Doctoral College in Statistical Physics
Leipzig-Lorraine-Lviv-Coventry

Maths Meets Myths:

Investigations of Networks in Ancient Narratives

IPAM Long Program Culture analytics

Workshop IV: Mathematical Analysis of Cultural Expressive Forms: Text Data : May 23-27, 2016

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EUROPEAN SCIENCE FOUNDATION

The Leverhulme Trust

Outline of Talk

1. Context: Culture Analytics & Statistical Physics
2. Tools: Network Science
3. Application 1: Comparative Epic Mythology *
4. Application 2: The Ossianic Controversy #

* P. Mac Carron & RK, Universal properties of mythological networks, Europhysics Letters 99 (2012) 28002

* P. Mac Carron & RK, Network analysis of the íslendinga sögur - the Sagas of Icelanders, European Physical Journal B 86 (2013) 407.

J. Yose, RK, P. MacCarron, T. Platini & J. Tonra, A Networks-Science Investigation into the Epic Poems of Ossian, submitted to Advances in complex Systems 2016.

Part 1

Culture analytics & Statistical Physics

Why are statistical physicists interested in humanities?

Personal answer = **curiosity**.

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., a single bee cannot swarm.

- Simple models, some inspired by statistical physics, have been developed to account for emergent social phenomena

→ "Sociophysics" or "complexity"
has emerged.

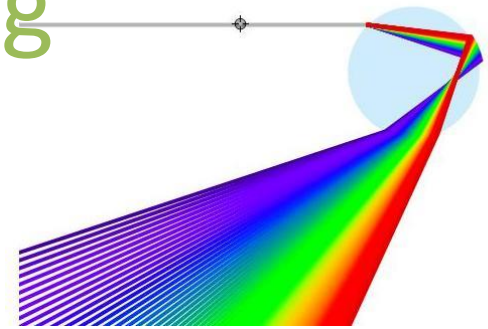
Two Cultures: Relationship between Science and Humanities

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

Statistical physics and sociology are closer than some may think:

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

• This was surprising because individuals are unpredictable.

• Sociology was originally called “social physics”.

• Nowadays “sociophysics” is a subject in its own right.

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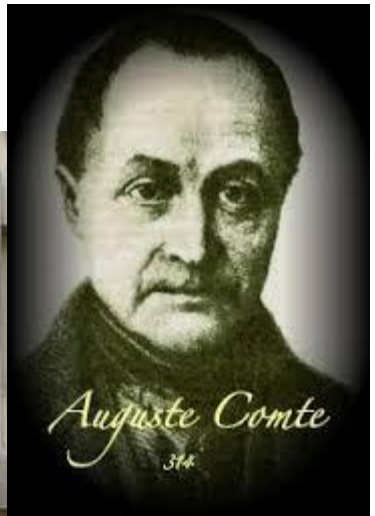
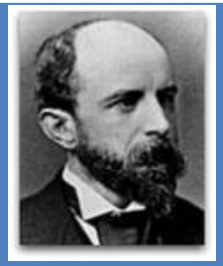
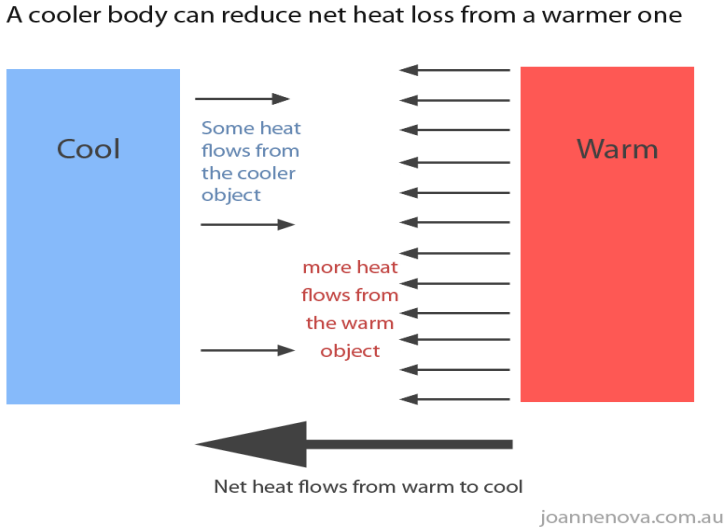


SOCIOPHYSICS IS OLDER THAN ONE MAY THINK

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 thermodynamicist's approach



E.g.: The Second Law of thermodynamics

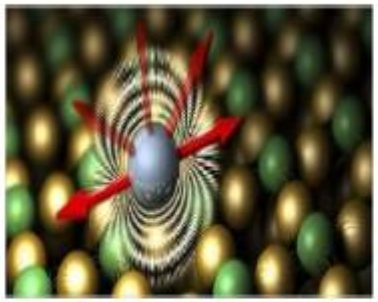
– entropy increases.

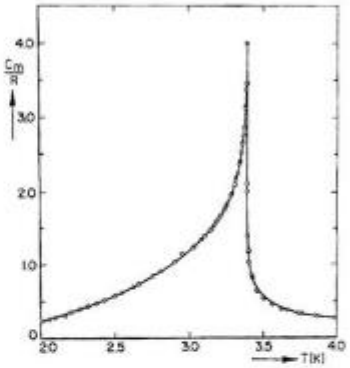
Theory of History (Henry Adams, 1838-1913):

"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 (characters) are not numbers
- True, but aspects of humans are *described* by numbers.

- The approach neglect details
- True, but the planets are more complicated than simple points, yet Kepler's laws are correct.
  Of course, a geographer cannot simplify like this! (Stauffer, 2004)
  The same model may be good for some purposes and bad for others.

- Physicists don't know what they're doing
- "If we knew what it was we were doing, it would not be called research, would it?" -**Albert Einstein**

We don't know the questions but we may help point to some answers.
This is why we need to collaborate!

