,000 stories collected from 3,500 people In the 19th century.

Danish folk belief have specific geographic associations: the outside, liminal, and inside landscape are threatened in different ways.



- *Nisse* threaten from within.
- *Witches* and *cunning folk* (< 10km);
- *Mound dwellers* (3-12km);
- *Elves* (5-15km);
- *Giants* (10-20km);
- *Robbers* (10-100km).
- The west is threatening, the east is civilised.

Phylogenetics

Jamie Tehrani (Durham) and Julien d'Huy (Sorbonne)

They have been applying phylogenetics to folktakes.

There is a long-running debate about the relationship between Little Red Riding Hood (Красная Шапочка) and East Asian tales.

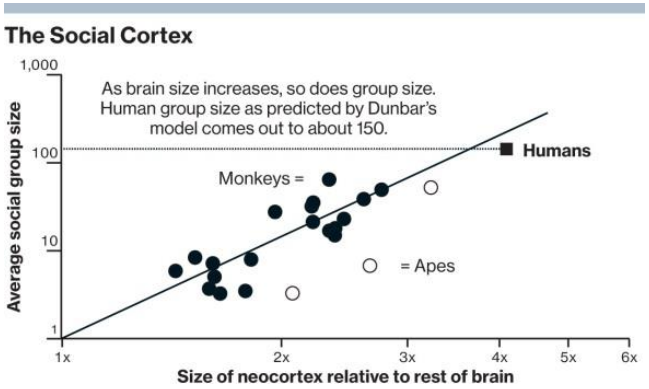
Some have suggested, based on resemblances,
that the East Asian tales were the source of the western tales.

Jamie turned that theory on its head,
suggesting that the Asian tales are
derived from a western source,
not vice versa.

Note: Jamie's paper was viewed over 76,000 times in under 2 years.
The Phylogeny of Little Red Riding Hood. PLoS ONE 8(11): e78871.

Anthropology & Psychology of Literature

E.g., **Robin Dunbar**'s (Oxford) is investigating cognitive constraints in real life:



and literature (e.g., Icelandic sagas & Shakespeare's plays).

E..g., Watching *Othello,* we have to *believe* that Iago *intends* that Othello *believes* that Desdemona *loves* Cassio, and that her love is *reciprocated*.

This is 5 orders of intentionality and 65% of population can barely handle it.

To commit to dramatic form, Shakespeare had to have 6 orders of menalising!

(For cognitive limits of scientists, see talk by Bertrand Berche on Wednesday.)

Analysis of Virtual Worlds

(Massive Multiplayer Online Games)

Y. Holovatch, O. Mryglod, M. Szell, S. Thurner (Lviv & Vienna)

"When soldiers take out a machine-gun nest at Fort Bragg, the machine gun is real and the teamwork is real. When the same soldiers take out a dragon in a synthetic world, the dragon is not real but the teamwork is..."
[Castronova, E., 2005.]

Computistics

Up to 6th century, the Irish Church reckoned the date of Easter by means of an 84-year cycle.

That cycle, however, had long been lost for 1269 years until in 1985 Dáibhí Ó Cróinín discovered a copy in Biblioteca Antoniana, Padua, Italy.