Objections by physicists

- Serge Galam's first paper (1980) was initially confiscated by his Head of Dept! [Galam, Physica A 336 (2004) 49]

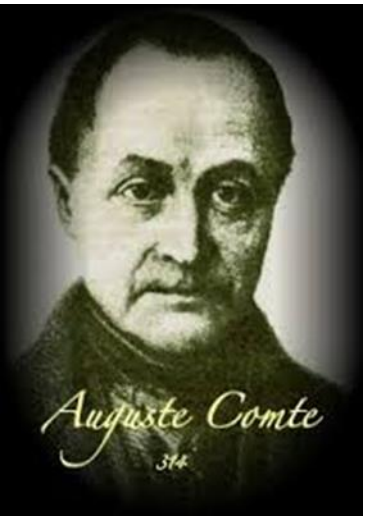
- This is not physics!

- I would reject such objections: *physics is not only about the physical!*

The (re-)emergence of emergence

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

Steven Hawking, 2000



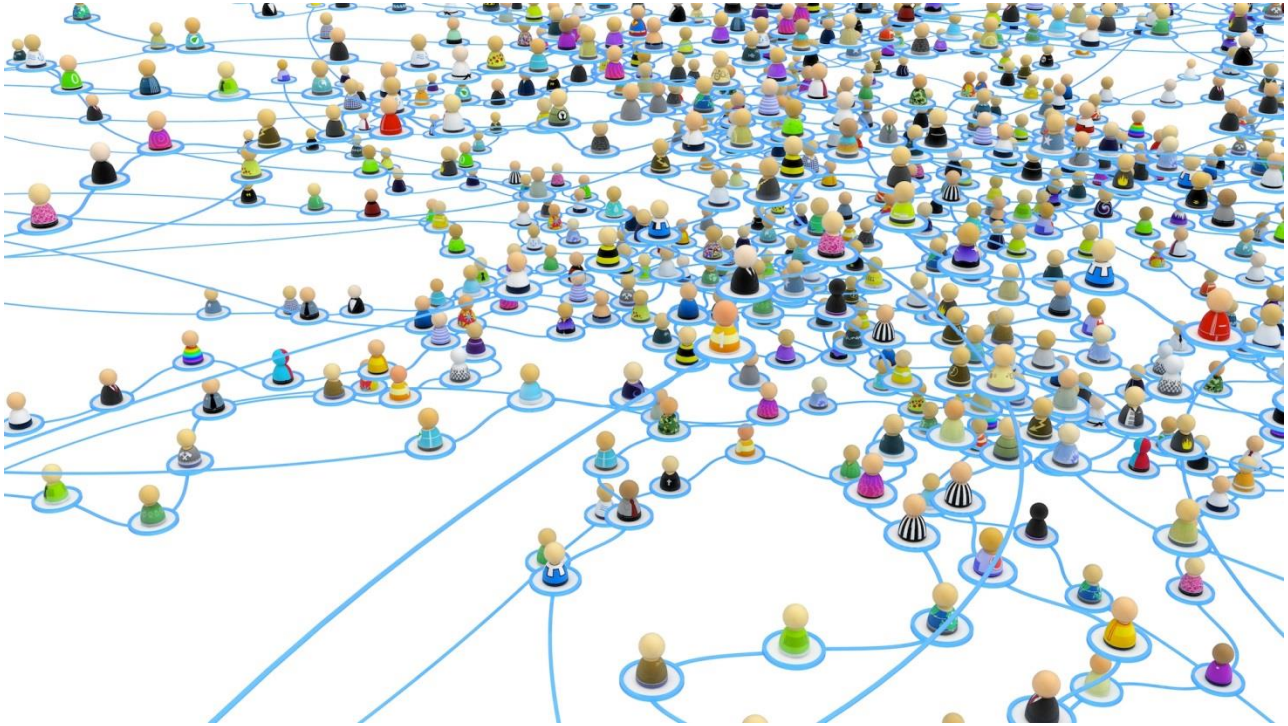
"Now that the human mind has grasped celestial and terrestrial physics, …there remains one science … social physics. This is what men have now most need of."

Auguste Compte, 1856

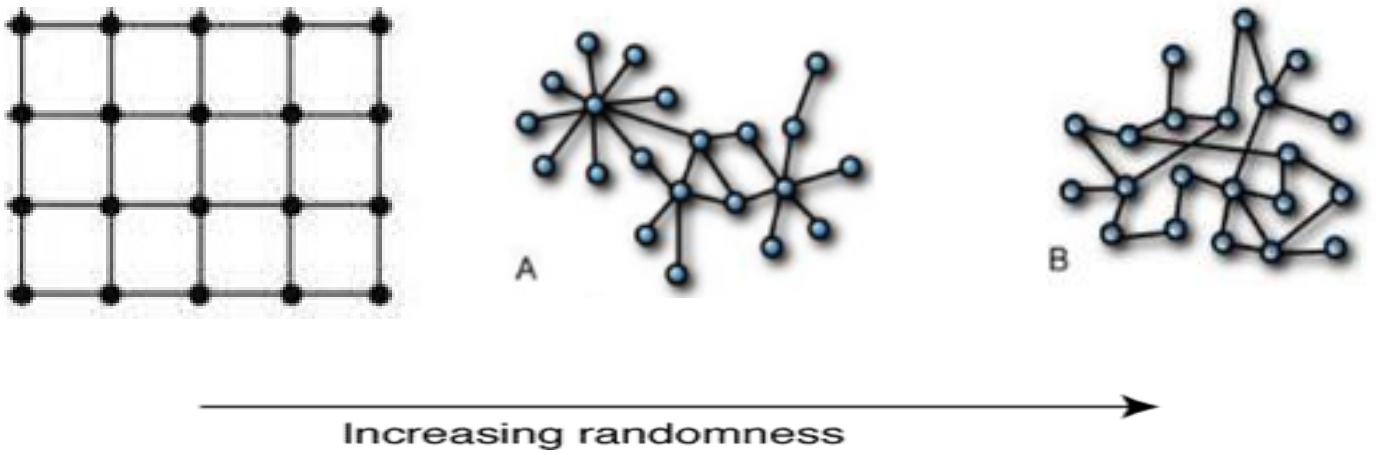
Part 2

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.

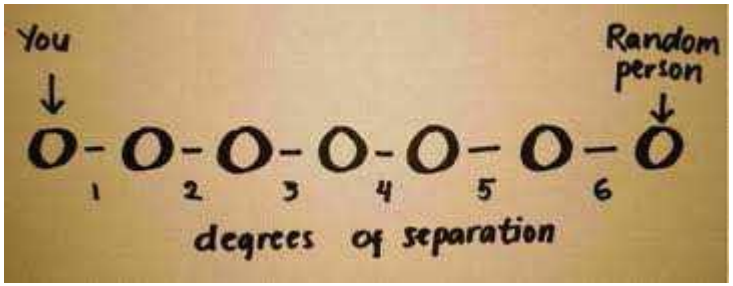


They notice structural similarities between the networks of

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

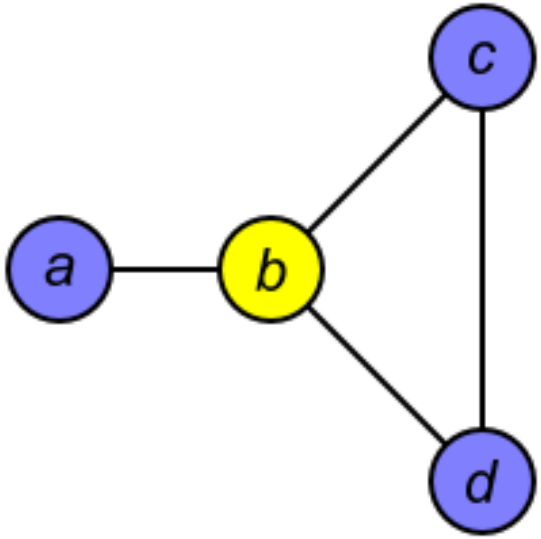
Simple Network Properties

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



- Structural Balance:
  ``The enemy of my enemy is my friend''

- 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 $C = 7/12$.

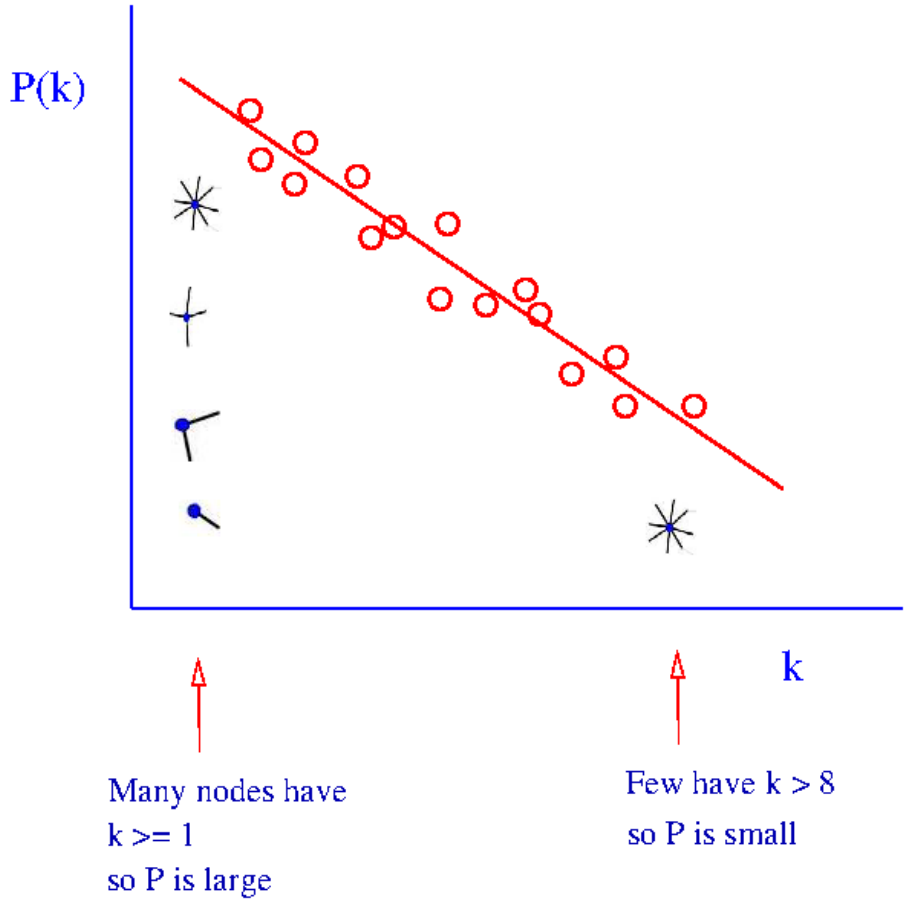


- Network is small world if $\ell \approx \ell_{random}$ and $C \gg C_{random}$.

Cumulative Degree Distribution

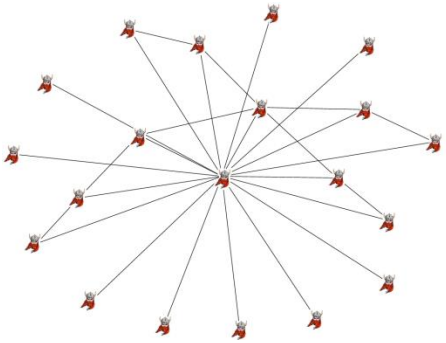
- Degree *k*: The number of links of a node.

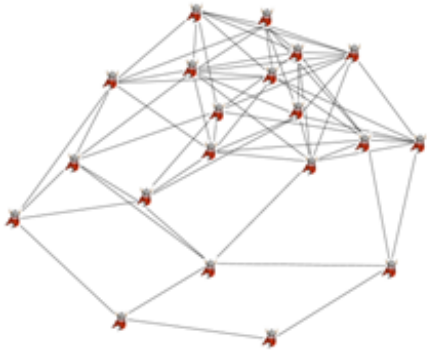
- *P*(*k*): The probability of a node having ≥ *k* links.



- **Assortativity**: ``*Birds of a feather flock together.*''

  Assortativity is the tendency for similar nodes to connect.