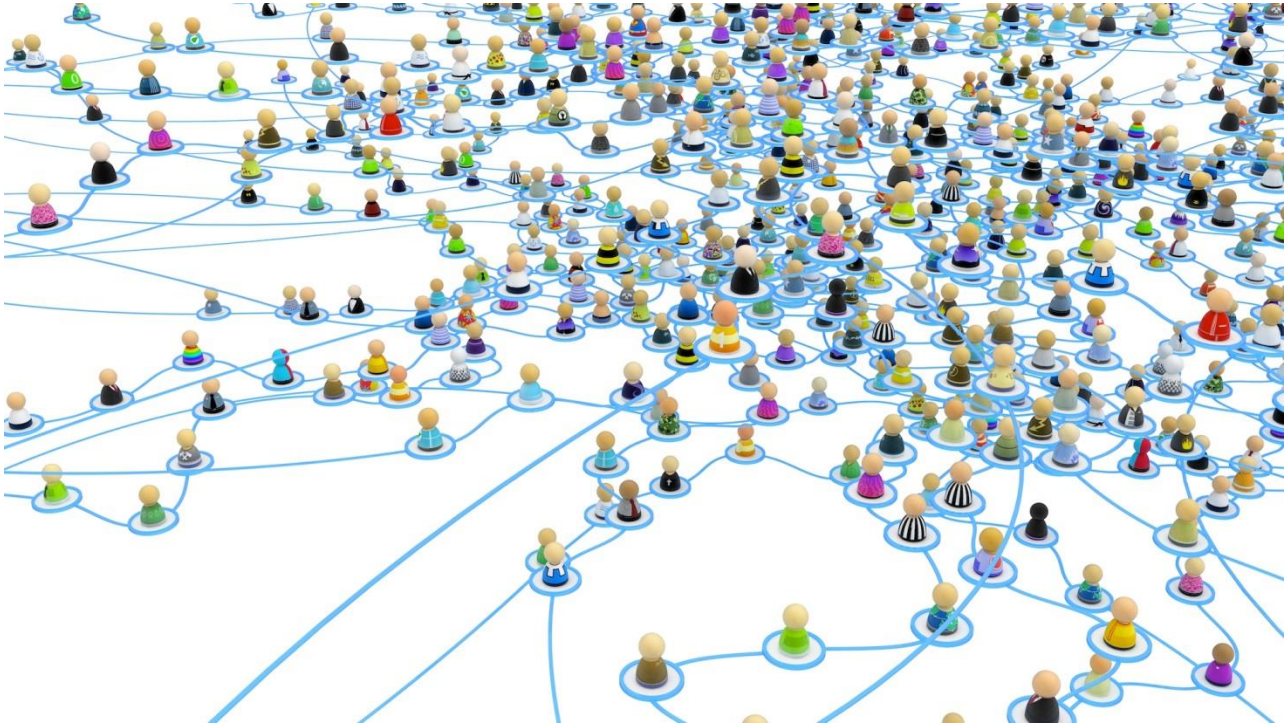
Over the past 30 years, Dan McCarthy has been using it to restore the chronology of Irish annals.

Part 3

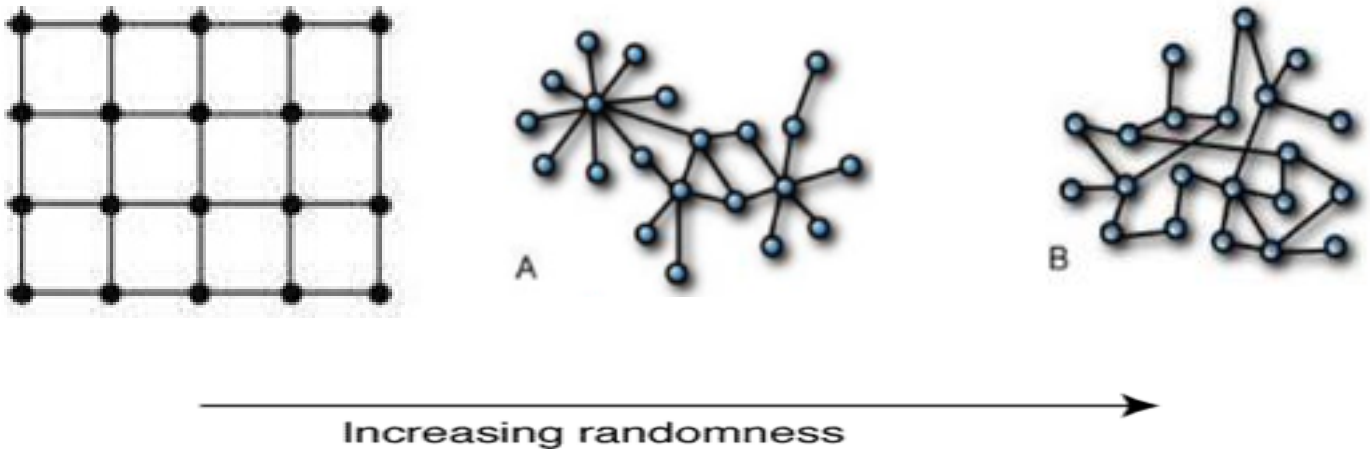
Statistical Physics Applied to Mythology