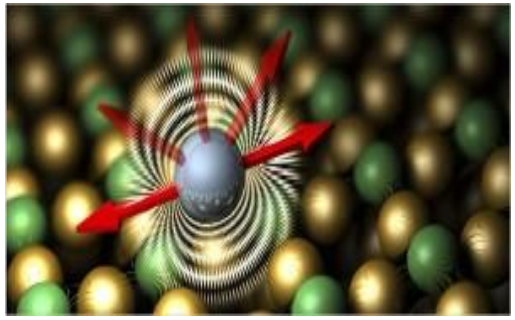


r = -1 ---------- *r = 0*---------- r = 1

Disassortative Assortative

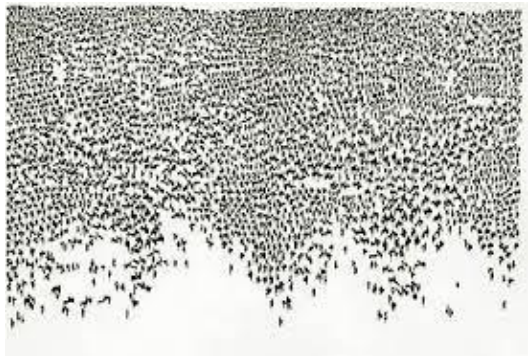
- It is measured using the Pearson correlation coefficient *r* and ranges from -1 to +1

Our aim: Character networks:

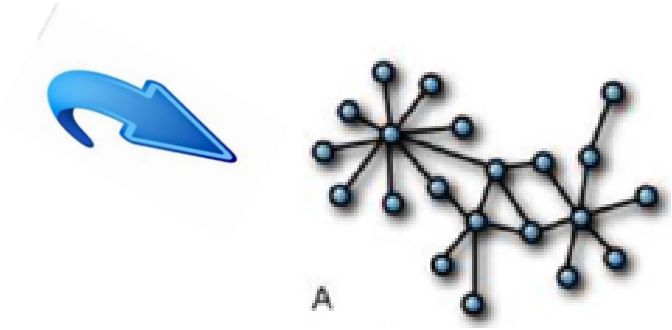


In statistical physics we consider many (simplified) atoms or molecules

In sociophysics we consider many (simplified) people



Here we consider many (simplified) characters



Social networks tend to be

- *Highly clustered*
- *Small world*
- *Structurally balanced*
- *hierarchical*
- *Right skewed*
- *community structure*
- *and have non-negative assortativity* ($r \gtrsim 0$).

Non-social networks may exhibit some of these properties but the combination of *all* seems indicative of social networks in many empirical studies carried out so far.

Part 3

Comparative Epic Mythology

Epic 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 for folktales is based on *events*.
- But there is no classification system in mythology.
- But there is a concept of universality (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 quantitative analysis of *interactions* in mythology - how everything is connected to everything else.

Character networks

We look at four famous epic narratives :

- *Njáls Saga* (Iceland)
- *The Iliad* (Greece)
- *Beowulf* (England)
- *An Táin Bó Cuailnge* (Ireland)

Njáls Saga is a 13th century Icelandic tale that describes events purported to have occurred after the settlement of Iceland.

Some believe the major occurrences described in the saga to be historically based, but there are clear elements of artistic embellishment.

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.

Archaeological excavations in Denmark and Sweden support historicity associated with some of the human characters, but not Beowulf himself.

The Táin is Ireland's greatest epic.

Some argue that such narratives corroborate Greek and Roman accounts of the Celts and offer us a "window on the iron age".

Others 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.

Data Harvesting

1. Read the books (we use English translations)
2. Entering characters' names into databases.
3. List the characters they interact with.
4. Defined links as **positive** ("friendly") when two characters know each other, are related, speak to one another, or appear in a small congregation together.
5. Define as **negative** ("hostile") if two characters meet in combat.

Network Statistics

Observation: There is little difference between *some* properties of the full networks and their positive subgraphs. In particular, the following differ by less than 10%: $\langle k \rangle$, γ, ℓ, ℓ_{max}, C .

We interpreted as indicating that, even though conflict is an essential element of each narrative, they are stories about human relations, driven primarily by positive interactions.

Network Statistics

Full Networks	N	<*k*>	γ	ℓ	ℓ_{max}	*C*	C_T	G_c	r_k	Δ
Iliad	716	7.7	1.7	3.5	10	0.4	0.5	99	-0.08	3
Njál	575	5.6	1.6	5.1	24	0.4	0.3	100	0.01	10
Táin	404	6.0	2.2	2.8	8	0.7	0.1	99	-0.33	12
Beowulf	74	4.6	2.4	2.4	6	0.6	0.4	69	-0.12	13

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

Njáls Saga and the *Iliad* look similar ($\gamma < 2$).

Beowulf and the *Táin* look similar ($\gamma > 2$).

Care in comparison: They have different sizes!

Network Statistics: Universal Features

- They are all small world.
- They have community structure.
- They are structurally balanced: *the enemy of my enemy is my friend.*
- They are robust: removing random nodes leaves the network mostly intact.
- These are likely to be *universal properties*.

Real social networks also have these features.

Does this signal an underlying social reality to the narratives ?

No...

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

These are also small worlds and structural balanced, etc.

So the universality of these features extends to fiction.

Assortativity vs Disassortativity

To get a clearer picture of the social structure of the societies, we look at the *positive networks* only.

We denote these by "+".

We find:

- *Njáls Saga*+ and the *Iliad*+ are assortative (r = 0.07 and r = 0.09).

- *Beowulf*+ and the *Táin*+ are disassortative (r = -0.07 and r = -0.32).

Beowulf and the *Táin* look different to *Njáls* and the *Iliad;* they look more "artificial". Can we use this as a guide to find the source of the difference?

Is there any sense in this?

Artificiality vs Realisticness

- Thomas O'Rahilly (1946): Such tales have no historical basis whatsoever.

- Kenneth Jackson (1964) "the characters **Conchobar** and **Cúchulainn**, **Ailill** and **Medb** and the rest … are … purely un-historical. But this does not mean that the traditional background, the setting, in which the Ulster cycle was built up is bogus."

- Modern scholarship => tales may reflect societies of medieval writers.

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

What would it take to make *Beowulf* assortative?

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 $r = 0.01$.

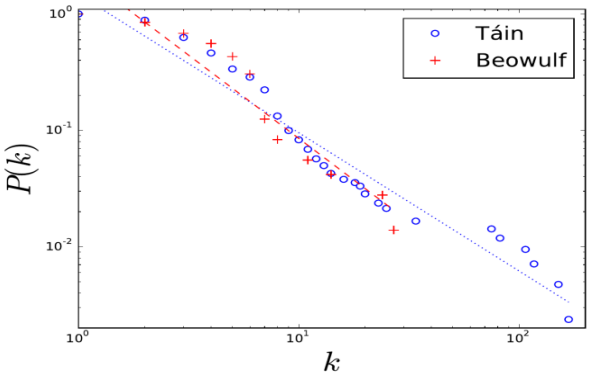
So it only took a local change to make *Beowulf** look like a real social network.

What about the *Táin*? Local or global change?

What would it take to make the Táin assortative?

Lets look at the degree distributions:

Beowulf has γ = 2.4. The *Táin* has γ = 2.2.



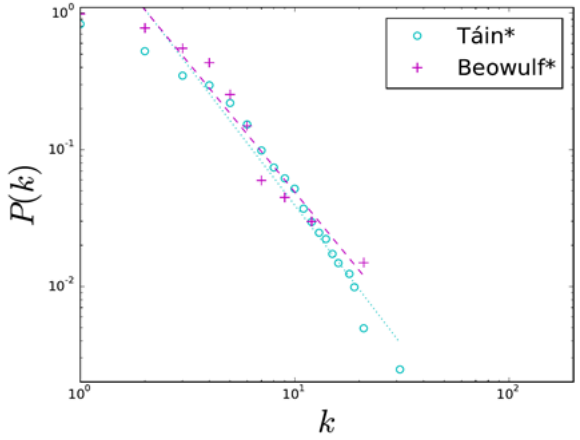
The resemblance between the two degree distributions is striking!

But the top six *Táin* characters are anomalous – they are over-connected relative to the others and relative to the *Beowulf* "guide".

To make them less connected, try removing their weakest links.

The resulting degree distributions are aligned:

*Beowulf** has γ = 2.2. The *Táin** has γ = 2.1.

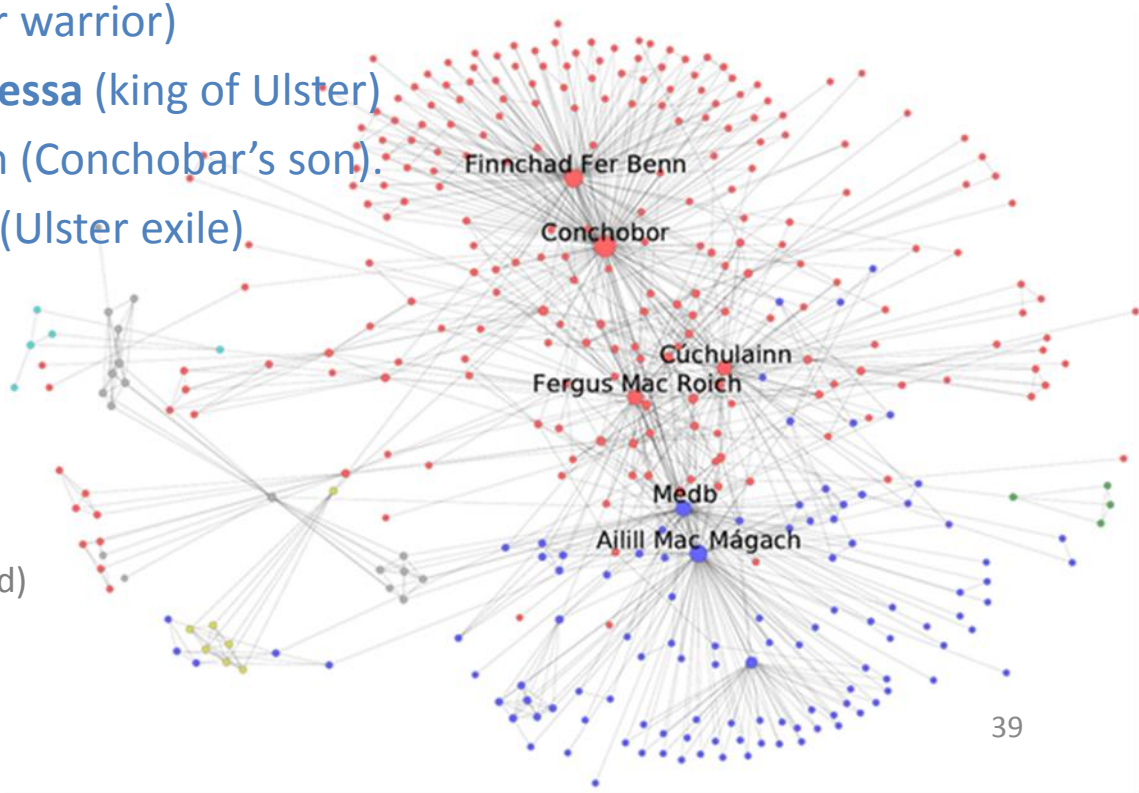


Assortativity Revisited

Moreover, the adjusted *Táin* network is assortative: it has $r = 0.03$.

The six anomalous characters are (bold listed by **Jackson**)

- **Medb** (queen of Connacht)
- **Ailill** (husband of Medb)
- **Cúchulainn** (Ulster warrior)
- **Conchobar mac Nessa** (king of Ulster)
- Finnchad Fer Benn (Conchobar's son).
- Fergus Mac Roich (Ulster exile)



The Girvan-Newman algorithm applied to the friendly network of the *Táin*. Different coloured vertices represent different communities.
The two largest are the Ulster faction (red) and the Connacht faction (blue).