(well… network science)

Complex Networks



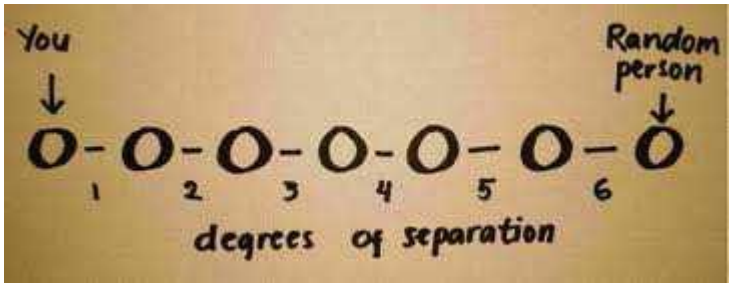
1998: Watts & Strogatz published the first small-world network model, which through a single parameter smoothly interpolates between a random graph and a lattice.



They notice structural similarities between the networks of

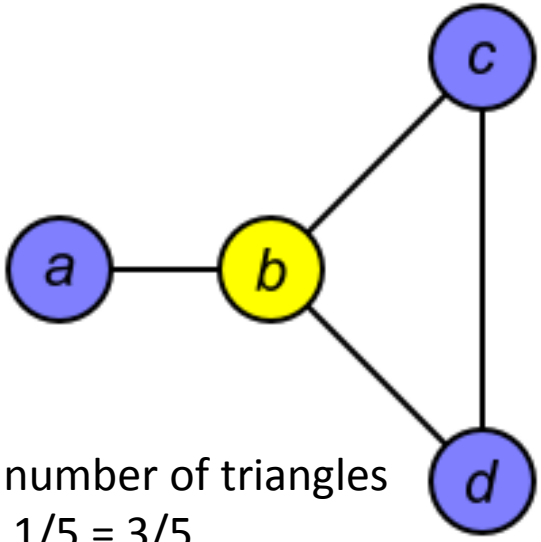
- Neural network of nematode worm
- US power grid
- Collaboration network of movie actors

Simple Network Properties



- Characteristic path length ℓ :
  relates to the idea of "six degrees of separation" (Stanley Milgram, 1967).

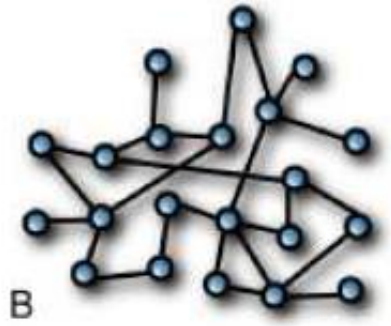
- Clustering coefficient :
  Here, there is one triangle going through *b*.
  There could be three such triangles.
  So the clustering coef. for *b* is 1/3.
  The mean clustering over all four sites is $C = 7/12$.

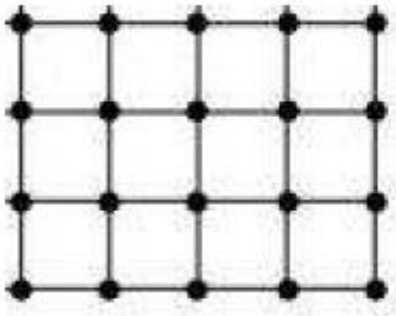


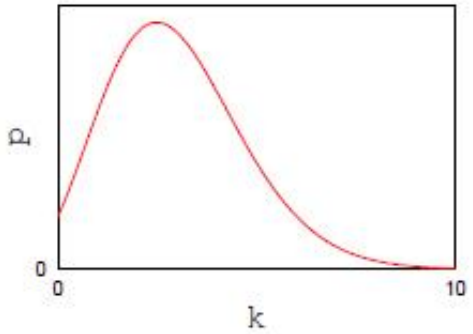
- The clustering transitivity is $C_T = 3N/N_t$, where N = number of triangles and N_t = number of paths of length 2. Here $C_T = 3 * 1/5 = 3/5$.