Conclusions

- Have introduced a way to visualise the societies in epic narratives.
- Using statistics, we can quantify their properties & compare them.
- We identify universal & distinguishing features:

Network	High clustering	Robust	Scale free	Assortative
Njál+	yes	yes	no	yes
Iliad+	yes	yes	no	yes
Beowulf+	yes	no	yes	no
Táin+	no	no	yes	no
Beowulf*	yes	no	yes	borderline
Táin*	yes	no	yes	borderline

} similar

} similar

We could also interpret our results as indicating:

- Icelanders like realistic stories (focused on society)
- Irish like superheroes (focused on individuals)

Part 4

The Epic Poems of Ossian

Ossian's Dream, Jean Auguste Dominique Ingres, 1813

The Background

- 1746: Battle of Culloden, Scotland.

- 1760: James Macpherson published *Fragments of Ancient Poetry, Collected in the Highlands of Scotland, and Translated from the Galic or Erse Language*

- Rhythmic prose and sparse diction created an ethereal atmosphere which captured the interest of a receptive public.

- 1760, 1761: Expedition to Highlands & Islands delivered
  Fingal: An Ancient Epic Poem in Six Books, Together with several Other Poems composed by Ossian the Son of Fingal

- 1763: *Temora: An Ancient Epic Poem in Eight Books…*


"INVENIRE"

Fragments of Ancient Poetry

HIGHLANDS OF SCOTLAND

Gaelic or Erse Language.

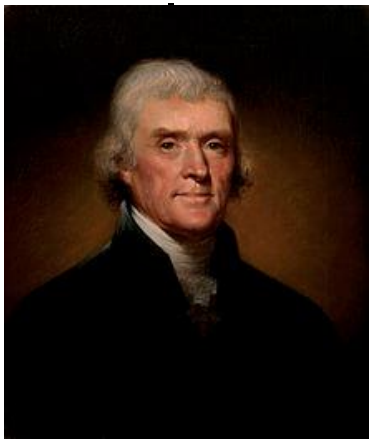
1760

JAMES MACPHERSON

Reception in Europe and USA was enormously positive:

- Napoleon took a copy on his campaigns
- Literature: Blake, Byron, Coleridge, Goethe, Scott, Wordsworth, …
- Music: Brahms, Mendelssohn, Schubert, …
- Art: Abildgaard, Gérard, Girodet, Ingres, Kauffmann, Krafft, Runge,
- There are towns called Ossian in Iowa, Indiana and New York
- Selma, Alabama owes its name to ``The Songs of Selma'' in Fingal.
- Thomas Jefferson stated that Ossian was “the greatest poet that has ever existed”

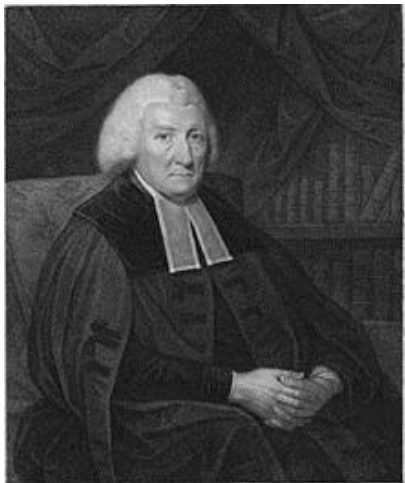
Prompted other nations to look at their ancient literature



Thomas Jefferson

Comparison with Classics was immediate (e.g., Hugh Blair):

Ossian = “Homer of the North”



Hugh Blair

- However…Samuel Johnson was not happy.

  "strong temptation to deceit"

- But… Johnson viewed Gaelic as

  "the rude speech of barbarous people"

- During the Imperial Era, British scholars and administrators aligned their attitudes towards classical history with imperialist ideologies.

- They though they carried the "torch of civilization".

- Thus conflict was …

Scotland vs England

Romanticism vs Classicism

Nationalism vs Imperialism

- **Reaction in Ireland was outrage!**

Charles Ó Connor

Sylvester O'Halloran

Ossianic poems were corruptions of the tales Fenian Cycle of Irish mythology.

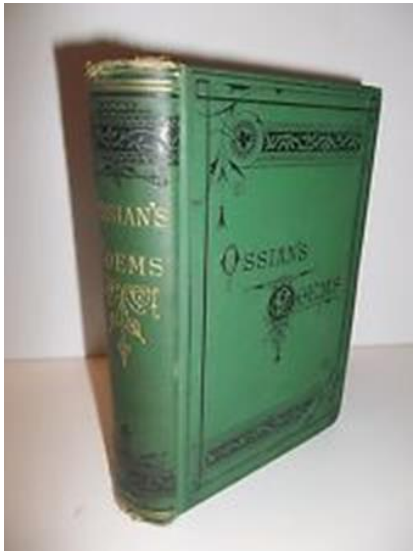
Thinly veiled characters, places, and situations from the Irish epic tradition were identified.

Macpherson	Irish Mythology
Ossian = "an illiterate Bard of an illiterate Age"	Oisín = warrior poet of the Fenian cycle
Fingal (Ossian's father) = 3rd century Scottish king	Finn MacCumhail = Leader of the Fianna Éireann (warrior band)
Cuchullin ="the General or Chief of the Irish tribes"	Cúchulainn, boy hero of Ulster cycle