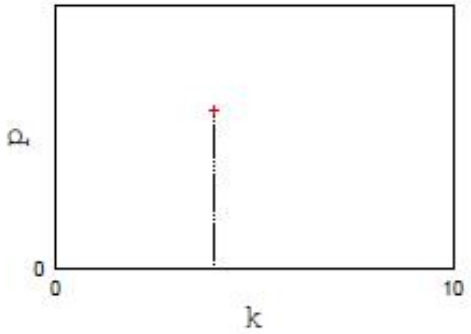
- Network is small world if $\ell \approx \ell_{random}$ and $C \gg C_{random}$.

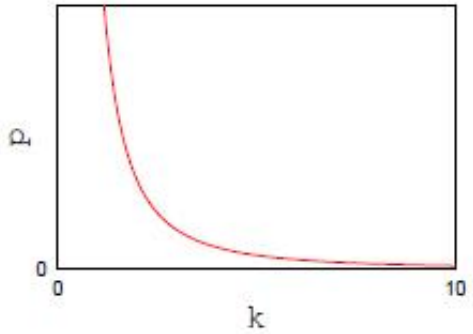
The degree of a node is the number of links it has.
$p(k)$ is the probability that a given node has degree k.











random network

regular lattice

complex network

$p(k)$ = random

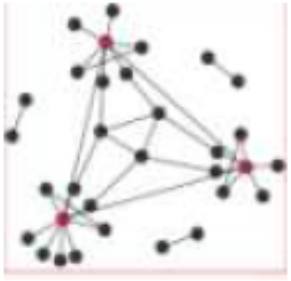
$p(k)$ = fixed

$p(k) \sim k^{-\gamma}$
(scale free)

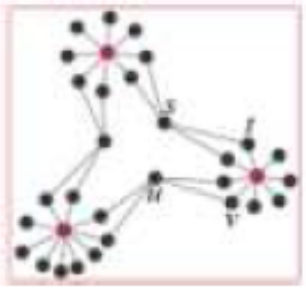
- Assortativity : “Birds of a feather flock together”.

Assortativity is a tendency for similar nodes to connect.

- In assortative networks, links between hubs are enhanced :



- In disassortative networks, links between hubs are suppressed :



It is measured by the Pearson correlation coefficient.

$$r_k = \frac{1}{\sigma_k^2}\left(E[k_1 k_2] - E[k_1]E[k_2]\right), \quad \text{where} \quad \sigma_k^2 = E[k^2] - E[k]^2.$$

Apply to Mythology

- Myths differ from legends and folktales.
  - Legends are based in definite historical timeframe (Robin Hood)
  - Folktales are meant to be fictitious (Little Red Riding Hood)
- The Aarne-Thompson classification system helps folklorists identify plot patterns in the narrative structures of traditional folktales. This is based on *events*.
- But there is no classification system in mythology.
- But there is a concept of universality in comparative mythology (Joseph Campbell's *monomyth*).
- We try to use network theory to compare them.
- We make no comments about events, emotions, meanings, qualitative aspects.
- What is new is our quantitive analysis of *interactions* in mythology - how everything is connected to everything else.

Here we look at three famous epic narratives :

The Iliad (Greece)

Beowulf (England)

An Táin Bó Cuailnge (Ireland)

We have results for many more, including various Finnish, Germanic, Greek, Icelandic, Irish, Welsh & Arthurian, etc. and from the Americas.

The Iliad is an epic poem attributed to Homer and is dated to the 8th century BC. Evidence suggests that the story may be based on a historical conflict during the 12th century BC.