Misappropriation of Ireland's Gaelic heroes for Scotland

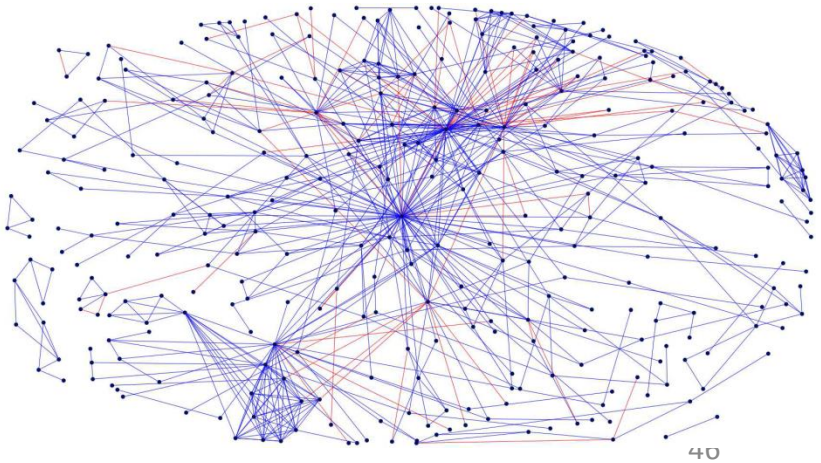
=> **"imposture"**

- **So… is Ossian the “Homer of the North” or an “imposture”?**



- Lets look at the networks

- We examine:
  - *Ossian*
  - *The Iliad*
  - *The Odyssey*
  - *Acallam na Senórach (Colloquy of the Ancients)*
  - A text by Lady Gregory (1904)



- We looked at the network statistics…

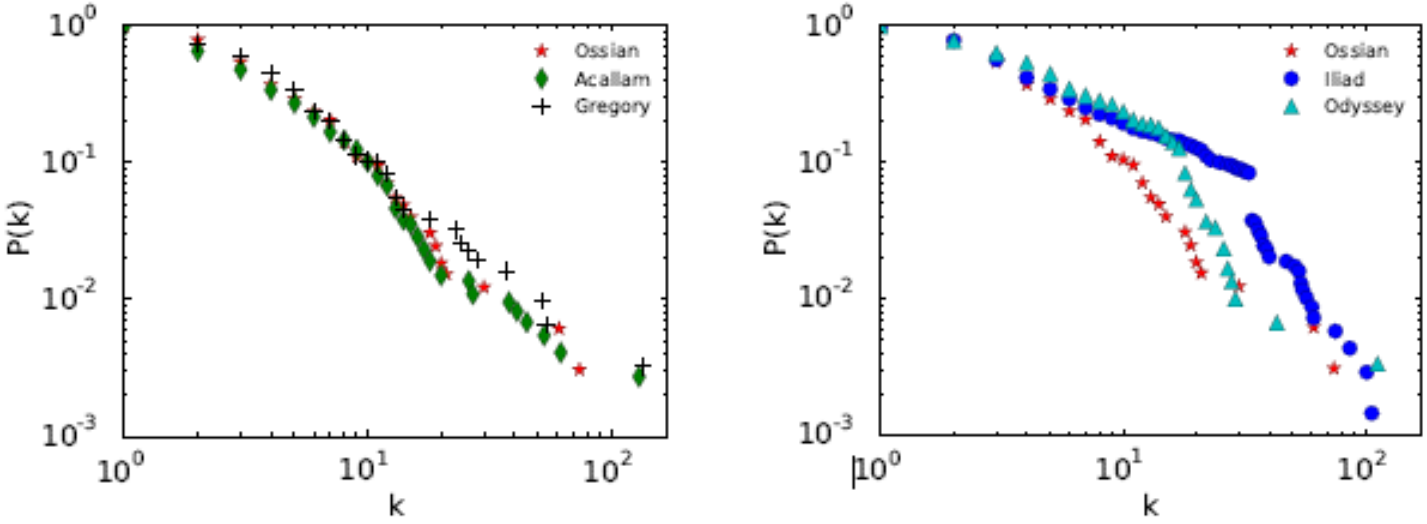
	Narrative	N	M	$\langle k \rangle$	ℓ	ℓ_{rand}	C	C_{rand}	C_T	r	Δ	G_c
Full	*Ossian*	325	748	4.60	3.62	3.91	0.49	0.01	0.27	-0.08	0.95	88.62%
	Acallam	732	1606	4.39	3.79	4.57	0.37	0.01	0.19	-0.10	0.97	76.91%
	Gregory	355	913	5.14	3.10	3.73	0.44	0.01	0.16	-0.18	0.97	94.65%
	Iliad	694	2684	7.74	3.49	3.42	0.44	0.01	0.45	-0.08	0.98	99.42%
	Odyssey	301	1019	6.77	3.29	3.18	0.45	0.02	0.38	-0.08	0.97	98.34%
Positive	*Ossian*	309	666	4.31	3.65	4.03	0.42	0.01	0.31	-0.06		82.20%
	Acallam	722	1513	4.19	3.72	4.69	0.38	0.01	0.20	-0.09		71.33%
	Gregory	337	833	4.94	3.23	3.78	0.45	0.01	0.18	-0.17		91.99%
	Iliad	640	2329	7.28	3.80	3.47	0.44	0.01	0.58	0.02		85.94%
	Odyssey	299	989	6.62	3.42	3.21	0.45	0.02	0.40	-0.08		97.32%
Negative	*Ossian*	87	82	1.89	5.30	6.61	0.00	0.02	0.00	-0.31		70.11%
	Acallam	86	93	2.16	2.32	5.53	0.00	0.00	0.00	-0.30		24.42%
	Gregory	95	80	1.68	4.75	8.13	0.00	0.01	0.00	-0.30		45.26%
	Iliad	321	355	2.21	4.46	7.00	0.00	0.00	0.00	-0.45		90.34%
	Odyssey	41	30	1.46	1.88	8.74	0.00	0.04	0.00	-0.18		26.83%

- But we don't discern much…

- The full networks are similar to the positive one

- And they are all structurally balanced small worlds with non-trivial topologies and large proportions of nodes belong to their giant components (universal properties).

Compare Degree Distributions



- Bottom Line: Ossian is like the Irish texts. It is not like the Classics.

- We perform various statistical tests to confirm this – fitting to degree distributions, Kolmogorov-Smirnov comparisons and measuring spectral distances (details on request).

So how could Macpherson have done it?