Beowulf is an Old English heroic epic, set in Scandinavia.

A single codex survives which is dated from between the 8th & 11th centuries.

Although the poem is embellished by obvious fiction, archaeological excavations in Denmark and Sweden support historicity associated with some of the human characters.

The main character Beowulf is mostly not believed to have existed.

The Táin is an Irish epic, surviving in three recensions in 12th and 14th century manuscripts.

It describes a conflict between Connacht and Ulster.

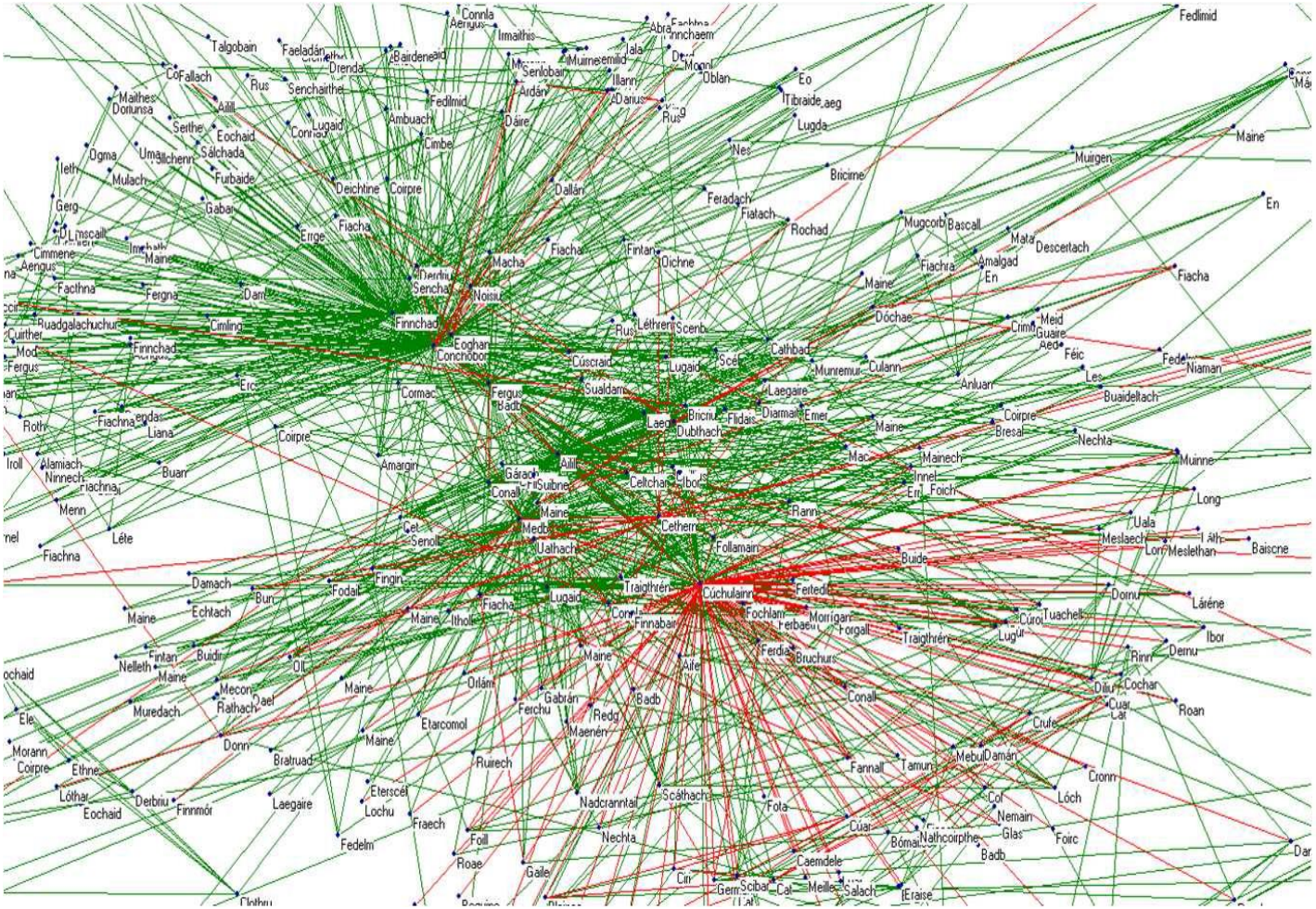
It was dated by medieval scholars to the first centuries BC.

Some (e.g., Jackson, 1964) argue that such narratives corroborate Greek and Roman accounts of the Celts and offer us a "window on the iron age".

Others (e.g., O'Rahilly, 1946) say that such tales have no historical basis whatsoever.

In the Táin, Connacht is led by queen Medb and her husband Ailill.
They intend to steal the famous bull Donn Cuailnge.
Because of a curse, the Ulster warriors cannot fight for some months.
A single Ulster hero, Cú Chulainn, defends Ulster until the curse is lifted.

An Táin Bó Cuailnge



"Critical Exponents"

Full Network	N	<k>	ℓ	ℓ_{rand}	C	C_{rand}	C_T	$C_{T\ rand}$
Beowulf	74	4.5	2.4	2.9	0.7	0.06	0.4	0.2
Táin	404	6.1	2.8	3.5	0.8	0.02	0.1	0.6
Iliad	716	7.4	3.5	3.5	0.6	0.01	0.5	0.1

They are all small world ($\ell \approx \ell$ and $C >> C_{rand}$).

For *Beowulf* and the *Iliad* , $C_T > C_{T\ rand}$.

But for the *Táin*, $C_T < C_{T\ rand}$.

So, Clustering transitivity shows the *Táin* is different to the other two.

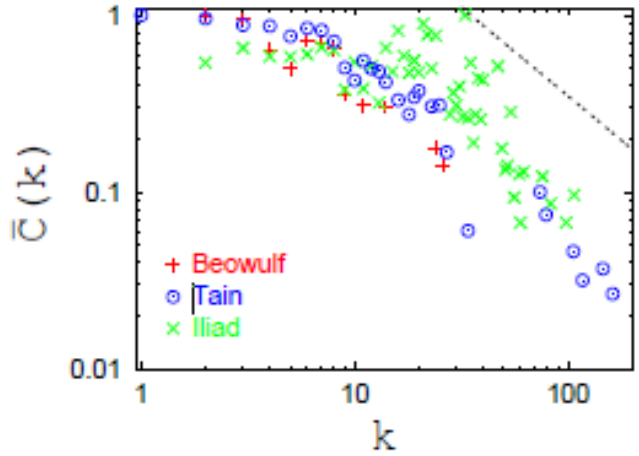
Hierarchical Structure

Hierarchical structure is tested by plotting mean clustering $C(k)$ against degree k and comparing with

$$C(k) \sim \frac{1}{k}$$

This means that

- nodes with low degree belong to densely interlinked clusters
- nodes with high degree bring together many small communities into a single, integrated network.



So they are all hierarchical.

Historicity?

Real social networks are small world and hierarchical (plus other properties such as structural balance).

Does this signal an underlying social reality to the narratives ?

No...

We also looked at some intentionally ficticious narratives (*Harry Potter*, *Lord of the Rings*, *Marvel Comics*, . . .).

These are also small world and hierarchical (with structural balance).

To explore further, look at assortativity - real social networks are assortative, the fictions we looked at are not !

Assortativity

Test for assortativity only using the **positive** (friendly) networks.

We find

- *Iliad* is assortative ($r = 0.10$)
- *Beowulf* is mildly disassortative ($r = -0.03$)
- *Táin* is strongly disassortative ($r = -0.32$).

Input knowledge from Humanities

Although embellished by obvious fiction, archaeological excavations in Denmark and Sweden support historicity of some human characters in *Beowulf*.

Beowulf himself is not believed to have existed.