- We imagine a sparsification process as follows:

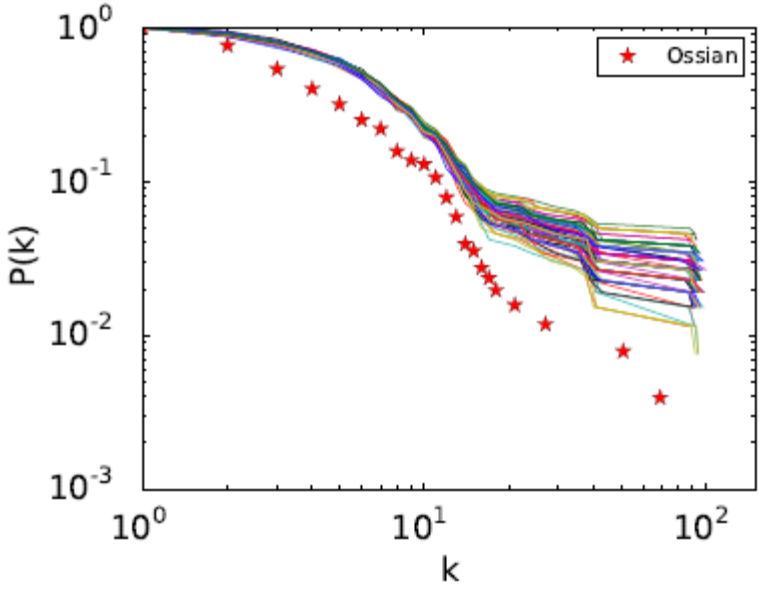
- *Acallam* has 732 nodes & 1606 edges (515 & 1364 in GC)
- *Ossian* has 325 nodes & 748 edges (254 & 596 in GC)
- Try to sparsify Acallam to get something like *Ossian*
- The probability a node survives is proportional to k^{β}
- $\beta = 0$ means complete randomness
- $\beta = 0$ means weak nodes are likely to be lost
- $\beta = \infty$ means deterministic selection
- Interesting mathematics ensue…

- We find $$\langle \kappa \rangle \simeq \frac{n}{N} \frac{\langle k^{\beta+1} \rangle^2}{\langle k \rangle \langle k^{\beta} \rangle^2}.$$

- The daughter can never look like the mother!

So how could he have done it?

- For example (100 simulations, $\beta = 1$)



- None of the daughters (candidate *Ossians*) look like *Ossian*.

So how could he have done it?

- A problem is that, even starting with the giant component of *Acallam*, sparsification introduces multiple components in the daughters.
- We need a method to sparsify without fragmenting.
- Consider the reverse process – growing the mother from daughter.

- We start with *Ossian* (GC has 254 nodes).
- We grow the network by preferential attachment – nodes are added to an existing node with probability proportional to its degree.

- Repeat 100 times:

	N	M	$\langle k \rangle$	ℓ	C	r_k	Ossian	Acallam
Ossian	254	596	4.69	3.62	0.45	-0.10		
Acallam	515	1364	5.30	3.71	0.41	-0.13		
Pref attach	515	1364	5.30(3.54)	3.35(0.01)	0.13(0.01)	-0.10(0.01)	100%	88%

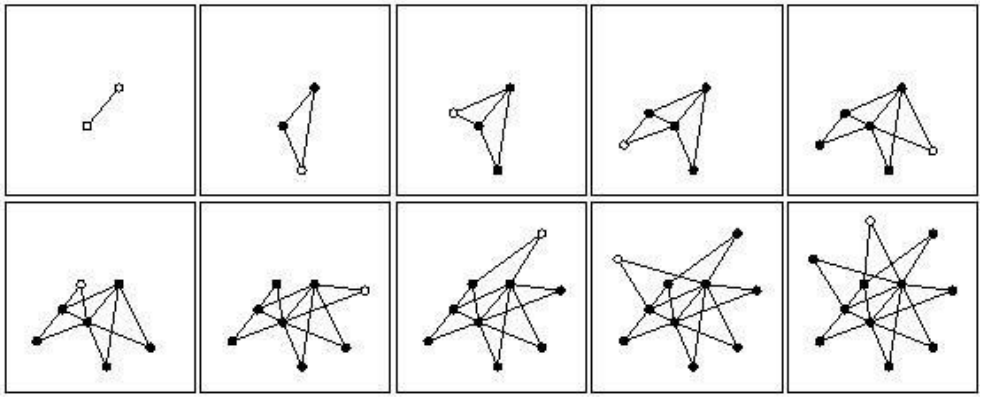
- All 100 mothers look like the daughter!

So how could he have done it?

- So, had Macpherson had network science to hand, he could have created Ossian from Acallam na Senórach by an inverse-preferential-attachment process.

- What is that?

- We are investigating…

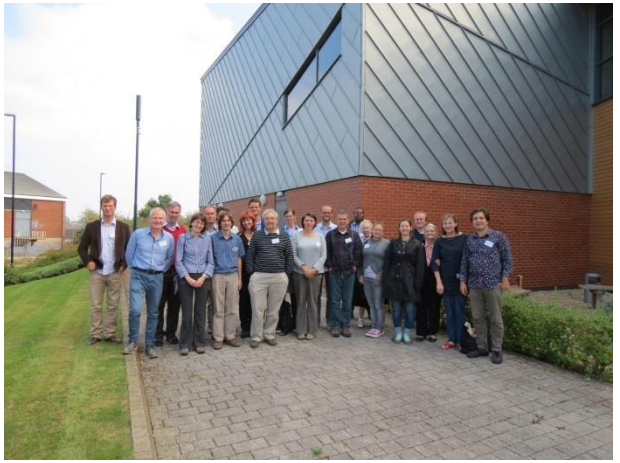


Conclusions:

- 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* and *Njáls saga*.
- *Beowulf* can be tweaked to appear more “realistic” by removing the eponymous protagonist.
- The feature of the *Táin* that makes it appear more ``artificial'' than the other epics lies with the top 6 characters, who are too connected.
- Local changes render it similar to the others.

- The social network of *Ossian* is very similar to that of the Irish Fenian cycle. It could be derived from it probabilistically.
- It is different to networks of the classics despite attempts to link Macphersons work to Homer.

Thanks to the MMM Consortium



And the principle of academic freedom