We remove Beowulf from the network and call the result *Beowulf**

We find *Beowulf** is assortative with $r = 0.01$.

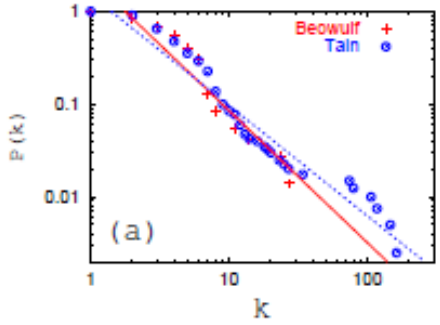
So *Beowulf** is like a real social network and not like a strongly fictional one.

At this point, assortativity corroborates antiquarians' interpretations of historicity : the societies in *Iliad* and *Beowulf** appear realistic while that of the *Táin* appears fictional.

Why is the *Táin* fictional ?

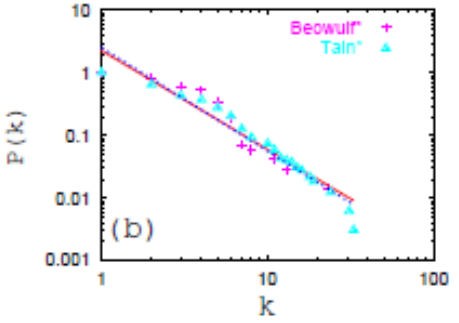
Degree Distributions

Compare *Beowulf* and *Táin* :
Beowulf has $\gamma = 2.4$.
Táin has $\gamma = 2.2$.



The resemblence is striking !
But the top 6 *Táin* characters are anomalous - they are too connected.
Try removing their weakest links...

Compare *Beowulf** and *Táin** :
*Beowulf** has $\gamma = 2.6$.
*Táin** has $\gamma = 2.7$.

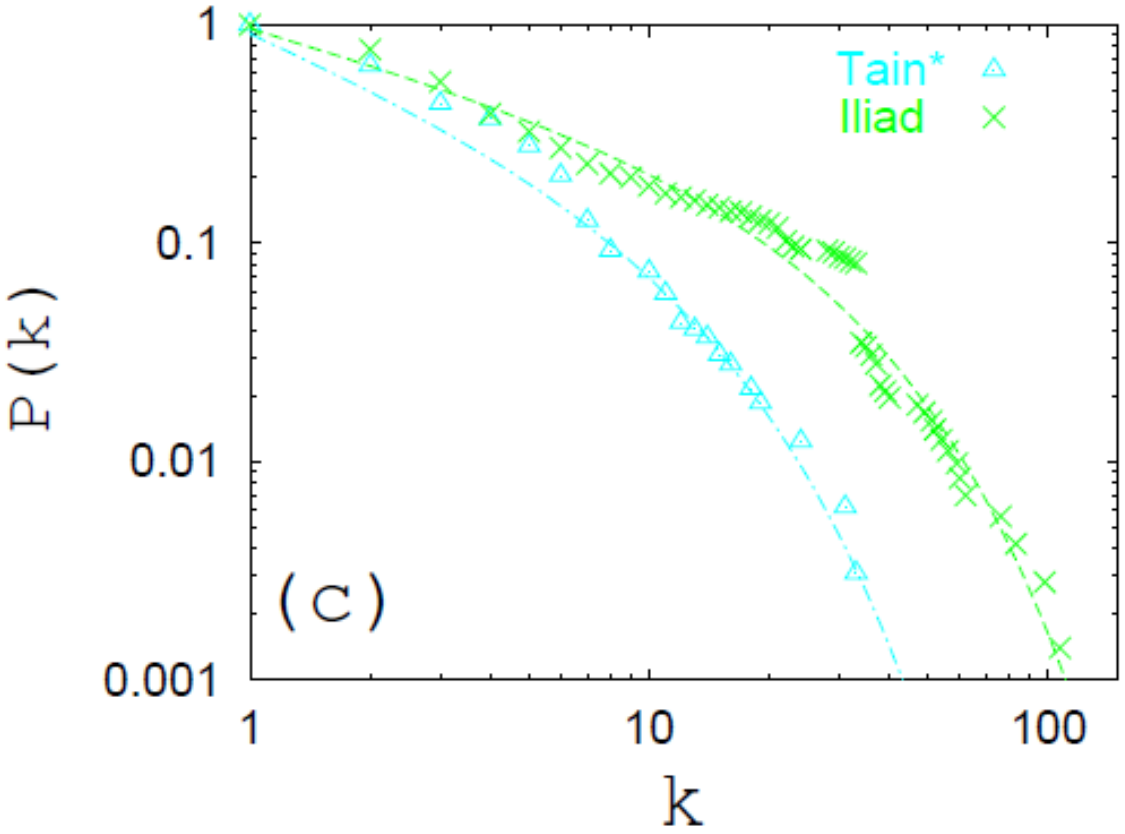


Top 6 *Táin** characters are now more in line.

Degree Distributions

Compare *Táin** to the *Iliad.*

In fact the *Iliad* is better fitted by a truncated power law :



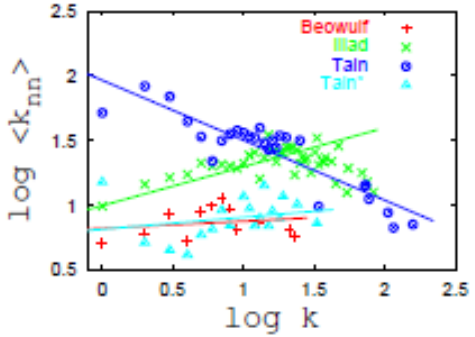
Top 6 *Táin** characters make *Táin** similar to the *Iliad.*

Assortativity Revisited

The *Táin** network is assortative - it has $r = 0.04$.
It now has all properties of a real social network.

Another way to test for assortativity is to plot the degree of neighbours of a vertex as a function of its degree.
Positive slope implies assortativity.
Negarive slope means disassortativity.

The Iliad and *Beowulf* have positive slope.
The *Táin* slope is negative.
The *Táin** slope is positive.



Top 6 *Táin** characters make *Táin** similar to the *Iliad*.

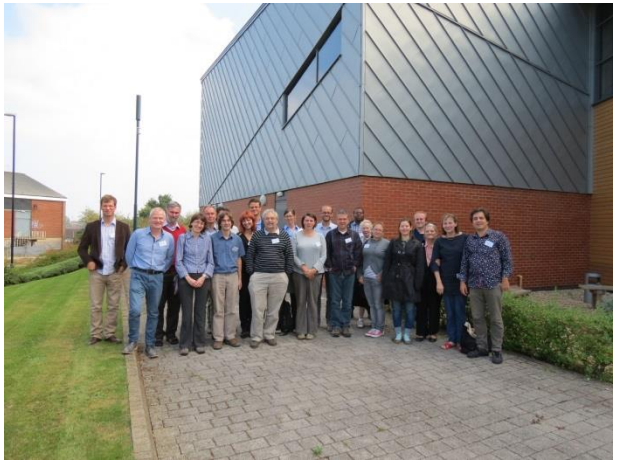
Conclusions:

- The network properties of Beowulf and the Táin are very similar and more “realistic” than intentionally fictional narratives, but less “realistic” than the network of the Iliad.
- Beowulf can be tweaked to appear more “realistic” by removing the eponymous protagonist.
- The artificiality of the Táin lies with the top 6 characters, who are too connected to be realistic.
- If the society in the Táin is to be believed, we speculate that each of the top 6 characters is an amalgam that became fused as the narrative was passed down orally through the generations.
- In fact, Jackson said (1964):

  “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. But this does not mean that the traditional background, the setting, in which the Ulster cycle was built up is bogus.”

- These are 4 of our 6 characters!

Thanks to the MMM Consortium



And the principle of academic freedom

https://youtu.be/b5tMomhjGKY